COUNTING ON THE KNOWLEDGE OF OTHERS: RATIONAL DEPENDENCE IN THE MATHEMATICS CLASSROOM

by

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DEDICATION

To Cassie and Chloë

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ABSTRACT

Rational dependence is the reasoned dependence on the expertise of others. This dissertation begins with the argument that if mathematics instruction is to help prepare students for the quantitative claims that they may expect to encounter in their everyday lives, then they need to be given the opportunity to develop rational dependence. In order to explore what happens when such opportunities are created, I collaborated with several teachers of quantitative literacy-focused undergraduate mathematics courses in order to introduce information-based problems, or those problems that require students to seek out and evaluate information sources outside of the classroom. I developed case studies for each location which informed cross-case observations about how these teachers used information-based problems. The resulting multiple case analysis allowed me to answer questions about whether and how opportunities for rational dependence arose in the context of such problems and what form the problems took as each of the teachers incorporated them into units on probability and statistics.

My analysis of classroom work suggests that opportunities for rational dependence were associated with the way that teachers used information-based problems and, in particular, the structure of the academic tasks through which the problems were implemented. All of the teachers prioritized their students' development of a critical stance towards quantitative claims over direct assessment of the credibility of sources. I also found that students in one of the classrooms were able to engage in sophisticated credibility assessment through dialogue with one

another about the relative credibility of their sources. Other features of the classroom tasks that contributed to opportunities for rational dependence included (a) how students were held accountable for the sources that they found, (b) how the teachers operationalized their students' development of a critical stance towards quantitative claims, and (c) the role that mathematics played in the tasks. The findings of this dissertation provide first steps towards developing ways of assessing opportunities for rational dependence available in the mathematics classroom.

CHAPTER I

Introduction

Teachers of mathematics are increasingly confronted with students who have access to varied sources of information outside of the classroom. The premise of a word problem can be challenged by a quick glance at Wikipedia, calculations that were formerly impossible to carry out on a graphing calculator can now be performed with ease using an answer engine like Wolfram Alpha, and students can track down discussions of test problems on various Q&A web-sites. Teachers have the option of either ignoring this reality or treating it as an imminent threat to be guarded against, but there are an increasing number of voices calling for mathematics teachers to involve student in the type of contextualized problems that invite them to seek out information outside of the classroom. These include those working on quantitative literacy (Steen, 2001), disciplinary literacy (Moje, 2007), and information literacy (Grafstein, 2002; Kim & Sin, 2011). Accordingly, this dissertation study looks at what happens when mathematics teachers provide such opportunities for their students through the use of *information-based problems* (Walraven, Brand-Gruwel, & Boshuizen, 2008) or those problems that require "students to identify information needs, locate corresponding information sources, extract and organize relevant information from each source, and synthesize information from a variety of sources" (Walraven et al., 2008, p.623). I begin this dissertation by presenting the argument that successful engagement with real-life quantitative claims is predicated on our *epistemic* *dependence* (Hardwig, 1985) on others, or the fact that much of what we know is dependent on our trust in the expertise of others. This observation is tempered by the fact that an individual can rely on others in a more or less rational way (Siegel, 1988). I refer to the practices that support the reasoned use of the knowledge of others as *rational dependence* and a major purpose of my inquiry is to observe attempts to create opportunities for rational dependence in mathematics classrooms. Then I proceed to look across several cases in which information-based problems have been used by college instructors in order to analyze the ensuing challenges and opportunities.

Students have always been able to draw on information outside of the classroom if they so choose, but a convergence of demands bound up with three different conceptions of literacy are serving to push this issue to the forefront. (1) A move to attend to how reading and writing is conducted in the disciplines and to use this as a way of thinking about how to teach those disciplines means that mathematics teachers must think more carefully about how those who work in STEM fields locate and evaluate mathematical resources (Schleppegrell, 2007; Moje, 2007; Shanahan & Shanahan, 2012). (2) While mathematics instruction has long been charged with an instrumental role with respect to training in the STEM fields, there have been more recent moves to develop curriculum that works toward a mathematical proficiency that can serve any individual in their everyday lives. This is sometimes framed as quantitative literacy (Steen, 2001), mathematical literacy, quantitative reasoning or granted a more limited scope as a type of statistical literacy (Cullinane & Treisman, 2010; Watson, 2013) and has seen some realization in courses offered by many colleges for non-STEM majors who need to fulfill a mathematics requirement as part of their liberal arts education. (3) Researchers in the information sciences have long recognized the importance of instruction in order to facilitate college and high school students' ability to research topics at the library (Rader, 2002). This interest has shifted its target, in course of the last 30 years, to the seeking out of information online. In fact, the exponential increase in internet use has provided a common focus for academic and everyday information-seeking, thus allowing similar tools to be used to examine both types of information-seeking.

In the remainder of this introduction, I elaborate on the argument that these types of problems have a place in the mathematics classroom, particularly those that focus on quantitative literacy instruction. Then I present a set of research questions motivated by this argument and the methodological approach that I used to investigate them. Finally, I provide an overview of the structure of the dissertation as a whole.

Rational Dependence in the Mathematics Classroom

What does all of this mean for mathematics instruction? While the importance of information-based problems for disciplinary literacy is easy to justify as long as one accepts that information-seeking is an important part of practice in the disciplines, it requires a little more unpacking to explain why this type of instruction might have a place in mathematics instruction. One way to begin such an explanation is to imagine an applied mathematics problem -- say students are given an editorial in which the author argues that federal guidelines on fuel efficiency will end up costing the country more money than it will save (Diefenderfer, 2009). Students are asked to read the editorial and then provided with several guiding questions that encourage the students to analyze the numerical argument contained in the article while noting some of the additional information that might be required prior to coming to a final verdict on the validity of the editorial's argument. While this activity is a legitimate applied mathematics problem, the real-world context (see Figure 1-1) suggests other directions that such a problem could be taken.

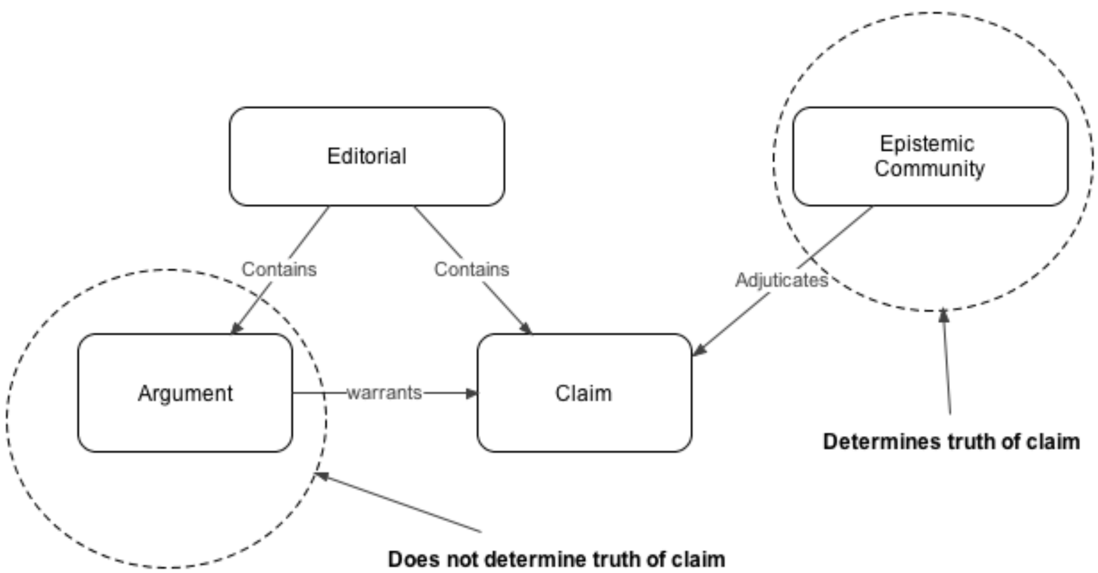

Figure 1-1. Relationship between Editorial, Claim, and Epistemic Community

If a reader were to actually want to determine whether the editorial's claim was true or not, they would want to locate the relevant *epistemic community* (Haas, 1992), or that community that possesses the expertise to tentatively rule on the truth of the claim. In other words, they would need to engage in the practice of rational dependence by finding experts on whom the students have good reason to rely. The problem as originally stated does not afford the students an opportunity to engage in this practice. They are not asked to seek out and evaluate those sources of information that might either corroborate or challenge the argument found in the editorial. An *information-based problem* (Walraven et al., 2008), on the other hand, requires that the student seek out and evaluate sources outside the classroom. In order to come to a better understanding of an information-based problem, the student must "identify information needs, locate corresponding information sources, extract and organize relevant information from each source, and synthesize information" (Walraven et al., 2008, p.2) in a process called *information-problem solving*. My inquiry can be framed, then, as a question about how mathematics teachers and their students cope with the introduction of information-based problems, and whether and how these problems afford opportunities for rational dependence in the classroom.

While the information-seeking behavior of academics has been well-documented by the information science community (Case, 2012) and one of the major findings of this work is that this behavior differs across disciplines (Palmer & Cragin, 2008), there are few attempts to educate students in the discipline about how that discipline-specific information-seeking is carried out (Grafstein, 2002). This would not necessarily be a problem if students were able to learn how to seek out information through generic instruction that could then be used to support quantitative reasoning, but research has shown that content knowledge is deeply tied to successful information-seeking (Walraven et al., 2008).

The seeking out of information on the internet becomes a dilemma for the instructor once they allow this activity to take place in their classroom. At this point, the question becomes not so much about classroom management (e.g., “What should the smartphone policy be?”, “How do I keep students from surreptitiously texting?”) but rather about managing the classroom’s *didactical contract*. I borrow this last term from Guy Brousseau (1997) who uses it to refer to the terms under which a task devolved to students can engage them in work that provides evidence that the envisioned learning has in fact occurred. In particular, this type of activity amounts to a modification of the traditional terms of the mathematical *tasks* (Herbst, 2006; Doyle, 1988), or the actions associated with a given problem along with an established set of resources.

Academic tasks as defined by Doyle (1988) consist of four components. A student must use the available *resources* through a series of *operations* in order to create a *product* which is valued according to a system of *accountability*. Herbst (2003) used Doyle’s model in order to describe three tensions that must be negotiated by mathematics teachers when they introduce novel tasks. By analyzing records of teaching, he found that each of the first three elements of Doyle’s (1988) task framework are associated with a dilemma. For example, there is a tension between making certain that the students produce the product that was originally specified and the desire to let them pursue original ideas that arise as they work on a novel problem.

Information-based problems are new to the mathematics classrooms and this means that it is incumbent on the researcher to attend to the choices that the teacher makes with respect to what student work counts as evidence of learning and how students are supported in carrying out that work.

Herbst (2006, p.314) has noted that “the school institution operates on the assumption that the mathematics class is the place where its subjects go to transact (or trade on) mathematical knowledge.” This economy of knowledge is complicated by the introduction of information-based problems. What can rightly serve as evidence of knowledge transacted when the student is asked to draw on the knowledge of others as well as their own? Or, to take the question one step further, what is the nature of the learning claims that can be made on the basis of this work? The answers to these questions are not straightforward, this dissertation reports on several cases in which college mathematics instructors introduced information-based problems to their classrooms and as can be seen in my analysis of the work of these teachers, they can and do negotiate very different contracts. As a consequence, they instill superficially similar tasks with varied stakes.

Research Questions

Up to this point, very little work on information problem-solving has been carried out in a discipline-specific classroom setting (e.g., Hoffman, Wu, Krajcik, & Soloway, 2003; Britt &

Aglinskas, 2002 for some examples) and a search of Google Scholar using relevant terms failed to bring to light any studies located in a mathematics classroom.[1] While information-based problems could theoretically appear in any mathematics classroom, they are particularly well-suited for a mathematics course aimed at fostering students' quantitative literacy (Steen, 2001) because the goals of such a course are directed toward the practice of mathematics outside of the classroom setting. As such, I look at undergraduate courses that fulfill a quantitative reasoning requirement and, more specifically, those that explicitly aim to prepare students for the mathematics that they may encounter in their everyday lives (hereafter referred to as quantitative literacy-focused courses). The following research questions focus on those mathematics classrooms when the instructors introduce information-based problems and, in particular, the ways in which the students engage with the problems:

1. How do undergraduate students in a quantitative literacy-focused course work with information-based problems introduced by their teacher? How do they use their content knowledge when working on those problems?

2. How does the teacher of the quantitative literacy-focused course work with students who are asked to solve information-based problems?

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[1] A search for "information-based problems", "information literacy", and "mathematics" fails to turn up any articles within the first 5 pages in which the use of these types of problems occur in a mathematics classroom. The extant reviews of research in this area (Walraven et al., 2008) does not include any examples either.

3. How are information-based problems affected by their introduction into a quantitative literacy-focused course?

The primary contribution of this work is to see how information-based problems are taken up in a mathematics classroom and how mathematics instruction is affected by the introduction of new resources and operations.

Multiple Case Study Analysis

For reasons that I elaborate in my historical overview,[2] it is very difficult to find information-based problems in the mathematics classroom. While researchers in the information sciences have argued that those teaching the disciplines ought to encourage students to seek out information online (Grafstein, 2002), there are few teachers who have taken up this idea.[3] In my adoption of the case study approach for the present work, I am taking up Yin's (2013) procedure for selecting a research method. In particular, he advocates for the following three criteria for

[2] These reasons include the prevalence of sequestered problem-solving for assessment purposes (Bransford & Schwartz, 1999), a preference for teaching *how* to do mathematics rather than how to locate mathematical knowledge, and concerns about the role of authority in the classroom.

[3] For example, a survey of the last two years of the popular professional journal, *Mathematics Teacher*, does not reveal any problems that encourage students to seek out information outside the classroom. The closest to this is a recurring feature called *Media Clips* where appearances of mathematics in the media are highlighted, but here the information source is provided. Similarly, there are cases where students are given data or asked to find very specific data (Jensen, 2013), but not any problems where students search for information in an unfettered way. There are exceptions to this, of course, and I address some of these in my literature review.

choosing a case study approach: (1) the research questions should be asking a “how” question about the phenomena of interest, (2), the phenomena is contemporary rather than historical and (3) the researcher should have little to no control over the events as they are observed. As can be seen above, my study readily fulfills the first two requirements. The third is less clear because of my role as the individual who introduced the idea of information-based problems to these instructors. Nonetheless, I argue that despite this intervention, my role during the development of the activities was purely as a resource and that the teachers held the initiative throughout the introduction and management of the information-based problems to the classes. During the actual implementation of the activities, I only acted as an observer, limiting my work to managing the recording equipment and writing field notes. In particular, I encouraged the teachers of record to make most of the decisions about how to assign and guide student work. This resulted in three distinct sites of implementation for these information-based problems and suggested that this first iteration of the broader study would operate best as a comparison across three cases.

The Work of the Students

Students’ difficulties with information seeking have been well documented in the information science literature. It is difficult for most students to choose appropriate search terms, judge the quality of the sources they encounter, and even to decide when to end their search

(Walraven, Brand-Gruwel, & Boshuizen, 2008). Furthermore, there has been an accumulation of evidence that domain expertise is an important mediating variable in the success of information problem-solving tasks (Brand-Gruwel, Wopereis, & Vermetten, 2005; MaKinster, Beghetto, & Plucker, 2002; Monereo, Fuentes, & Sànchez, 2000). These problems present a challenge to any attempt to introduce information-seeking into the classroom and they motivate my first question and its accompanying question: *How do undergraduate students in an everyday college mathematics class work with a series of information-based problems? How do they use their content knowledge when making decisions about how to search for and evaluate sources?*

In the course of this study, I have had the opportunity to observe three different samples of students working in three different classroom settings. My observations of classroom work have been supplemented by interviews with teachers, teaching assistants, and students, and inspection of records of student work. I have carried out a cross-case analysis across the three settings in order to develop a conceptual framework of information-based problems in the mathematics classroom. This framework describes how these students handle the information-based problems that they are assigned and suggests some of the ways in which teacher supports, the teacher's framing of the task, and the students' prior knowledge interact with one another in the context of these problems. As it is the case that all of these problems were introduced in the context of statistics instruction, my analysis provides some more specific insights into the different ways in which statistical literacy (Gal, 2002) is tapped by a variety of information-based problems.

The Work of the Teachers

A central premise of this work is that teachers in the disciplines are not used to assigning information-based problems to their students. This means that this opportunity to observe multiple cases of mathematics teachers' management of these novel tasks is all the more valuable. My desire to analyze how actual experienced teachers, who are already managing the norms and obligations (Herbst, 2006; Herbst & Chazan, 2012) of their everyday mathematics instruction, introduce novel information problem-solving tasks to their classes motivates my research question: *How does the instructor in a quantitative literacy class work with students who are asked to solve a series of information-based problems?* These information-based problems could have been introduced to students in an isolated session run by somebody who was not bound by the same professional obligations and norms as the instructor of record, as would happen if the lesson were to be taught by myself or an information science specialist. This state of affairs would be problematic because it would have provided no information about the conditions under which these novel problems satisfy and/or conflict with the demands that a practicing teacher has to manage every day.

In order to answer the questions above, I drew from the same data used to analyze student work, however I looked at the enactment of these information-based problems through a different lens. In particular, I focused both on a number of interviews that were conducted with each teacher in order to ascertain their perspective on the problems, how they planned to manage the work, and what they foresaw that students would gain from their participation in these activities. This was set against the actual interactions that I observed play out in each classroom as the teachers introduced the problems to their students, provided cues to their students about what aspects of the information sources to focus on, and gave feedback to the students as they engaged in debate, presented before their peers, and/or took part in whole-class discussions. My cross-case analysis demonstrates that the introduction of information-based problems to the classroom can take place for a number of different reasons and that the opportunities for learning associated with a problem can vary widely depending on how the teacher chooses to focus their students' work.

The Information-Based Problems

While I used my cross-case analysis to look at the different ways in which mathematics teachers introduce information-based problems to their classrooms, I also wanted to characterize the resulting problems from the students' perspective. This motivated my research question: *How are information-based problems transformed as they are introduced into a mathematics class which meant to prepare students for the mathematics that they will encounter in their everyday lives?* The examples of information-based problems that appear in the literature (Wallace, Kupperman, Krajcik, & Soloway, 2000; Wiley, Goldman, Graesser, Sanchez, Ash, &

Hemmerich, 2009) are unfettered by the demands of classroom instruction and so those who crafted the problems did not need to answer as to whether the problems provided evidence of learning, were congruent with the goals set out in the course syllabus, or incorporated the disciplinary topics covered in the class.

In order to address this research question, I employ the construct of academic tasks (Doyle, 1983) described above. This has proved advantageous because it has allowed me to revisit the data, and use the resulting analysis to describe the work of the students and the teachers from a different perspective. I used my interview data, classroom observations, classroom transcripts, and the student work itself in order to characterize the ways in which the different academic tasks involved in these information-based problems differed across settings and, in particular, to describe how the mathematical and information-problem solving aspects of the tasks fit together. The analysis of these tasks has helped inform my development of a scheme for assessing the opportunities an information-based problem may provide for the practice of rational dependence in the classroom.

Summary of the Dissertation

Chapter 2 of the dissertation begins with a more elaborated argument for the place of information-based problems in the mathematics classroom. I then proceed to provide some historical context for why information-based problems have been largely avoided in subject-area instruction while also describing the three strands of literacy instruction that help to motivate the teaching problem addressed by the empirical study. Chapter 3 provides a description of the context in which my case studies took place and describes the methodological approach to data collection and analysis. Chapter 4 contains the individual case reports specific to each of the three sites. Chapters 5 and 6 present the multi-case assertions along with the analysis of student work and teacher management that warrants those assertions. The final chapter summarizes the theory developed in the previous two chapters, sets the findings of this work in a larger context, and describes future directions for the work.

CHAPTER II

Theoretical and Empirical Literature Review

Rational Dependence as an Educational Goal

What is the rationale for providing opportunities for rational dependence in a quantitative literacy course? Looking at the situation from the other way around, one can ask a different question: How much can we learn about highly contextualized problems that are mathematical in full or in part without relying on pertinent experts and expert communities? The epistemologist John Hardwig (1985) argues that we are very limited in this respect with his notion of *epistemic dependence*:

> The layman's appeal to the intellectual authority of the expert, his epistemic dependence on the expert, and his intellectual inferiority to the expert (in matters on which the expert is expert) are all expressed by the formula […]: [The layman] has good reasons to believe [the expert] has good reasons to believe that p. But the layman's epistemic inferiority and dependence can be even more radical – in many such cases, extensive training and special competence may be necessary before [the layman] could conduct the necessary inquiry. And, lacking this training and competence, [the layman] may not even be able to understand [the expert]'s reasons, or, even if he does understand them, he may not be able to appreciate why they are good reasons (Hardwig, 1985, p. 338)

I would only supplement this description with three points. First, while the layperson/expert dichotomy may sound divisive, it should be remembered that we are all in the same boat. That is to say, an expert is only an expert in a highly circumscribed domain and the moment she steps beyond that limited sphere her status reverts to that of a layperson. Thus, we do not live in a world that consists of two classes: experts and laypeople. Rather, we are all laypeople who are occasionally granted the opportunity (or responsibility) to contribute our thinking on those few matters that touch upon the areas of our expertise. Second, while Hardwig (1985) refers to individual experts, he also acknowledges that anybody who might be called an expert also belongs to and depends on a community that enables, shares, and affirms the expert's status as an expert. Any scholar must trust in the findings of other scholars whether their object of study is particle physics or Milton. Thus, it may make more sense to speak of an epistemic community (Haas, 1992) with respect to a given topic rather than isolated experts. Finally and crucially, as Harvey Siegel (1988) notes, an individual's awareness of her epistemic dependence does not give her leave to relinquish her rationality, it only highlights that she must use her reason to decide between sources of information rather than relying on her direct knowledge of the field. In his paper responding to Hardwig (1985), Siegel spells out many of the considerations that would occupy a hypothetical layperson, Smith, prior to accepting the opinion of a hypothetical expert, Jones, on a topic of import:

> She must, first, determine whether this is a question about which she ought to defer to expert opinion: Does she have the ability to become expert and reason about the matter directly? If so, is it rational for her to expend the requisite time and effort? Supposing that one of these questions is answered in the negative (*rationally* so answered, of course), Smith must ask herself: Is this question one concerning which there is likely to be reliable expert opinion? Is it likely to admit of evidence which an expert might come to recognize? Is the relevant field of inquiry sufficiently developed and sophisticated that there is reason to regard its practitioners as experts? And what about Jones: What sort of expert is she? Would other experts agree with her? Is she rightly regarded as an expert? Does she have

> a conflict of interest in this case? Is there any other special circumstances which renders her expert judgment in this case problematic? (Siegel, 1988, p. 4)

By way of contrast with the educational goal of intellectual independence (Norris, 1997), I hereafter refer to skills displayed by Siegel's hypothetical student as *rational dependence*, or the ability of an individual to rationally seek out and draw from relevant epistemic communities.

While the concept of epistemic dependence is a description of an unavoidable state of affairs, rational dependence is an aspiration based on the idea that a student could do more than simply depend on somebody else for information, they could make reasoned inferences about whom to trust on a given topic. This reasoning includes but is not limited to the determination of whether a relevant epistemic community exists, who might be said to represent this community, and whether a given piece of expert testimony is corroborated by others. The situation outlined is a confrontation between a layperson and an expert but we can nuance that by noting that it is arguably more accurate to say that the truth of a claim is warranted by a community (Adler & Haas, 1992; Collins & Evans, 2007) rather than any individual expert. It is also worth noting that Kuhn's (1991) investigation of personal epistemologies, a research program that I return to later in this chapter, suggests that it would be misleading to talk about trust in a black and white way. Rather, college students tend to move from a position of absolute trust in experts to a position of radical relativity where no one's perspective is privileged and finally to a point of view that acknowledges that there exist good reasons to at least provisionally privilege the opinions of some individuals over others when it comes to subjects that fall within their area of expertise.

These considerations do nothing to mitigate the essential problem: people necessarily come by much of their knowledge of the world around them through trust in a variety of epistemic communities rather than through direct investigation. My task in this chapter is to explore the various ways in which the education community has engaged with this problem.

In the first section of this chapter I survey some research programs that have touched on the issue of rational dependence and attempt to use this to better delineate the work that is yet to be done. These include studies on knowledge building communities (Scardamalia & Bereiter, 2006), disciplinary literacy (Moje, 2007; Norris & Phillips, 2003), and personal epistemologies (Kuhn, Cheney, & Weinstock, 2000). I conclude this first section by touching on some potential criticisms of this type of work (Lemke, 1990; Inglis & Mejia-Ramos, 2009). In the second section of the chapter, I describe the work on information problem solving (Brand-Gruwel & Stadtler, 2011) that most directly informs the empirical study that is at the heart of this dissertation. I also describe what we currently know about how students seek out and assess information sources (Agosto, 2002; Rieh & Hilligoss, 2008). In the third and last section of this chapter, I discuss the work in mathematics education that plays an important part of my analysis of the mathematics classrooms that are the subject of this study. This includes Herbst and Chazan's (2012) work on the practical rationality of mathematics teachers and the development of a model for statistical literacy (Gal, 2002).

The Prospect and Perils of Rational Dependence in the Classroom

Finding a Place for Rational Dependence in the Classroom

Knowledge Building. In his review of the conflicting goals of science education, Duschl (2008) highlighted two efforts at science education reform that characterized the latter half of the Twentieth-Century: the first was the push to apprentice students into science careers in the wake of Sputnik, the second was the effort to produce a scientifically-literate general populace. These two reform efforts highlight a fundamental distinction between the types of work toward which education in the disciplines can orient students. On the one hand, students may be taught the basic concepts of science along with an approximation of the procedures enacted by scientists. Duschl describes how most science curricula focuses on

> (a) "what we know" as identified in textbooks or by the authority of the teacher or (b) the general processes of science without any meaningful connections to relevant contexts or the development of conceptual knowledge. (Duschl, 2008, p. 269)

This type of instruction is potentially useful, notwithstanding the many debates about how best to carry it out, for preparing the subset of students who will pursue STEM careers. It is not clear, however, how this type of knowledge affects an individual's ability to ascertain the truth of already established scientific claims.

So what is it helpful for a consumer of scientific knowledge to know? Duschl (2008) argues that "in the rapidly changing world of STEM activities, an understanding of criteria for evaluating knowledge claims, that is, deciding what counts, is as important as an understanding of conceptual frameworks for developing knowledge claims" (Duschl, 2008, p.279). Scardamalia and Bereiter (2006) further explore the tensions surrounding the use of expert knowledge when they point out that "we do not want students to meekly accept authoritative pronouncements" while noting that "it is impossible to function in society without taking large amounts of information on authority" and that "even when it comes to challenging authoritative pronouncements, doing so effectively normally depends on bringing in other authoritative information as evidence" (Scardamalia & Bereiter, 2006, p.102). They point up the crucial role of information seeking when they note that "a key factor [in discouraging intentional learning] seems to be the structure of classroom communication, in which the teacher serves as the hub through which all information passes" (Scardamalia & Bereiter, 2006, p.104) and they further argue that "a knowledge building technology should facilitate *using* information, as distinct from learning it" (Scardamalia & Bereiter, 2006, p.107).

Given that the reliance on work and knowledge of others is so fundamental to progress in the sciences, it follows that a science curriculum intending to emulate the work of actual scientists would attempt to help students achieve rational dependence. This is exactly what was done by Scardamalia and Bereiter (1994) when they first developed the CSILE (Computer Supported Intentional Learning Environment) in the early eighties. The CSILE was a networked environment that provided students with ways of storing notes in a searchable database and even include a basic publication system that incorporated peer review (Scardamalia & Bereiter, 1994).

This environment eventually evolved into Knowledge Forum, the centerpiece of Scardamalia and Bereiter's (2010) Knowledge Building pedagogy. Knowledge Building pedagogy is founded on two distinct concepts: intentional learning and Knowledge Building (Scardamalia & Bereiter, 2010). The former is a type of learning that occurs within the individual while the latter involves the communal construction of knowledge. Intentional learning is a "cognitive process that has learning as a goal rather than an incidental outcome" (Bereiter & Scardamalia, 1989), but my focus here is on the process of Knowledge Building.

As is evident in the description of the CSILE, this environment is intended to model the way that scientific progress is accomplished outside of the classroom. The concept of Knowledge Building stems from a distinction between first-order and second-order environments (Scardamalia & Bereiter, 1994); the former support learning as an acclimation of the individual to a "stable system of routines" (Scardamalia & Bereiter, 1994, p.267) while the latter encourages a dialectical learning that moves forward the knowledge of the community as a whole. The canonical example of a second-order environment is the productive scientific research group, and the idea that instruction should give students insight into the way that knowledge is produced in the discipline has been taken up in a larger way by recent work on disciplinary literacy instruction.

Disciplinary Literacy. In her review of research on *disciplinary literacy*, i.e, instruction that focuses on the languages and text typical of the discipline being taught, Moje (2007) describes a number of perspectives on why and how disciplinary literacy instruction ought to benefit students. I want to focus on two of these perspectives: "access to useable disciplinary knowledge and ways of knowing" (Moje, 2007, p.8) and "access to ways of producing knowledge" (Moje, 2007, p.9). The first perspective takes up Norris and Phillip's (2003) concept of *derived literacy* which refers to "a focus on useable knowledge that does not attend to the role of language and texts in developing this useable and applied knowledge of a given discipline" (Moje, 2007, p.8), while the second perspective shifts the focus to the way that tools are used to produce disciplinary knowledge. By contrasting these two perspectives with one another, Moje both acknowledges the importance of providing students access to the actual knowledge created by members of an epistemic community and the processes by which that knowledge is created.

However, there is an element of this work that is elided in both of the perspectives described above, that of the seeking out and locating knowledge. Norris (1995; Gaon & Norris, 2001) has addressed this issue in his analysis of *intellectual independence* as an educational goal. Grounded largely in the work of Hardwig (1985; 1991) cited above, Norris's initial line of argument has been outlined in the introduction to this chapter; Gaon and Norris (2001) go on to argue that there are *content-transcendent* modes of inquiry into claims made by experts and that even if

> only an expert can appraise the methodological validity of evidential claims, the non-expert can, and indeed should, always ask such questions as: Does this scientific belief embody or support any particular social hierarchies such as those based on race, on gender, or on class? If so, what normative assumptions have been made? Have these norms been thematised and justified scientifically, or are

> they simply assumed? Have alternate accounts of the same phenomenon been developed? By whom? What were the grounds for choosing one account over another? Are these grounds themselves free of normative assumptions; are they as certain as they appear? Who decided? (Gaon & Norris, 2001, p.200)

In an another piece, Norris (1995) breaks down what science education might look like if it served to prepare students to attain an intellectual independence tempered by their dependence on expert communities. He stressed three components of this program: a) learning science in the sense outlined by Moje's (2007) "usable disciplinary knowledge" sense, b) learning about the history and philosophy of science, and c) "learning to live with science" (Norris, 1995, p.214).

This last component is elaborated by Norris, "the only access to scientific truth for most of us is through the efforts of scientific experts [...] therefore, students need to acquire the disposition to question, and to seek other opinions on scientific issues that matter in their lives and in their community" (Norris, 1995, p.215). But this questioning disposition should not, per Norris, be indiscriminate,

> A skeptical disposition is not sufficient if one does not know how to exercise wisely that skepticism. To do this, students need to be taught first that the object of their skepticism should be the believability of experts, not the evidence supporting scientific knowledge claims. They should be taught how to use criteria for judging experts: the role and weight of consensus; the role and weight of prestige in the scientific community; the role and weight of publication and successful competition for research grants; and so on. As part of learning to live with science, students need practice in judging the credibility of scientific experts. This practice should be based on real-world problems that currently affect their lives. (Norris, 1995, p. 216)

The crucial point here being that students should be turning their attention to the credibility of the experts themselves rather than the evidence that those experts present. This prescription may seem extreme, but my investigation is only predicated on the notion that investigating experts' claims should at least involve issues of credibility and not that those issues should overshadow all other considerations. Even though Norris is focused on science education, I take the term, content-transcendent goal, to imply that these goals would apply equally well to other fields, including mathematics. Bearing this in mind, I have developed a representation (see Figure 2-1) of the different types of disciplinary literacy outlined above which is useful for looking more closely at the cases at the center of this study. The circle on the left includes components of all different types of disciplinary literacy and the arrows are meant to draw attention to the existence both to those multiple types and to the existence of subtypes such as statistical literacy.

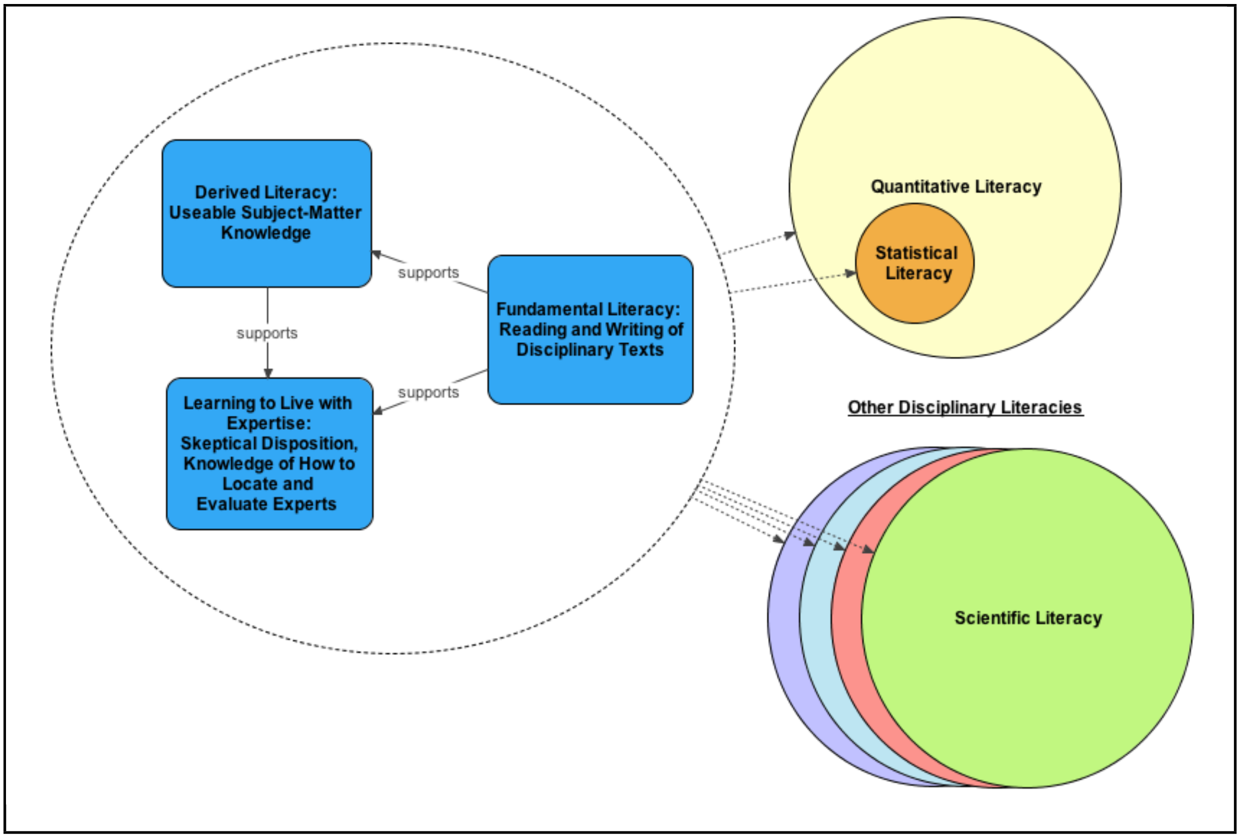

Figure 2-1. Relationships between Types and Components of Disciplinary Literacy

This leads into the question of quantitative literacy. While there has been some exploration of how mathematical texts are produced (Bass, 2006) a la Moje's (2007) second perspective on disciplinary literacy, most of the work in this area has focused on the derived sense of literacy, usually referred to as quantitative literacy. Specifically, mathematicians (Steen, 2001), mathematics education researchers (Schoenfeld, 2001), and many others have argued that the calculus-oriented mathematics track currently prevalent in our public school system does not provide the type of mathematical knowledge that is most productive of good citizenship.[4] Lynn

[4] See Cullinane and Treisman (2010) for a recent example.

Steen, a mathematician and prominent advocate for quantitative literacy instruction, states that "even individuals who have studied trigonometry and calculus often remain largely ignorant of common abuses of data and all too often find themselves unable to comprehend (much less articulate) the nuances of quantitative inferences" (Steen, 2001, p.2). Concerns about the ability of the average citizen to navigate this "data-drenched" society appear well-founded, it has been established that people (even those who are well-educated) make consistent errors when called upon to make quantitative judgments (Kahneman et. al., 1982) and that, by any extant measure, a sizable proportion of the population have a low level of quantitative literacy (Kirsch et. al., 1993; Wilkins et. al., 2000). A typical curricular response to this perceived problem is exemplified by a recently published textbook, *Case Studies for Quantitative Reasoning* (Madison, Boersma, Diefenderfer, & Dingman, 2009): students are presented with newspaper articles in which the authors employ quantitative arguments and then the students are asked to evaluate those arguments. These problems are, in fact, very similar to the information-based problems that I sketched out in the introduction with one major difference, they do not give the student an opportunity to engage in further research in order to determine whether the author that they are reading is credible or to see what the relevant epistemic community has to say about the claims. While quantitative literacy is undoubtedly important, I would like to see how quantitative literacy skills interact with the information problem solving skills that citizens are so often called on to employ in the course of their everyday decision-making.

Personal epistemologies. Kuhn (1991) analyzed the argumentation of students in her classic work, *The Skills of Argument*, and used her findings to support the idea that these students' personal epistemologies progressed through three developmental stages: absolutism, multiplism, and evaluatism. In brief, absolutists believe that all assertions are either true or false, multiplists believe that all assertions are essentially opinions, and evaluatists have reached a stage where they recognize that while it is impossible to determine the truth value of an assertion there are criteria through which assertions can be judged against one another. Interestingly, Kuhn argues that her subjects' status on this continuum can be captured entirely by their attitude toward experts. Those at the absolutist stage believe that experts can attain true knowledge about the objects of their study; those at the multiplist stage believe that experts have no special authority and, in some cases, that true experts simply don't exist; and those at the evaluatist stage don't believe that experts can attain complete certainty but recognize that experts have better grounds than others -- namely the subjects' themselves -- for their opinions. Furthermore, Kuhn found that the quality of the participants' argumentation improved according to where they fell on the continuum and that their certainty in their own point-of-view decreased according to where they fell on the continuum.[5]

Conversely, Kienhues, Stadtler, and Bromme (2011) suggest that the activity of searching the web can have a positive influence on individual's personal epistemologies. These researchers

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[5] Despite the fundamental role of the participants' relationship to expertise, Kuhn doesn't document many appeals to authority and doesn't devote much space to the analysis of those appeals. Specifically, there are two documented uses of this type of argument, one in the case of a student and one in the case of somebody described as an expert, and in both cases the use of that type of argument is simply characterized as a less-than-ideal form of evidence.

had participants investigate how to treat high-blood pressure in order to provide advice for a hypothetical "friend". One group was provided with web-sites that contained consistent points-of-view while the other group was provided with web-sites representing different points-of-view. When quizzed after spending some time searching the web, the latter group exhibited epistemic beliefs more consistent with a mature personal epistemology than the former group. This suggests that students may benefit from the opportunity to weigh different experts' opinions even without being given explicit guidance.

The dangers of dependence. Historically, writers on education in the disciplines have tended to argue that teachers avoid indoctrination by fostering intellectual independence in their charges (Munby, 1980; Kitchener, 1992; Norris, 1997). Lemke, for example, in *Talking Science* (1990), refers to a "technocratic elite: managers who try to control decisions by appealing to 'the findings of experts'" (Lemke, 1990, p. 129). He goes on to say that "science teaching often succeeds only too well in convincing students that science is inherently so much more complex and difficult than other subjects" (Lemke, 1990, p. 129). Lemke points out how science instruction often employs "a dull, alienating language" (Lemke, 1990, p. 134) and that science is represented as a particularly inaccessible and authoritative field. While it is difficult to dispute this portrait of science instruction and it could even be argued that similar alienation can and does occur in every discipline, I believe that the *possibility* of rational dependence on authority can be argued through a closer look at some recent analyses of the concept of indoctrination and the use of appeals to authority in argumentation.

In his examination of religious upbringing and the perils of indoctrination, Hand (2002) argues that

> The distinction between *appealing to* and *bypassing* a person's reason represents an exhaustive division of the possible ways of imparting beliefs. It is also clear that any method of imparting beliefs which falls into the latter category qualifies as indoctrination. What is not clear and what is not in fact the case, is that the only way of imparting beliefs in the former category is by proving them. [...] Another way, and the way in which all of us acquire a great many of our rationally held beliefs, is by *the exercise of perceived intellectual authority.* (Hand, 2002, p. 550-1, italics in the original)

It is telling that Hand considered the role of intellectual authorities because he was trying to seriously consider how the intellectually honest believer can raise their child without being accused of indoctrination. His basic argument runs parallel to Hardwig's earlier arguments about epistemic dependence, and Hand concludes that frequent appeals to intellectual authorities are unavoidable. But when and where is it intellectually honest to make that sort of appeal?

While an appeal to authority can be a logical fallacy, it is only fallacious under certain circumstances. As outlined by Walton (1989), there are three commonly cited ways to abuse the *argumentem ad verecundiam*[6] that are particular to appeals to an authority who is supposed to possess expertise (as opposed to other authorities such as those who have been granted legal authority):

[6] Argument from authority

1) An authority is cited with respect to a different field than the one in which they actually possess expertise.

2) The authority cited is not a "true" authority but "only a figure of prestige or glamor, an opinion trend-setter" (Walton, 1989, p.60).

3) The appeal is too vague, only pointing to a group of unspecified experts and/or authorities.

On the other hand, Woods and Walton (1974; 1982) were able to develop six criteria for reasonable appeals to authority from an analysis of case studies:

> First, the judgment put forward by the expert must actually fall within his field of competence. Second, the cited expert must be a legitimate expert, and not merely a celebrity, or someone not an expert. A third factor is the question of how authoritative an expert is, even if he is a legitimate expert in a field. Questions of specialization within fields of expertise are relevant here. Fourth, if several qualified experts have been consulted, there should be some way of resolving inconsistencies and disagreements that may arise. Fifth, if objective evidence is also available, this should be taken into account. In particular, an expert should be able to back up his opinion, if queried, by citing evidence in his field. The sixth requirement is that the expert's sayso must be correctly interpreted. (Walton, 1989, p.60)

Aside from the fallacious status of some appeals to authority, it is possible that this form of argumentation is avoided in a classroom setting insofar as it is seen as a way of avoiding rather than engaging in disciplinary work. But there are two reasons that appeals to authorities deserve to hold an important place in any instruction regardless of the content matter. After all, as an important part of authentic argumentation, the introduction of this activity into the classroom allows teachers to address the difference between fallacious and reasonable appeals to authority. Furthermore, it provides an opportunity for the practice of supporting skills such as those related to information seeking and evaluation.

The role of appeals to authority in the mathematics classroom was explored in a study by Inglis and Mejia-Ramos (2009). The researchers presented undergraduate students and research mathematicians with different proofs which, on a random basis, either included a warrant from an intellectual authority or did not. In so doing, Inglis and Mejia-Ramos (2009) suggest that the use of an authority is not inherently problematic, citing their finding that those with expertise in mathematical proof tended to rely on others when confronted with a proof that falls outside of their area of expertise. However, they go on to say:

> During their studies, weaker students are disproportionately likely to be uncertain about the arguments they meet, so it is not surprising that it is they who are regarded as being more likely to rely on authority figures to judge arguments. However, we suggest that relying on, or looking for, an authority figure should not be seen as undesirable behavior per se. Instead, the emphasis should be placed on empowering students by ensuring that they are in a position where they do not need to take into account an authority figure: where they have little uncertainty about the mathematical status of formal arguments. (Inglis & Mejia-Ramos, 2009, p.44)

The implication that students should only be presented with formal arguments with a clear mathematical status would appear to be contradicted by the finding that research mathematicians are willing to rely on the expertise of others, but Inglis and Mejia-Ramos actually point to the fact that those research mathematicians only do that when they lack expertise in the area to argue that students should only work with claims that they already feel confident about (Inglis & Mejia-Ramos, 2009). With rational dependence in mind, a different lesson could be taken from this research; namely, that in the interest of disciplinary literacy, a mathematics teacher ought to allow for situations that require appeals to authority as long as the appeals to authority are adequately monitored and subject to feedback.

As detailed above, Kuhn's (1991) empirical study of student's argumentation describes the personal epistemologies entirely in terms of the participants' relationship to expertise, implying that one of the best correlates for quality of argumentation is how one approaches authoritative information. Furthermore, as I noted above, Walton (1989; 1997; 2006) provides normative guidelines for the use of an appeal to authority in an argument. In light of all of this, it is telling, if understandable, that appeals to authority do not enjoy any real attention in the literature on argument in the classroom (e.g., Duschle & Osborne, 2002; Kuhn et al., 1997; Scott, 1998). In the next section I review work carried out in the field of information science, where both normative and empirical frameworks for thinking about information seeking have been developed.

The Information Science Perspective

Information Problem-Solving

While the work cited above alludes to the importance of allowing students access to outside information sources, it is another field, that of information science, where researchers have worked to develop tools that help students approach problems that require outside sources of information. The basic concept underlying this work is that of *information problem-solving.* Eisenberg and Berkowitz (1990) provide a widely used set of supports, in the form of a six-stage instructional model (see Figure 2-2), for information problem-solving, the name they gave to the activity involved in solving problems where "individuals begin seeking and using information when they find themselves unable to progress through a particular situation without increasing the depth of their existing knowledge and understanding" (Moore, 1995, p.1).

Walraven, Brand-Gruwel, and Boshuizen (2008) carried out a recent review of the literature on information problem-solving in order to identify those aspects of the process that prove most challenging for children, college students, and adults. In particular, these researchers found that college students and young adults, more generally, need help with specifying search terms, judging search results, judging source and information, regulation (i.e., keeping track of how they search for information), and that domain expertise was an important mediating variable in the success of information problem-solving tasks.

1. Task Definition
1.1 Define the information problem
1.2 Identify information needed in order to complete the task
2. Information Seeking Strategies
2.1 Determine the range of possible sources
2.2 Evaluate the different possible sources to determine priorities
3. Location and Access
3.1 Locate sources
3.2 Find information within sources
4. Use of Information
4.1 Engage the information in a source
4.2 Extract relevant information from a source
5. Synthesis
5.1 Organize information from multiple sources
5.2 Present the information
6. Evaluation
6.1 Judge the product
6.2 Judge the information problem-solving process

Figure 2-2. Big6 Skills model of information problem solving (from Eisenberg & Berkowitz, 2001)

The specification of search terms is actually a common problem for information-seekers of all ages. Students tend to have difficulty knowing which search terms to use and often end up with results that are much too broad for their purpose (Large & Beheshti, 2000). Notably, this was also one area where success has been correlated strongly with domain expertise, searchers with relevant domain knowledge appear to be much better at identifying generative search terms (MaKinster et al., 2002). The judging of search results as well as sources appear to be similarly tied to the prior knowledge of the information seeker. Those without pertinent knowledge would often adopt the problematic strategy of inspecting search results one at a time in the order of their listing rather than initially discriminating results with greater potential and better markers of credibility (MaKinster et al., 2002). The ability to engage in this type of discrimination may be facilitated by the experts' use of heuristics in order to more efficiently identify valuable information sources (Hilligoss & Rieh, 2007). It has even been found that domain expertise is a greater factor in successful information problem solving than expertise with the computer (Monereo, Fuentes, & Sànchez, 2000; Brand-Gruwel, Wopereis, & Vermetten, 2005).

Information-Based Problems

Recently, the journal *Learning and Instruction* devoted part of a special issue to research on *information-based problems*. These are precisely those problems that require students to engage in information problem-solving and, more specifically, the evaluation of sources and information. In their introduction to this issue, Brand-Gruwel and Stadtler (2011) explain why this work is important:

> Inherent to the model is the assumption that due to the growing specialization in all scientific areas there is a large number of (everyday) problems, for which

> knowledge is necessary that exceeds what an individual might know as part of his or her general education. Consequently, an individual needs to access external sources of knowledge for solving these problems. (Gruwel & Stadtler, 2011, p. 176)

The authors go on to note that prior research has found that effective source evaluation is influenced heavily by the ability and inclination to critically look at search results when inquiry occurs online, relevant knowledge of the domain in question, and epistemic beliefs.

The importance of generic search and evaluation skills is demonstrated by the effectiveness of the SEEK web tutor (Graesser et al., 2007; Wiley et al., 2009), a tool that supports students in solving information-based problems by encouraging the evaluation of the quality of search results and the authorship and support for claims found within specific sources. These authors' experiments provided evidence of learning gains on some measures (Graesser et al., 2007) and greater differentiation in judgments of reliability (Wiley et al., 2009). With respect to background content knowledge, Bråten, Strømsø, and Salmerón (2011) found that students with low content knowledge (in this case, related to climate change) were more likely to misplace their trust and less able to judge the relevance of sources. As noted above, Kienhues, Stadtler, and Bromme (2011) found that inquiry into an information-based problem was associated with the development of more advanced epistemic beliefs when students were exposed to contradictory sources of information. These findings suggest that support for generic searching and evaluation skills will be most productive when applied to an area where students have relevant domain knowledge and, vice-versa, that the application of domain knowledge to an information-based problem ought to be supported by generic instruction in the search for and evaluation of sources.

What do we know about Information-Seeking Behaviors of Young Adults?

Satisficing. *Satisficing* was coined by Herbert Simon (1955) in order to provide an explanation of human behavior that better fitted with observed phenomena than rational choice theory, the idea that humans weigh costs and benefits in order to maximize personal advantage (Friedman, 1953). Satisficing behavior occurs when a person adopts a strategy that satisfies their immediate needs rather than maximizing their utility. This behavior is often seen, sometimes to the discouragement of their instructors, in schoolwork-related activities. It is commonplace that students will do the minimum amount of work that will allow them to attain their goal, usually an acceptable grade, rather than performing to the absolute best of their abilities. This phenomenon is not limited to students of course. Connaway, Dickey, and Radford (2011) argue that convenience is a critical feature of information-seeking behaviors in almost every context that has been studied. Biddix, Chung, and Park (2011) studied administered open-ended questionnaires to 282 college students and the results confirmed that young adults value efficiency of web-searching over the credibility of the sources they found. This led them to rely on accessible web-sites like Wikipedia or recommendations of friends. Kim and Sin (2011) also confirmed, through a survey of 576 undergraduates, that students value sources that are seen as accessible and easy to use even if they understand that peer-reviewed sources may be more reliable. It is of significance for this study that Kim and Sin (2011) argue that one way to combat this tendency would be to take information literacy instruction out of the library and to embed it in content courses.

It is crucial for this analysis to recognize that the context often dictates the nature of the efforts engaged in by students -- indeed, it matters whether the participants in an activity see themselves as students. Agosto (2002) was one of the first to directly ask whether the bounded rationality framework, the framework developed from Simon's insight that the rationality of the individual is subject to constraints such as that which is described above, could be applied to information-seeking behavior. Her subjects consisted of 20 high school students in an accelerated leadership program who were asked to participate in a 50 minute web-searching session. The researchers carried out a qualitative analysis of the student's searching behaviors. They found that time, cognitive, and physical constraints were all operating during the session. They also identified two common behavior sets, *reduction* and *termination,* that appeared to provide evidence of satisficing. Reduction behaviors encompass any moves that are used to limit the number of websites used as information sources. These behaviors include returning to familiar websites, skimming search engine synopses, and skimming the site itself in order to look for signs of a low-quality information source that they could safely ignore. Termination behaviors are those moves that lead a searcher to cease their search and include the acceptance of a particular website as an acceptable source, reaching a time limit, or simply deciding that there was too much information collected to justify visiting any additional sites.

Mansourian and Ford (2007) carried out a similar qualitative analysis with 37 members of an academic community (including staff, faculty, and students). These researchers largely confirmed Agosto's findings with respect to satisficing behaviors, but they also found that the information seeker's perception of the extent and importance of missed information had a large influence on when they were willing to terminate their search. This result is particularly important for thinking about how content knowledge influences information seeking behavior. In fact, this suggests a fundamental difference between the expert and layperson as they seek out information. Presumably, the expert has a better sense of the extent of the relevant knowledge-base and we might, therefore, hypothesize that she is better positioned to know when to terminate a search or when it would be worth investing a little more time in the pursuit.

Credibility assessment. In her review of the concept of *credibility* for the most recent Encyclopedia of Library and Information Sciences, Rieh (2010) defines credibility as "people's assessment of whether information is trustworthy based on their own expertise and knowledge" (Rieh, 2010, p.1338). Rieh stresses that this involves two independent components: trustworthiness and expertise. An individual may believe an information source to be honest while doubting its intellectual authority, and they may just as easily have faith in the source's expertise while doubting its good faith. In her subsequent review of the literature, Rieh (2010) makes a further distinction between *source credibility*, the information seeker's assessment of the trustworthiness and expertise of a given source, *message credibility,* characteristics of the message itself that either contribute or detract from its trustworthiness, and *media credibility* or the trust an individual has in the media channel through which they receive a message, as exemplified by earlier research that examined whether messages encountered online were seen to be as credible as those encountered in traditional print media (Johnson & Kaye, 1998). Similarly, Sundin and Francke (2009) observed and interviewed a class of secondary students as they worked on a school project on gender equality in order to determine how the students were approaching the credibility of what they found. The authors identified several credibility-related themes: The importance of Google and Wikipedia, trust in sources referred by other trusted contacts, a trust in printed materials over web-based materials, and credibility assessment based on the genre of the information object.

Hilligoss and Rieh (2008) further developed a descriptive framework for college student's credibility assessment based on the qualitative analysis of diaries kept by 24 students. This analysis yielded three main levels of assessment: the construct, heuristics, and interaction. The first level pertains to general conceptualizations of credibility and the second describes participants' general rules of thumb. The last level, interactive, actually addresses interactions between students and specific sources of information. The types of credibility assessment that fall into this last level include content cues, peripheral source cues, and peripheral information object clues. A student is using content cues if they are actually evaluating whether the argument put forward by a source is true or not; a student is using peripheral source cues if they are attending to status of the source (e.g., name recognition, whether they have pertinent expertise, whether they are trustworthy); finally, peripheral information object cues refer to the structure of the text (e.g., number of citations, presence of an abstract, type of font).

Information Literacy as a Practice

The term 'information literacy' has been defined in a dizzying number of ways but information seeking consistently plays a central role since information must be accessed and evaluated if it is to be used by the student (Bawden, 2001).[7] Traditional studies of information seeking tend to foreground the behaviors, emotions, and cognition of the individual seeker. This research may be of great use to the information professional who is granted insight into the experiences of potential clients and patrons (e.g. Bell, 2001; Hartel, 2006), but it doesn't provide many tools for understanding how to improve information literacy apart from the valuable information provided about how people assess the credibility of information sources (Rieh and Danielson, 2007). The evaluation of information has often been the focus of information literacy instruction (Bruce, 1997); this imperative has led to the enumeration of criteria for assessing sources, a pedagogical strategy that has been disparagingly referred to as the checklist method (Meola, 2004; Metzger, 2007). A student might be asked to "check to see if the information is

[7] See Bawden (2001) for an excellent history of the term.

current [...] consider whether the views represented are facts or opinions [...] seek out other sources to validate the information" (Metzger, 2007, p.2080) along with a host of other tasks. A number of critiques have been leveled at this method (Fister, 2003; Meola, 2004; Metzger, 2007). One of the most suggestive comes from Burbules (2001) who argues that savvy web users could be "deceived by 'obvious' markers of credibility that — precisely because they are general reliable indicators of credibility — are easily falsified by clever information-providers with an eye toward deception" (Burbules, 2001, p.1).

How does one grapple with this paradox? Burbules (2001) suggests that "the best safeguard [against misleading information] is to check one's judgments against the judgments of a community with which one has confidence". This suggestion, though, is difficult to operationalize from an instructional standpoint. How do teachers introduce students to appropriate communities of judgment without impinging on their students' agency and making ethical judgments that are not theirs to make? Another author who has made note of the problems with the rote evaluation of sources is Fister (2003) who, in her examination of the "ritual abuse" scare of the 1980s, recounts the way in which misinformation traveled through many media channels that are often considered to be authoritative. In speaking of her study's implications for information literacy instruction, Fisher concludes that "the best solution, possibly the only solution, is to give students many opportunities to develop their own ability to evaluate sources directly through practice" (Fister, 2003, p.11). This case study amply demonstrates the limitations of the traditional prescriptive approach for the evaluation of sources, but her analysis fails to provide anything more concrete than the admonishment to give students plenty of experience.

Tuominen et al. (2005) address this deficiency by suggesting that information literacy be defined as a sociotechnical practice. They define this approach against the traditional study of information behavior which draws on “one of the basic categories of behavioral research, that is, need” (Savolainen, 2007, p.114). In contrast, those interested in information practices argue that “information seeking and retrieval are dimensions of social practices and that they are instances and dimensions of our participation in the social world in diverse roles, and in diverse communities of sharing” (Talja and Hansen, 2005, p.125). Taking this perspective seriously implicates empirical studies that fail to attend to the social environment in which information seeking occurs and suggests that information literacy will be of minimal use if it merely consists of generalized heuristics that are independent of context. Accordingly, the sociotechnical practice described by Tuominen et al. (2005) assumes that:

> Reading may be seen as essentially a shared activity in the sense that it deals with the evaluation of different and often conflicting versions of reality. Groups and communities read and evaluate texts collaboratively. Interpretation and evaluation in scientific and other knowledge domains is undertaken in specialized ‘communities of practice’ or ‘epistemic communities’” (Tuominen et al., 2005, p. 337)

This implies that the student be initiated into appropriate ‘communities of practice’ (Lave and Wenger, 1991) or at least be given the tools to draw upon the knowledge held by those communities. This doesn’t, in and of itself, answer the pedagogical question posed above: how do teachers introduce students to appropriate communities? Indeed, Tuominen et al. (2005, p. 341) close their article with a call for further research: “we need to understand the practices of these communities before we can effectively teach [information literacy].” The present study is, in part, an answer to this call.

Other authors have recently critiqued traditional approaches to information literacy for many of the same reasons and while their responses don’t explicitly situate information literacy as a sociotechnical practice, their prescriptions are consonant with that idea. For example, Andersen (2006) suggests that information literacy be seen as a set of sociopolitical skills. He draws upon composition studies and the writings of Habermas about the public sphere in order to argue that the access to and evaluation of information is dependent upon an understanding of how knowledge is organized in society. Most pertinent to my current work, he argues that this knowledge serves to recover “the argumentative context” of documents since this is lost when they are approached via information systems. Similarly, Lankes (2008) suggests that information literacy needs to adopt a “reliability approach” toward the evaluation of information. In making this point, Lankes calls attention to another paradox of information seeking — the “information self-sufficiency paradox” which states that “end users are becoming more responsible for making information determinations, but […] they are becoming more dependent on the information provided to them by others” (Lankes, 2008, p.104). Thus, information literacy instruction cannot take self-sufficiency as a goal, rather, it must “educate youth to assess credibility in participatory ways" by teaching them to carry out credibility assessment "through 'conversation', typified by collaboration with others" (Lankes, 2008, p.116).

Mathematics Instruction: Means and Goals

McCrory Wallace (2004) has outlined some of the challenges to the teacher that arise when the internet is allowed as a resource in the classroom. In a qualitative analysis of three secondary school teachers, she identified five affordances of the internet that may shape and be shaped by the practice of teaching: the lack of boundaries, questions of intellectual authority, instability of the text, pedagogical context, and disciplinary context (McCrory Wallace, 2004). My interest at this juncture is not so much in the nature of the affordances themselves, rather I wish to question what is meant by "shape and be shaped by"? As noted in the introduction, the actions of teachers and students in the classroom can often be best understood as part of the development, maintenance, or possible involution of the classroom's didactical contract (Brousseau, 1997), or the set of expectations of students and their teacher that must be fulfilled in order for a knowledge transaction to be legitimized. While the mathematics classroom serves an important and often exclusive role as the site for the trading and certifying of mathematical knowledge, this function becomes more ambiguous when we are talking about settings, as above, in which quantitative literacy is the focus of instruction. The goals of these classes (not to mention the evidence that supports claims about the accomplishment of these goals) can be as varied as the different ways of looking at quantitative literacy itself (Wilkins, 2009). The ambiguity of learning goals in these situations coupled with the introduction of resources that are not typical of the mathematics classroom suggests that it is particularly important to attend to how the terms of the mathematical tasks (Herbst, 2006; Doyle, 1988) that constitute work in the classroom are defined.

The Practical Rationality of the Mathematics Teacher

In order to look at how and why mathematics teachers manage work the way that they do, Herbst and Chazan's (2012) account of practical rationality proves particularly helpful. This framework is based on the idea that a teacher's decision-making can be best understood by positing the existence of a didactical contract (Brousseau, 1997) in the classroom through which instructional exchanges are played out: the teacher assigns tasks where the product can be taken as evidence of an article of knowledge. The teacher's actions may be justified by a set of norms typical of the instructional situation while professional obligations (to the discipline of mathematics, to the interpersonal dynamics of the classroom, to the students as individuals, and to the institution in which instruction takes place) can justify departures from those norms (Herbst & Chazan, 2012). This account of practical rationality demonstrates how important it is to place teachers' decisions within the context of instructional exchanges if one is to get a realistic picture of the actions that a teacher is likely to take along with their rationale for those actions (Herbst, Nachlieli, & Chazan, 2011).

In particular, Herbst (2003) suggested that mathematics teachers struggle with several tensions when introducing novel tasks to their classrooms. He based these tensions on the elements of Doyle's (1988) task framework: teachers can keep students focused on the product that the teacher originally assigned or otherwise take up student work that is more aligned with the knowledge that originally motivated the task; the teacher can guide students to carry out operations in the initially specified way or allow the students to draw their own conclusions about what operations they need to use; the teacher can direct the student to those features of the available resources that are relevant to the task or provide students with the opportunity to make choices about which features of the resources are necessary for the task. These are all facets of what Herbst (2003) refers to as "the need for a teacher to reconcile *responsiveness* to what emerges from students' work on a task with *accountability* to an agenda for knowledge development" (Herbst, 2003, p. 198). As documented by McCrory Wallace (2004), the use of the internet in a mathematics classroom certainly qualifies as a deviation from ordinary classroom practice and comes with a number of different shifts in the didactical contract that must be negotiated by the instructor. One way, then, to understand this shift is to document how and why professional obligations are called on in order to justify the use of the affordances introduced by information-based problems. For example, while mathematics instructors normally do not give students credit for citing intellectual authorities, citations are an important part of information problem-solving and this, in turn, gives rise to questions about how the teacher grants status to those citations. A similar issue arises with the disciplinary context; McCrory Wallace (2004) documents multiple teachers who, in their use of the internet, “gave up disciplinary goals in favor of other objectives” (McCrory Wallace, 2004, p.481) such as student motivation and interest in the subject area. Herbst and Chazan (2012) have documented that mathematics teachers have a professional obligation to their discipline but there is still room for elaboration of the components of this obligation and the breaches introduced by activities like information-based problems may provide an opportunity to accomplish some of this. Along these lines, the study reported in this dissertation focuses on the topic of statistics, as this is unit where the information-based problems were introduced, and so I address the concept of statistical literacy in the final section of this review.

Modeling Statistical Literacy

Statistical literacy differs from the statistical knowledge that might be taken from any given Introduction to Statistics Course in that it is, in the words of Katherine Wallman during her Presidential Address to the American Statistical Association, “the ability to understand and critically evaluate statistical results that permeate our daily lives -- coupled with the ability to appreciate the contributions that statistical thinking can make in public and private, professional and personal decisions” (quoted in Watson & Callingham, p.6). Gal (2002) added to this definition by also including a second component centered on the ability of the student to communicate statistical information in a relevant and meaningful way. While the mathematics encountered outside of the classroom need not be limited to statistics, the seeking out of claims about correlations, polling results, and representations of data were the most natural focus for the information-based problems used in this study.[8] It is also the case that arguments have been made that statistical literacy ought to be a core focus of that mathematics instruction that is not aimed at preparing students for the STEM fields. The first NCTM Standards, for example, stated that knowledge of statistics was necessary for being “an informed citizen” and an “intelligent consumer” (NCTM, 1989, p.109) and continued to be a theme in the 2000 Standards. Cullinane and Treisman (2010) in their working paper describing the Statway Initiative,[9] a developmental mathematics curriculum with a focus on statistics, argue that current mathematics instruction for non-STEM majors is often misguided in its focus on decontextualized mathematical skills and that the development of the ability to reason with data especially under conditions of uncertainty is a crucial skill that every citizen needs.

Statistical misconceptions are prevalent in modern society, to the point that Huck (2009) is able to catalog and provide evidence for 52 statistical misconceptions that commonly afflict adults no matter their education level. Most pertinent to the topics covered by the mathematics teachers in this study are misconceptions about probability, sampling, and estimation. Students

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[8] Further description of the problems and the rationale for their inclusion appears in chapter 3.

[9] The website for the Statway Initiative can be found at http://www.carnegiefoundation.org/statway

have been shown to consistently have difficulty understanding the relationship between sample size and population size, and to believe that the sample must necessarily share the same characteristics with the population (Castro Sotos et al., 2007). There are also a number of common misinterpretations of the p-value, that it signals the probability that the result occurred by chance, the probability of making a mistake, or that it indicates the strength of a treatment. In my analysis, I attend both to evidence that students hold these misconceptions and look at whether the teachers are on watch for them.

In order to better describe what it looks like when a student possesses statistical literacy, Gal (2002) developed a model for the construct that involves both knowledge and disposition components. The knowledge elements of Gal's (2002) model include literacy skills, statistical knowledge, mathematical knowledge, knowledge of relevant context, and knowledge of critical questions applicable to statistical claims. The dispositional elements include beliefs, attitudes, and the inclination to take a critical stance. The notion that statistical literacy includes dispositional elements is particularly crucial when reconciling the concept with rational dependence. The propensity to seek out further sources of information and to take steps to determine whether a statistical claim is supported by those with relevant expertise are both aspects of rational dependence.

Summary of the Chapter

In this chapter, I began by defining the concept of rational dependence and then surveying some research programs that touch on closely allied issues, primarily the idea that students need to be supported in learning how to do that component of disciplinary work that involves seeking out and evaluating the knowledge of others. This survey touched on Scardamalia & Bereiter's (2006) work on knowledge building communities, Moje (2007) and Norris's (1995) explorations of what it means to develop disciplinary literacy, and Kuhn's (1991) work on the development of personal epistemologies. After this, I surveyed work being done in the information sciences on information problem solving (Brand-Gruwel & Stadtler, 2011) and the information seeking behavior of students. In particular, I brought in the idea of information-based problems as a central part of this work and looked at how the assessment of credibility has been conceptualized by those at the forefront of the field (Rieh, 2010). Finally, I introduced Herbst and Chazan's (2012) work on the practical rationality of mathematics teaching as a way of thinking about how experienced mathematics teachers justify the decisions that they make in the classroom and introduced a model of statistical literacy (Gal, 2002) that helps me better describe how the mathematics teachers who have collaborated in this study think about the topics that they are teaching.

CHAPTER III

Methodology

As a reminder, the research questions that motivated this study are as follows:

1. How do undergraduate students in a quantitative literacy-focused course work with information-based problems introduced by their teacher? How do they use their content knowledge when working on those problems?

2. How does the teacher of the quantitative literacy-focused course work with students who are asked to solve information-based problems?

3. How are information-based problems affected by their introduction into a quantitative literacy-focused course?

The previous chapter was intended to help establish the relevance of these questions and to outline some of the theoretical perspectives that inform my investigation of them. In this section, I begin by describing the over-arching multiple case study methodology that I am using to present the results of the empirical study. Then I speak more specifically about what is meant by quantitative-literacy focused courses and why they are appropriate settings for the investigation of these questions. Then I describe the three sites of the study in greater detail, in terms of the institutional settings, the teachers, and the students. Finally, I outline the process of data collection and analysis that informs the reporting in the subsequent chapters of the dissertation.

The Multiple Case Study Approach

In his *Case Study Research: Design and Methods* (2014), Yin suggests several criteria for deciding whether a case study approach is appropriate for a given set of research questions. The criteria are as follows: a) the questions being asked should be "how" questions, b) the researcher should have very little control over what is happening in the site or sites of interest, c) the object of research should be contemporary rather than historical (Yin, 2014). As I noted in the introduction to this work, the first and third criteria are easily met by my research questions but the second condition is more questionable because information-based problems are not typical of mathematics classes at any level. Nonetheless, two considerations, one having to do with the focus of my inquiry and one having to do with the way in which I worked with my collaborating mathematics instructors, led me to take up the case study approach instead. First, as reflected in my research question above, I am primarily interested in the way in which experienced practicing mathematics teachers implement information-based problems situated in their day-to-day instruction. Stake (2004), when describing the case study methodology, says that

> Qualitative understanding of cases requires experiencing the activity of the case as it occurs in its contexts and in its particular situation. The situation is expected

> to shape the activity, as well as the experiencing and interpreting of the activity. In choosing a case, we almost always choose to study its situation. (Stake, 2004, p.2)

By "situation", I take it that Stake refers to the setting in which it occurs and follow Herbst's (2006) argument that the mathematics classroom, as one such setting, is "a context that imposes often unspoken but no less real conditions and constraints on the mathematical activity that teachers may enable" (Herbst, 2006, p.314). Thus I refer to the context as a crucial element in understanding *how* instructors and students work with information-based problems. One could imagine a design experiment in which the problems were tightly defined by the researcher, the lesson was planned out in order to take best advantage of existing research, and the actual management of the work was carried out by the researcher in tandem with the instructor of record. While there is the place for the development of such activities, as signaled by my research questions, I am most interested in what happens when teachers and students engage with information-based problems in the context of a class rather than in trying to create an ideal environment for such problems.

This brings me to the second consideration which has to do with how the teachers took up the information-based problems. I discuss the particulars of my recruitment strategy and my interactions with the collaborating instructors below, but it suffices to say that those that responded to my proposal were wholeheartedly engaged with it -- they each said that these information-based problems responded to needs in their classrooms, had their own ideas about what students would gain from the work and how it should be implemented, and want to continue to use these types of problems in future iterations of their courses. This being the case, I was in the agreeable position of being able to let my enthusiastic collaborators plan and implement the classes in which these problems were introduced with minimal intervention from myself. I describe exactly when and where I influenced the instructors at the planning stage, but, barring a couple of questions that I posed from the audience toward the end of a lesson, I was only ever an observer as the teachers worked with their students.[10]

In taking up the multiple case study analysis, I was forced to deal with what Stake (2004) refers to as the *case-quintain dilemma.* The *quintain* is how Stake refers that the phenomenon which is under investigation in the multiple case study, a phenomenon to which the cases all belong as members. For this research study, the quintain is the management of information-based problems in mathematics classrooms. While each individual case provides some insight into the research questions through the development of a case narrative and accompanying findings, the cross-case analysis is the heart of the study and where the most generative claims about the quintain are to be found. The cross-case assertions that constitute that analysis are developed by looking across the three case reports via a procedure that I outline at the end of this chapter. The aforementioned case-quintain dilemma is the question of whether the specifics of a case or the generalizations produced by looking across cases should be the primary focus of the study. As the individual case reports are written up, it is difficult to feel justified in taking any of the

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[10] There was one exception to this, I was the primary instructor during an initial pilot and, in many ways, this serves as an exception that proves the rule. I discuss the experience briefly below, but the main outcome was that I realized that it is difficult, if not impossible, to answer my research questions when the activity is treated as an isolated lesson being introduced by a third-party in the classroom.

individual findings and to apply them to the quintain, even when one has been careful to triangulate and collect adequate confirmation of the findings (Stakes, 2006; Yin, 2014), but I attempt to show as I outline my methodology in more depth, that it is possible to make more general assertions that provide valuable insight into the quintain by comparing and merging findings while being careful to be clear about the scope of the reported assertions.

Rationale for Quantitative Literacy Classrooms

As I initially planned this study, it was clear that it could prove difficult to find a mathematics classroom where information-based problems could be introduced without seeming like a gross breach of students' expectations. Furthermore, if I were to gain an honest assessment of how teachers introduce and manage these types of problems, it would work best if the teachers in question felt that the problems aligned with their goals for the course. Fortunately, there is a genre of undergraduate mathematics course that is both ill-defined enough to be amenable to the introduction of an entirely new type of problem even as the goals are, at least in some implementations, focused on preparing students to deal with the mathematics that they may encounter in their everyday lives. I refer to these courses as *quantitative literacy mathematics courses* and they are typically offered as a means for non-STEM majors to fulfill their university's mathematics or quantitative reasoning requirement. Unfortunately, there has not been very much research carried out on these types of courses, to the point where I have had to coin a tentative name for them in order to be able to talk about them in a succinct way. This lack of attention is a little shocking given the concern that has been lately expressed for the development of college students' quantitative literacy (Steen, 2001) and the concerns expressed about creating a viable mathematical track for students who are not going into STEM fields (Cullinane & Treisman, 2010). The characteristics of this category of mathematics course are quite variable, as shall be clear from my descriptions of the courses that became the sites for the case studies reported here. These courses share certain characteristics: they do not have any set mathematical prerequisites nor do they serve as a prerequisite for any subsequent course, they touch on topics that are supposed to have stand-alone value (e.g., reading polls, appreciating the beauty of mathematics) rather than being instrumental for the learning of more advanced mathematical topics, they fulfill a university mathematics requirement although they are not usually the only course in the university to do so.

I began my search for collaborating teachers by looking across over 20 nearby higher education institutions to see if they offered courses matching the description provided above. There was some difficulty even at this stage because of the various ways that these courses can be described, there were no entirely reliable keywords that I could use to search for the quantitative literacy-focused mathematics courses and so I had to read through the course catalog for each of these institutions. The resulting courses had quite a variety of names, including *Quantitative Reasoning, Topics in Mathematics, Contemporary Mathematics, Mathematical Science in the Modern World, Excursions in Mathematics,* and *Mathematics in Today's World*. I found that 15 of the schools had quantitative literacy-focused mathematics classes and I sent e-mails to the department heads of the mathematics departments at each of these schools in order to find out who was responsible for these classes and whether I could be put in contact with that person. After receiving positive responses from the department heads at 7 of the institutions, I sent out another round of e-mails providing a very succinct description of my research interest and an invitation for further conversation if the recipient was interested.[11] These e-mails led to further discussions with eight different instructors and I established active collaborations with four of them.[12]

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[11]Here is an example of the general format that I followed in these e-mails:

Dear ______,

I was referred to you by _________. She suggested that you might be interested in a research collaboration related to the ______ course that you're teaching in the Winter. I'm a doctoral candidate at _________ and I'm studying the implementation of activities in math courses (particularly those that are intended to prepare students for the mathematics that they may encounter in their everyday lives) that involve the seeking out and evaluation of information online. Is this something that you would be interested in talking more about?

Thanks for your time!

Best,

Ander

[12] The other four potential collaborations did not take place due to scheduling conflicts. In three instances, the course was not being offered at the right time and in the fourth, a collaboration was actually begun but it was not able to implemented due to unforeseen personal circumstances of the instructor.

Description of the Settings and Participants

In what follows, I describe the three locations used for my study,[13] provide further detail on the specific courses, and briefly describe the teachers and students. The three locations are as follows:

A**. Phi Public Research University, The Entry Program, Topics in Mathematics**.[14] This university is a doctoral research university with very high research activity. The Entry Program is a set of summer activities that are designed to prepare students who were entering the university from nontraditional backgrounds. Practically speaking, this means that most of the students are either from the inner city or rural school districts. Those students in the program who are majoring in a STEM field are required to take a summer pre-calculus course while the remaining students are required to take the Topics in Mathematics course. This latter course was entering its second year of existence when I first began collaborating with the course designer, Tim, who was also the lead instructor. Tim is an experienced university instructor with a doctorate in mathematics and his primary teaching duty over the past seven years had been the teaching of an

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[13] I also collaborated with an instructor at a fourth location, Kappa Community College, but this was my earliest experience engaging in this sort of collaboration and a miscommunication on my part resulted in my taking on the role of primary instructor for the class in which we introduced the information-based problems and so there was little opportunity for me to capture data that would answer my primary research questions. On the positive side, the practical experience was helpful because it helped me better understand how to negotiate my role with the collaborator whom I worked with afterward.

[14] The names of the universities are all pseudonyms. The names of the classes are pseudonyms as well although they have been choses to reflect the title of the actual class (e.g., a class called “Consumer Mathematics” might be changed to “Personal Finance Mathematics”.

accelerated calculus course for students interested in STEM careers. The Topics in Mathematics course was, therefore, a change for Tim and as the course was novel and given minimal oversight, there was some flexibility in the course's curriculum. Tim has taken a broad approach, teaching units on voting, basic statistics, fractals, and fair division, as he adjusted the course after the first iteration removing some units that were confusing for the students and adding others that he thought might pique their interest. This second iteration of the course was divided into two sections, containing 13 and 9 students respectively. The first section was taught by Tim and the other was taught by an experienced secondary mathematics instructor named Richard.

B. Rho Regional Public University, Quantitative Reasoning. This is a large public university that does not have a research focus but offers graduate degrees primarily in the professions. The Quantitative Reasoning course, appropriately, fulfills the university's quantitative reasoning requirement for students who are not taking courses in the calculus or statistics track. As the course is not a prerequisite for any other course at the university, the majority of the students taking it tend to be Juniors or Seniors who are trying to fulfill the requirement before they graduate. In particular, in the iteration of the course that I attended, there were 14 students and a plurality of them intended to enter the nursing program offered by the university.

In an interview with the head of the Department of Mathematics, he explained to me that he intentionally left the content of this course open-ended because he believes that the instructors will be better able to teach the course if they have the freedom to choose topics that most interest them. This was reflected in the course that I saw, taught by Anne, in which the students were already introduced some elements of information problem-solving. This took the form of a central project in which students were asked to collect data about Rho University and another college of their choice. Anne has a Masters in Mathematics and had taught this course every year for the previous four years, she also taught a number of other courses in the mathematics department including statistics and pre-calculus. She was concurrently completing a second Masters degree in mathematics education while she taught *Quantitative* Reasoning. The primary topics covered by this version of the course were data presentation, estimation, probability, statistics, and financial mathematics.

C. Delta Doctoral Research University, Mathematics in Today's World. This is a large public doctoral research university where the graduate degrees are mostly in the STEM fields. The course fulfills the university's formal reasoning requirement and, similarly to the course at Rho, is taken largely by Juniors and Seniors who must fulfill the requirement before they graduate. This is the only case in which I did not have the opportunity to interview the original designer of the course, but my discussions with the instructor (Ivan) made it clear that he had control over what content would be introduced. Ivan is a research mathematician and an experienced mathematics teacher who has taught at Delta University for over 15 years. He had taught *Mathematics in Today's World* in the past, but this was this was his first time teaching it in the last few years and he developed an entirely new syllabus for this version of the course. His version of the course touched on elections, polling, data representations, financial mathematics, probability, and fractal geometry. There were 39 students in the section I observed and Ivan told me that many of the students were education and nursing students although he was not able to provide me with exact numbers.

I speak in more depth about my interactions with each instructor during the individual case narratives, but my interviews with the designers/instructors of all four of these courses revealed that they shared one major goal: To help students feel less intimidated by the mathematics that they see in the media. As I met with the instructors of each of these courses, I found that they were not only open to the idea of information-based problems, they all expressed excitement about these problems and seemed to feel that they would positively contribute to their classes. Each of the instructors also independently came to the same conclusion about the sections of the syllabus where these problems could best be placed, namely the sections devoted to probability and statistics. However, as currently designed, these activities are very constrained. They essentially treat the danger of unreliable sources of information by avoiding the problem entirely and directing the students to a specific resource and having them answer a question that is amenable to a single answer (e.g., students are directed to an online mortgage loan calculator, given the price of a house along with an interest rate, and asked to use the calculator to determine monthly payments along with the length of time over which the payments would have to be made). The Quantitative Reasoning course did not contain any sort of information-based problems as part of its standard curriculum but Anne, the instructor with whom I collaborated, was an avowed proponent of information-seeking activities and she had introduced a class project wherein students were required to identify a point of comparison between Rho University and another university in the area. Students had to gather information in order to create a graph comparing universities on the basis of graduation rates, average parental income of the student population, racial demographics or something of the sort. This activity is an information-based problem and the students are allowed to choose their own information sources unlike the Quest activities used at Kappa Community. Nonetheless, Anne felt that the course could benefit from information-based problems with a more specific learning goal.

The Topics in Mathematics course at Phi University was only going to be in its second iteration and Tim was still actively deciding which topics to cover. This provided a perfect opportunity to introduce new types of problems to the course. I speak more about the development process as I introduce the cases in-depth, but I note here that my initial meeting with Tim led him to decide to include a section on statistics that he had not included in the first iteration of the course. We developed the structure of the information-based problem throughout the preceding term along with a couple of undergraduate assistants. The final version of the problem evolved into an ambitious debate activity that lasted for two weeks. Students had to choose from a selection of controversial topics (gun control, marijuana legalization, single-sex education, and the death penalty) and be ready to debate either side of the issue using statistical data located on their own. At Delta University, Ivan drafted a similar activity although he explicitly decided against a debate format. Instead, he had students form small groups and prepare presentations that, in the case of the first problem, presented a critique of an article that used statistics to make a causal claim about a controversial topic (e.g., autism and vaccination rates, gun control and crime rates) and, in the case of the second problem, examine conditional probabilities by looking at publicly available data sources.

Data Collection

My involvement in these classrooms involved four stages:

1. I met with the instructor in order to establish our division of labor and how the information-based problem(s) would be integrated into the existing curriculum.[15]

2. I sat in on the classroom prior to the use of the information-based problems in order to have a point of comparison for the work going on in the classroom.

3. One or two information problem-solving lessons were introduced to each class. The lessons are detailed in the case narratives and the appendices but, in brief, each lesson fell into three parts, subject to modifications resulting from my preliminary meeting with the instructor: an introductory lecture, an information-based problem assigned to work on outside of the classroom, and an in-class portion of the work in which the findings of the students were

[15] Talking to the instructors about their role was delicate because their work was one of my objects of study. In explaining this to the instructors, I stressed, with all honesty, that they would be represented as the experienced competent math instructors that they are and that my documentation of their use of these activities was to serve as an illustration of how an experienced and competent math instructor works with these activities and would not be used to in any way to make claims about *whether* they were good at their job or not.

reported and discussed. My only involvement with the initial lecture was indirect as I had introduced the concept of information-based problems to the instructors and so my influence may have been felt on how they introduced the concept to their students. During the in-class portion of the work, I spent most of the time observing without interfering. The instructors, however, introduced me to the students as an interested researcher and I asked an occasional question of the students at Rho University during their discussions.

4. I conducted semistructured interviews with all of the instructors, with teacher assistants at Phi University and with several of the students at Rho University.

As per Yin (2006), the most important data sources for a successful case study are the following: documentation, archival records, interviews, direct observation, participant-observation, and physical artifacts. I drew from most of these sources as displayed in Figure 3-1. The documents that I collected over the course of the study served four distinct purposes:

1) The course descriptions, textbooks, and syllabi were used to establish a baseline description of the nature and goals of the courses at the three universities. This is most elaborated in the narratives detailing each case and greatly informs the cross-case analysis in the body of the dissertation. These documents were used in conjunction with the teacher interviews and classroom observations for this purpose.

2) The syllabi and, more importantly, the assignment hand-outs were used to build a description of the information-based problems themselves and the manner in which they were assigned. The most elaborated description of these appear in the individual case narratives, but this proved most important in the cross-case analysis of teacher work. The comparison of how the teachers took up and modified my initial ideas is a crucial part of my claims about students' opportunities to engage in the productive information literacy practices described in chapter 2. These documents were used in conjunction with the teacher interviews and classroom observations for this purpose.

3) While the analysis of student credibility arguments is primarily focused on the in-class activities, the written records of student work served as an important supplement for this analysis. I used these documents to corroborate and expand on the oral arguments made by the students. Surprisingly, however, these documents were most illuminating for what they did not contain. As I describe in the case reports, the students' written work did not generally contain credibility arguments as sophisticated as those that arose in the classroom discussions, if they contained them at all.

4) Finally, the articles referenced by the students served as evidence for the deeper analysis of student claims about the content and the credibility of the content that they found in the course of their information-seeking. As can be seen in chapter 4, the student in-class work served to highlight quite a few statistical misconceptions, mistakes and misreadings. The original articles helped me determine when and where the students' reporting went astray.

Documentation	Archival records	Interviews	Direct observation	Participant-observation	Physical artifacts
*Course descriptions *Textbooks *Course syllabi *Assignment hand-outs *Student work *Articles referenced by student work	None	*Instructors (Before, during, and after) *Teaching assistants (Phi University) *Students (Rho University)	*Classroom work before, during, and after	*Planning meetings	*Smartphones *Laptops

Figure 3-1. Data sources

Interviews. In every case, the interviews that I conducted were semi-structured. I went into each interview with an initial set of guiding questions but allowed the interviewee to take the interview in other directions if it seemed important to them (Weiss, 1995).[16] I also probed with additional improvised follow-up questions if a particular incident or topic appeared to be relevant to my research questions. There were points where this process even led to a change in the protocol as was the case with the teacher at Delta University. In the interviews that followed the classroom activity, he displayed such frustration with a subset of his students that I ended up modifying my initial interview protocol in order to better probe his thoughts on the nature of these student mistakes and how he intended to address these mistakes in the future. The interviews themselves served several analytical purposes:

1) I analyzed the teacher interviews alongside episodes in which the teachers interacted with students as part of my cross-case analysis of teacher work. These interviews were particularly important for characterizing both the goals that the teachers' had for the information-

[16] The protocols all appear in the appendices.

based problems and whether they felt that the implementation of the problems actually fulfilled those goals.

2) My interviews with the two Teaching Assistants at Phi University along with student interviews at Rho University helped provide some insight into the students' information-seeking process. At Phi University, the TA's were each responsible for a study hall in which students had an opportunity to seek out their help with assignments from that day's class. This provided them with valuable insight into the challenges encountered by the students as they worked on the information-based problems. In both instances, my follow-up interview focused on common student concerns and the TA's observations of student information-seeking. I also asked the TA's to reflect on the role of the debate activity within the class as a whole.

3) At Rho University, I had the opportunity to interview a subset of student volunteers after the first time that the teacher introduced an information-based problem. I asked the students about how they went about searching for information and what informed their decisions about which information sources to use. As with the TA's, I also asked some more global questions about the activity itself and whether they felt that it was a positive addition to the course.

Direct observation. This is the core of my case analysis. I sat in on each class before, during, and after the introduction of information-based problems. I wrote up field notes while visiting the class and also used audio- and video-taping during the in-class activities associated with the information-based problems. I used these stable records for transcription and subsequent analysis of student work and teacher interactions with students. The field notes created during my visits helped focus my analysis and also helped me better characterize the “natural state” of the classroom prior to the introduction of the information-based problems. I describe the analytical approach that I took to the data, once it was collected, below.

Participant-observation. While I introduced the idea of information-based problems to the instructors of these classes, I would not characterize my presence in the classroom as participant-observation in any of the cases. The instructor introduced me to the class, in each class, and briefly described the nature of my interest in the work. After having done this, I generally spent my time making sure that the recording equipment was operating correctly and taking field notes on what I was seeing in the classroom. My involvement rarely went beyond this. The only exception are a couple of questions that I posed to student presenters at Rho University and Delta University respectively. I detail those contributions in their turn.

On the other hand, I was acting as a participant-observer during the planning meetings for the Topics in Mathematics course at Phi University. This occurred partly because the planning of this course was already being carried out collaboratively with two undergraduate teaching assistants. As I was privy to these discussions and as the instructor was eagerly soliciting input about the course, it seemed appropriate to contribute to the planning work. This intervention would be problematic if the object of my research was the genesis of the information-based problems, but my questions are only about the implementation of these problems. Nonetheless, I describe the nature and extent of my contribution, as best as I can, in the case narrative for Phi University.

Physical artifacts. I had not anticipated that any physical artifacts would come into play when I initially created my plan for data collection. As it turned out, however, there were several incidents at Rho University where students interacted with smartphones and laptops that they had at hand while discussing the information-based problems. This technology use plays a part in my analysis of the way in which students went about assessing the credibility of the sources submitted by their peers.

Summary of the Analysis

In this section I present a brief overview of my analytical process and follow this with a more detailed description specific to each step of the analysis. Even though this dissertation is a multiple case study (Stake, 2006), the analysis began with individual case reports.[17] These reports consisted of a narrative of each case along with a set of *case-specific observations* that served as a bridge between the particulars of the case and the broader phenomenon that was the

[17] I present the pertinent features of the individual case reports in chapter 4 but these do not constitute the entire case reports, rather they are essentially excerpts

object of the cross-case analysis:[18] the opportunities for rational dependence afforded as mathematics teachers introduce information-based problems to their classrooms.[19] It was in the context of the individual case report, and writing the case-specific observations in particular, that I engaged in transcript-level coding describing the work of the students and the work of the teacher as it bore on the potential for rational dependence in the classroom. I detail this coding and how it informed the development of case-specific observations, below.

The cross-case analysis proper began with my reading through each of the individual case reports and taking structured notes relating the content of the reports to my research questions. I used these notes, in turn, to develop matrices used to generate cross-case observations. I provide an example below but, in brief, these matrices were used to indicate the relevance of each of the case-specific observations to the themes of the cross-case analysis. After using the matrices to order the case-specific observations according to their relevance to each of my research questions, I developed *cross-case observations* to account for as many of the most relevant case-specific observations as possible;[20] I describe this process in greater detail below. These cross-

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[18] The case-specific observations are referred to as *findings* by Stake (2006). I refer to case-specific findings in my study both to make it easier for the reader to distinguish between observations about individual cases versus observations that span multiple cases, and to acknowledge their empirical status.

[19] Stake (2006) uses the term *quintain* to refer to the phenomenon that is the object of a multiple case study analysis. He uses this term of art in order to better indicate that the object of the multiple case analysis is an object that does not exist solely in any of the particular cases. For the sake of the reader, I will continue to refer to the *object of study*, the *phenomenon,* or name it in full.

[20] The cross-case observations are referred to as *assertions* by Stake (2006). I refer to case-specific findings in my study both to make it easier for the reader to distinguish between observations about individual cases versus observations that span multiple cases, and to acknowledge their empirical status.

case observations are presented in chapters 5 and 6; they are the core of the cross-case analysis and inform the concluding discussion in chapter 7.

Individual Case Reports

The Individual Case Report and Case-Specific Observations

The individual case reports each consist of a case narrative along with a set of case-specific observations. The case narrative was developed from the data collection described above: field notes, transcriptions of the implementation of the information-based problems, transcripts of interviews, student work, and the documents describing the requirements of the problems. This data is used to describe the context of the course, the preparation for the information-based problems, the implementation of the problems, and the teachers' reflections on the problems. The core of each individual case report is a set of *case-specific observations* that are influenced by the larger research questions but specific to the cases. Stake cautions that "the [Case-specific observations] are Case-based not [Research question]-based"[21] (Stake, 2006, p. 59). That is to say, while the research questions influenced my analytical approach as I describe below, a priority of the multiple case study is to maintain a view of activity in its situation. Practically speaking, this means that I developed each case report separately, using my field

[21] Stake (2006) refers to 'findings' and 'themes' rather than 'case-specific observations' and 'research questions'.

notes to write out a case narrative, transcribing the student talk and interviews, while memoing and highlighting key passages throughout. The case-specific observations are not a place for generalizations, rather they are a crucial part of the data from which I developed the more general cross-case observations. In making the case-specific observations, I followed Stake (2006) and Yin's (2014) injunctions to support them with at least three pieces of evidence and to triangulate between data sources whenever possible.

As one illustrative example of how I developed these case-specific observations, I briefly describe the process that led to the generation of two of the case-specific observations that are part of the Phi University case report (see Figure 3-2).

Case-Specific Observation 1.4: In their framing of the students' task, the teachers focused on two knowledge elements of statistical literacy (the creation and interpretation of graphs, and critical skills) and one dispositional element (the adoption of a critical stance).
Case-Specific Observation 1.5: The teachers highlighted student engagement as a positive outcome of the debate.

Figure 3-2. Two of the Case-Specific Observations from the Phi University Case Report

I came out of Tim's summer course at Phi University with an extensive corpus of data in the form of field notes, integrative memos, audio and video records. I had transcribed the audio records over the fall and segmented out the interactions between the teachers and the students as I carried out the transcription. My initial open coding of these transcriptions gave rise to some themes (e.g., keeping time, encouraging questions) but they felt rather generic to me and were not giving me insight into my research questions. It was only once I had settled on the case study methodology and took up Yin's (2003) recommendation to base definitions on existing research whenever possible, that I decided to use Gal's (2002) model of statistical literacy as a lens for looking across both my interview data with Tim and his contributions in class. This helped me to articulate Finding 1.4 and it was during my review of the corpus of Tim's contributions to see whether there were any themes unaccounted for by the statistical literacy framework that I developed Case-Specific Observation 1.5.

Students and Credibility Assessment

As I noted in the previous chapter, the assessment of the credibility of sources is central to the practice of rational dependence. In order to explore the way in which students in the three cases made claims about the credibility of the sources that they used, I have used Toulmin's (2003) argument scheme as an analytical tool. In this section I briefly review the pertinent concepts and provide an example of what this analysis looked like. Toulmin (2003) asserts that a claim if it is challenged is initially supported by *data*. If the truth of this data is also challenged by the listener then that data must be treated as another claim that may be contested and defended in the same manner as the initial claim. As Toulmin also refers to data as *grounds* for a claim and in order to draw a distinction between the quantitative data that is going to be the subject of much of the work recounted in this study and the citations that serve to support that data, I use the term *grounds* to refer to the citations' role in the argument. *Warrants* are the often implicit logical connectors between grounds and the claims that the grounds support. There are a number of different types of warrants but I am most concerned here with the argument from authority.[22] That is when the warrant is an appeal to the intellectual authority or believability of the source of the grounds for the claim in question. Now if somebody were to challenge the validity of a warrant then a response defending the warrant is referred to as *backing*. In the case of appeals to authority, the backing may take many forms (e.g., credentials, organizational affiliation, aesthetics). The concepts outlined above are the source of the coding scheme presented in Figure 3-3.

Element of Argument	Definition	Examples
Grounds	Citations used to support data that was previously introduced to an argument.	Author, Organization, Website
Warrant (Appeal to Authority)	The rationale for connecting the grounds to the data it supports.	The often implicit claim that the cited source is credible.
Backing	A reason to believe that the cited source is credible.	Content Cues, Peripheral Source Cues, Peripheral Information Object Cues

Figure 3-3. The Elements of Argument used for the Coding of Student Discourse after Toulmin (2003) and Hilligoss and Rieh (2008)

In order to answer my questions about how students' work on information-based problems and how they draw on their knowledge of the discipline, I pay particular attention to

[22] There are, in fact, a number of different classification schemes for warrants, including the classical distinction between ethos, pathos, and logos, or the more recent GASCAP acronym: generalization, analogy, sign, causality, authority, and principle (Fulkerson, 1996).

the difference between backing that points to characteristics of the source itself and backing that points to the argument contained in the source. In so doing, I draw on the credibility model created by Hilligoss and Rieh (2008) in which they describe three types of credibility assessment that occur at the point of interaction between an individual and an information source: content cues, peripheral source cues, and peripheral information object cues. As described in the last chapter, these cues address the actual content of the argument, the characteristics of the source of information, and the characteristics of the information object created by the source respectively. I provide some examples of these codes from my own analysis. The first excerpt (see Figure 3-4) is from the small-group discussion associated with the first information-based problem at Rho University. I initially coded any citation of a source as an instance of grounds (highlighted in blue in Figure 3-4). These are not necessarily formal citations; an informal reference to the source of the data was sufficient as when Faith said that "the author was from a journal" below.[23] If that was the end of the statement then I would have only coded for backing but there were two additional backing statements. I coded "it was from a journal of toxicology" as a peripheral source cue type of backing. It was easy to decide that this phrase counted as backing because Faith added "so that's pretty credible". However, even without that additional clause, I still would have coded that the statement as a peripheral source cue because Faith's decision to include the field of study (toxicology) suggests that she felt that the field of study mattered for the claims being made. I also coded the next sentence as a peripheral information object cue

[23] All student names are pseudonyms.

because rather than referring to any indicators of the expertise or background of the source, Faith implies that the structure of the information object itself is a source of credibility.

Faith: For the other two, the one that I did have data on, and it was a p-value not an r-value, it was the lymphocytes of the population of children with autism spectrum disorder and their unaffected siblings. It's like their talking about the hypersensitivity of the vaccines to the b-cells of the body and how that can trigger autism. And the author was from a journal, it was from a journal of toxicology, so that's pretty credible. It had like, it was a primary literature piece, it had a methods and materials section, it had an abstract and that stuff, so it seemed like --
Donna: It was research-
Faith: Yeah, and the only thing I missed was the p-value because I didn't realize that was the r-value, but it wasn't focused on so much the correlation between vaccines and autism but tests that they ran from the hypersensitivity to the cells. So it was kind of-

Figure 3-4. Credibility Argument Coding from Second Group, First Session, 2/6/14, Lines 58 - 67

An example of an excerpt that I coded as a content cue appears in Figure 3-5. The student, Tom, is responding to a peer who has opened the discussion by describing the article that she found that she deemed most credible. Tom is responding in kind and asserts the articles credibility by pointing to the "values" and "work" contained in the article itself. This is not a peripheral information object cue because he is using the content of the article -- however superficial his understanding of that content might be -- as a marker of credibility rather than its form. The existence of grounds for the claims made by the article is entirely implicit here and this is partly a function of how the task is being carried out by the students.

Tom: I'd say my third [article] too because like they studied [the Mozart Effect], they took different groups and they even found that sometimes it make it worse, and had all the values, like 50 pages of work. I was like "oh my god!", I was like "just scroll down"

Figure 3-5. Credibility Argument Coding from Fourth Group, First Session, 2/6/14, Lines 5 - 7

I discuss this more when presenting my analysis of student work in chapter 5, but as the students were explicitly told to discuss the credibility of their sources, they understandably begin by referring to the source in question ("my third [article]") and then the backing for its credibility. It was only after all of this that Tom actually referred more than allusively ("they even found that sometimes it makes it worse") to the claims made by the article. I applied this coding scheme to the debates at Phi University, the small group discussions (multiple audio recorders allowed me to capture and transcribe concurrent discussions) and final discussions at Rho University, and the group presentations at Delta University. I present and interpret the results of this coding as part of the individual case reports in chapter 4.

Accounting for the Work of the Teacher

In order to better inform my analysis of the work of the teacher I parsed the classroom transcripts into episodes in which the teacher interacted with students. This was a natural unit of analysis as these interactions were both limited in scope and occurred relatively infrequently. The lack of extended teacher interactions was likely due to the activity structures at the three cases which were all student-centered debates, discussions, or presentations. In order to capture those interactions with students that were specifically concerned with opportunities for the development of rational dependence, I initially coded the teacher-student interactions according to the Eisenberg and Berkowitz (1990) model of the information problem-solving process. As it turned out, the only code that was used with any regularity was that corresponding to the fourth step in the process: "Evaluate different possible sources to determine priorities" (Eisenberg & Berkowitz, 2001, p.2). I eventually titled this code "credibility assessment" in order to correspond to phenomenon that I was attempting to capture with my coding of the student dialogue. The resulting corpus of episodes largely overlapped with student talk about credibility (See Figure 3-6 for an example) although there were many more student episodes addressing credibility.

Gretchen (Student): Um, as far as credibility. I'd say are most credible was done by Gallup because Gallup is most widely known and a lot of people use Gallup.

Anne (Teacher): Okay, so Gallup,for those of you who don't know, is a major polling company that's spread all over the United States.

Gretchen: The other one is by Pew Research Center, which I had never heard of-

Anne: That's actually a pretty credible place too.

Figure 3-6. Episode of teacher-student interaction coded for Credibility.

After exhausting the coding for steps in the information problem-solving process, I categorized the remaining episodes of teacher-student interaction as *classroom management*, *content-related,* or *off-topic.* Episodes were coded as content-related when the teacher addressed a mathematical topic and off-topic when the teacher spoke about something unrelated to the course (for example, small talk about classical music occasioned by a small group discussion about whether listening to classical music while studying leads to better test scores). The resulting corpus of teacher-student interactions was relatively small and, as will be seen in the analysis, the absence of talk about the information problem-solving process has been just as relevant to my case-specific observations as its presence.

The Cross-Case Analysis

The cross-case analysis began after I had achieved some distance from the individual case reports. Stake (2006) suggests that the author of the cross-case analysis should be a different researcher than the author of the individual case reports, but he also recognizes that this cannot always happen, especially in the context of a dissertation study, and notes that there are some advantages that accrue when they are one and the same person, namely that the author of the cross-case analysis is better able to bear in mind all the of the cases simultaneously as they read across the individual reports. For my purposes, these notes consisted of a very brief synopsis of the narrative, a description of the constraints of the particular case (for example, whether there were some data sources that were unavailable), a summation of what made the case unique among the others (for example, differences in activity structures), a record of my opinion about the prominence of each research question for the case, and a similar record with respect to the expected utility of the case for answering each research question. I also made note of the case-specific observations and specific passages that might help shed light on the research questions.

Having written out those structured notes, I followed Stake's (2006) procedure and created a matrix (see Figure 3-7) that cross-referenced the case-specific observations with themes based on the my research questions.[24] In the matrix, I ranked how pertinent each observation was to the theme and this, in turn, provided me with a way of organizing the case-specific observations relative to my research questions. I developed tentative cross-case observations by collecting together those findings that were most relevant to a given theme. I would then rank the cross-case observations according to their importance to the target phenomenon (i.e., the

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[24] The themes were as follows:

Theme 1: How does the instructor of a quantitative literacy class work with students who are asked to solve a series of information-based problems?
Theme 2: How and why do teachers' modify the initial information-based problems as they introduce them to their classes?
Theme 3: How does students‘ disciplinary literacy influence their process of information problem solving?
Theme 4: How do undergraduate students in a quantitative literacy class work with a series of information-based problems?
Theme 5: More particularly, what elements of statistical literacy are exhibited by the students in the context of these problems and how do they use that knowledge?
Theme 6: How does the work of these students support, conflict with, or extend the established findings of information-seeking behavior and information literacy research?

While these themes were originally used to organize the cross-case observations, for the purposes of reporting the cross-case analysis, I reverted to the original research questions from which the themes were derived. I made this decision in the interest of clarity for the reader since when they were included in the body of the dissertation, they only served to insert another, largely redundant, stratum of statements between the research questions and the cross-case observations.

opportunities for rational dependence that occurred when information-based problems were introduced to a mathematics classroom) also making note of their strength (i.e., the weight of evidence in its favor).

	Themes					
Phi Univ.	1	2	3	4	5	6
Case-Specific Observation 1.1						
Case-Specific Observation 1.2						
etc.						
Rho Univ.	1	2	3	4	5	6
Case-Specific Observation 2.1						
Case-Specific Observation 2.2						
etc.						
Delta Univ.	1	2	3	4	5	6
Case-Specific Observation 3.1						
Case-Specific Observation 3.2						
etc.						

Figure 3-7. Matrix for Generating Cross-Case Observations (Stake, 2006, p.51)

Taking both of these factors into consideration, I composed a cross-case observation that attempted to account for the most relevant case-specific observations and repeated the process for the same set of observations whenever there were remaining observations that had not been addressed (Stake, 2006). In doing this, I was bearing in mind Stake's (2006) edict that "the assertion should have a single or common focus, a contribution toward understanding the [phenomenon], and evidence from more than one case to support it"[25] (Stake, 2006, p. 56).

As I did above for the case-specific observations, I provide an example of how this process worked for two of the cross-case observations. I began the process of generating the cross-case observations by developing the matrix described above and appearing in Figure 3-7. After having done this, I created different tables for each theme, sorting the case-specific observations according to their relevance to the theme in question. For example, the table created for Theme 4 appears as Figure 3-8 below.[26]

[25] Stake (2006) refers to 'the quintain' rather than 'the phenomenon'.

[26] Theme 4 is "How do undergraduate students in a quantitative literacy class work with a series of information-based problems."

Case-Specific Observation 1.1: Students produced very few arguments about the credibility of sources. They used sources to ground their claims while rarely providing backing for those sources.	H
Case-Specific Observation 1.2: Students' lack of mathematical knowledge may have limited their ability, in some cases, to find information that they needed, but there was little evidence of this in the debates themselves.	H
Case-Specific Observation 1.3: Students encountered some typical difficulties seeking out and evaluating information, but this was not noticed by the teachers.	H
Case-Specific Observation 2.1: Even though they were responding to exactly the same questions, the students were able to make much more sophisticated credibility arguments during their in-class discussion than they had in their written reports.	H
Case-Specific Observation 2.4: Some groups made use of the tools at hand (e.g., smartphones, laptops) to corroborate information that they already found or to look into the validity of something reported by an absent student.	H
Case-Specific Observation 3.1: Students' credibility arguments were mostly confined to the first information-based problem and those arguments were all about the content rather than the sources.	H
Case-Specific Observation 2.2: In the first session, students were searching for articles and then looking for a correlation coefficient within the articles, but they rarely found a correlation coefficient.	M
Case-Specific Observation 2.3: In the second session, students were searching for articles with confidence intervals and they were usually successful in finding those.	M
Case-Specific Observation 2.5: Students preferred to work with information resources that did not contain mathematics that they could not understand.	M
Case-Specific Observation 2.7: The instructor addressed the credibility of sources much more often in the second session than in the first session.	M
Case-Specific Observation 3.2: Students' adoption of a critical attitude could be used to forward an ideological agenda.	M
Case-Specific Observation 3.4: The second information-based problem provided an opportunity for students to compare different sources of information, but the work presented by the students was focused on calculating probabilities rather than information-seeking.	M
Case-Specific Observation 1.4: In their framing of the students' task, the teachers focused on two knowledge elements of statistical literacy (the creation and interpretation of graphs, and critical skills) and one dispositional element (the adoption of a critical stance).	L
Case-Specific Observation 1.5: The teachers highlighted student engagement as a positive outcome of the debate.	L
Case-Specific Observation 1.6: The teachers chose not to evaluate the content of the student presentation, choosing instead to give students full-credit based on a holistic appraisal of the effort that the class had put into the activity.	L
Case-Specific Observation 2.6: In the first session, the instructor prioritized the identification of a particular piece of mathematical content, the correlation coefficient, to the exclusion of any discussion of the credibility of sources.	L
Case-Specific Observation 3.3: A number of the groups made mathematical errors and betrayed statistical misconceptions during their presentations; this appeared to be the most prominent outcome of the presentations from the teacher's perspective.	L
Case-Specific Observation 3.5: The teacher's interventions focused on the students' analysis of the mathematical content found in their sources.	L
Case-Specific Observation 3.6: The teacher was primarily concerned with developing students' critical stance as realized through the asking and answering of critical questions.	L

Figure 3-8: Case-Specific Observations Sorted According to Relevance to Theme 4

The cells are color-coded according to the case where blue is Phi University, orange is Rho University, and green is Delta University. Each observation was coded according to their relevance to the theme where L is a low degree of relevance, M is a medium degree of relevance, and H is a high degree of relevance, and I attended to the case-specific observations according to how they were notated. After reading and rereading the case-specific observations recorded in Figure 3-8 along with their longer write-ups in the case reports, I decided that I should be able to address the observations regarding the information seeking of the students in the first two cases (Case-Specific Observations 1.2, 1.3, and 2.4). The students at Phi University and Rho University did not have very much difficulty seeking information in general but they experienced some particular difficulties all centered on credibility assessment. Having made note of these observations, I linked them to other case-specific observations about credibility assessment, namely 1.1, 2.1, and 3.1 where I found that students only made arguments in very specific circumstances. I initially created two cross-case observations, one addressing the fact that the students information seeking could at least roughly be described by the Big6 information problem-solving model,[27] and the other addressing the general lack of credibility assessment during most of the observed activities. I ended up combining those two observations into Cross-Case Observation 3.1 9 (see Figure 3-9) because they collectively dealt with the entirety of the information problem-solving process.

[27] The details about the information problem-solving process appears in the explanatory material accompanying the case-specific observations and is only glancingly alluded to in the statement.

Theme 3: How does the work of these students support, conflict with, or extend the established findings of information-seeking behavior and information literacy research?	
	Cross-Case Observation 3.1: The students in these cases largely followed a typical information problem solving process but they did not engage in any credibility assessment unless they were specifically told to do so.
	Cross-Case Observation 3.2: Students were mostly able to fulfill the terms of the assignments that they were given but there was much evidence of satisficing.

Figure 3-9. Two of the Cross-Case Observations from the Multiple Case Analysis

The subsequent development of Cross-Case Observation 3.2 was born from a comparison of the case-specific observations with existing literature on the information seeking behavior of college students -- one of the major findings being the tendency of those students to privilege sources that are accessible and easy to use (Connaway, Dickey, & Radford, 2011; Biddix, Chung, & Park, 2011; Kim & Sin, 2011). The first cross-case observation helped describe whether and how students were engaging in the information problem-solving process but it did not address whether the students were satisfying the terms of the problems that they had been given by their teachers. I used largely the same case-specific observations, but in this case I looked at what it meant, for example, that the students at Rho University provided such superficial written work when asked to describe the credibility of their sources. This phenomena occurred in the other cases as well, albeit not to as great an extent, and I realized that it could be best described as satisficing behavior. This way of describing what I was seeing was all the more useful because that type of behavior has been very well documented among information-seekers.

A similar process was followed for generating the remainder of the cross-case observations. I used spreadsheets[28] to bring together those case-specific observations that were most relevant to a given theme and then proceeded to look for overarching observations that could account for what I was seeing across the cases. As with both of the examples above, I often went to the outside literature in order to gain insights into how best to describe what I was observing in a useful way.

Summary of Chapter

In this chapter, I have provided some initial context for the empirical study that is the subject of the rest of this dissertation. I then described the multiple case study approach as well as the three sites that are the subject of the study. Then I outlined the process that I used to carry out the multiple case analysis following this with sections providing further detail on the individual case reports and the cross-case observations. The case-specific observations formed the basis for the analysis that I used to produce the cross-case observations. Along with the case-specific observations, I included a description of how I analyzed student discourse through the use of a coding scheme for evaluating arguments about the credibility of sources, and the way in which I created a corpus of teacher-student interactions pertaining to the information problem-

[28] Stake (2006) suggests strips of paper.

solving process. Finally, I provided examples of how I generated the case-specific observations and the subsequent cross-case assertions.

CHAPTER IV

Individual Cases

The following three case reports offer descriptions of the manner in which the information-based problems were introduced and managed at the three sites. These descriptions help provide a context for understanding the differences between the tasks observed at each case and provide grounds for hypothesizing how and why those differences may have affected the students' opportunities to exercise their rational dependence. These opportunities are addressed by three themes that recur throughout the cases. First, the cases provide evidence about whether the students were able to engage in the credibility assessment that is basic to the practice of rational dependence. Even though all of the students made decisions about which information sources to use, they were positioned to do this in different ways in each classroom. In fact, there was only one case where students' judgments about the credibility of their sources became an explicit part of the classroom work. Second, these cases demonstrate that students' mathematical knowledge can influence the exercise of rational dependence in a number of different ways. For example, the teachers all chose to include mathematical work as part of the information-based problems, but the students' lack of mathematical knowledge sometimes undercut their ability to make use of sources. Third, all of the teachers introduced tasks that encouraged students to take a critical stance towards the mathematical content of their sources. These tasks differed from one another both with respect to their implications about what it means to critically appraise a quantitative claim and how much opportunity they provided for rational dependence in a broader sense.

Phi University: Case Narrative

Introduction

The lead teacher at Phi University provided a problem that appeared to be ideally situated to encourage students to seek out and evaluate information sources: a debate about a controversial topic in which students were partnered with one another and tasked to come up with arguments in defense of both sides. This problem could have compelled students to seek out the most credible sources of information in order to better construct an unassailable set of arguments when it came time to debate their peers. The case-specific observations, however, suggest that this debate did not address that sort of credibility assessment. The lead teacher did include a mathematical task intended to foster a critical sense (Gal, 2002) towards the quantitative claims found in their sources, but the development of this critical sense was approached indirectly. Rather than directly question the quantitative claims appearing in the sources, the students were required to produce statistical charts and graphs that would support their own argument under the theory that this work would help students approach other's quantitative claims more analytically. Altogether, this case demonstrates that the creation of opportunities for the practice of rational dependence in a mathematics classroom is anything but straightforward and introduces a theme that we will revisit throughout this study: the extent and nature of those opportunities are governed by the teachers' attempts to reconcile the teaching of mathematics with the opportunities offered by information-based problems.

Background and Context

As part of its mission as a public university, Phi University developed The Entry Program as a summer program to help students coming from traditionally underserved locations. The Topics in Mathematics course was introduced to help those students in the program who were not majoring in the STEM fields and for whom the university's mathematics requirement might be a stumbling block. The course had been introduced a year prior to my contact with Tim, the lead instructor; the first version of the class had covered topics such as transfinite numbers, fractals, and probability theory. Tim appeared to be well-suited for this course as much of his teaching experience involved non-traditional mathematics classes designed to pique the interest of advanced high school students and students on the university's honors track.

Preparation

I first contacted Tim almost 6 months before the course was to be taught. He had decided to spend a good portion of the Winter and Spring terms meeting with three undergraduate assistants who would go through the textbook (Burger & Starbird, 2005) and provide their feedback on what their fellow students might find most interesting. It was during this time that Tim came up with the idea for a debate during which students could be required to engage in information problem-solving as they gathered the resources for making an argument on both sides of a controversial issue. At the end of the summer, I interviewed Tim and he gave his perspective on the genesis of the debate idea:

> And I don't remember who said it first, I think it might have been me but I'm not sure, who said, maybe we should have a debate. What if we had people try to take two sides and support them with statistics. A lot of the section, the first part of the book, the first part of the book's chapter on stats is about, it's an odd take, they start off by talking about how statistics can be misused. Or at least used in a biased way, and they give some examples of, you know, one that sticks in my mind is that the democratic version of a tax cut and the republicans version, both two graphs from the same data that, if you look at them, give a very different emotional message about what's going to happen. The republicans make it look like a very fair tax cut and the democrats make it look like it's biased towards rich people and same data. So that's where the book starts, the whole first section is about that, how to misuse data. (Tim, 8/14/13, Lines 12 - 22)

This framing of the debate problem suggests that the focus was inspired to some degree by the textbook and also foreshadows how important it was to Tim that students learn how to "misuse" data.

Narrative of the Information-Based Problem

The “First Ever Topics in Mathematics Statistical Debates”, as Tim came to call them, were a culminating event for the class. Accordingly, the logistics of the debates were complex especially since it involved a second section of the course being taught concurrently in an adjoining room by Rich, an experienced local high school mathematics instructor. Fortunately, there were two undergraduate teaching assistants, Jenny and Rita, who helped manage where the students were supposed to be during the debates. These TAs ran study halls in the evening designed to give students time to devote to the assignment from that day’s class and so my interviews with them were a useful source of data on how the students were dealing with the assignments.

The debates were structured so that each group presented a 5-minute opening statement that they had rehearsed ahead of time. This opening statement needed to include a representation, usually in the form of a graph or a table, of some statistical data supporting the argument. After the opening statements, both groups were given the opportunity for a one minute rebuttal. Each debate ended with an opportunity for the audience to pose questions for the groups although, as I elaborate below, the two instructors framed the Q&A portions differently for their respective sections. It should be noted, especially in light of my comparison between the two instructors, that there was some movement between the two classrooms as the debates progressed. The classrooms adjoined one another and the scheduling of the debates was such that students from different classrooms were sometimes asked to debate one another.

Case-Specific Observations

The first three case-specific observations address the students' work (see Figure 4-1). I begin by looking at their assessment of the sources that they used, then the role of the students' mathematical knowledge, and, finally, their information problem-solving process. The last three observations deal with the work of the teachers. First I discuss how the teachers framed the task, particularly in terms of Gal's (2002) model of statistical literacy, and then I look more closely at how the teachers evaluated their students' work and what they wanted their students to gain from it.

Case-Specific Observation 1.1: Students produced few arguments about the credibility of sources. They used sources to ground their claims while rarely providing backing for those sources.
Case-Specific Observation 1.2: Lack of mathematical knowledge appears to have limited the students' ability to find information at times, but there was little evidence of these difficulties in the debates.
Case-Specific Observation 1.3: Students encountered some difficulties seeking out and evaluating information. These difficulties were not noticed by the teachers.
Case-Specific Observation 1.4: In their framing of the students' task, the teachers focused on two knowledge elements of statistical literacy (the creation and interpretation of graphs, and critical skills) and one dispositional element (the adoption of a critical stance).
Case-Specific Observation 1.5: The teachers highlighted student engagement as a positive outcome of the debate.
Case-Specific Observation 1.6: The teachers chose not to evaluate the content of the student presentation, choosing instead to give students full-credit based on a holistic appraisal of the effort that the class had put into the activity.

Figure 4-1. Case-Specific Observations for Phi University

Role of Credibility Arguments

Case-Specific Observation 1.1: Students produced few arguments about the credibility of sources. They used sources to ground their claims while rarely providing backing for those sources.

Providing an information-based problem does not necessarily lead students to critically assess the credibility of sources. While the students in both sections of this course were required to make use of and cite sources, they rarely provided grounds for their choices. In fact, while sources were cited 52 times over the course of 8 distinct debates (see Table 4-1), there was only one time when a student gave a reason for their choice of source.[29] The lack of credibility arguments in the students' presentations deserves some explanation given that the information-based problems were intended to provide a venue for assessing sources. It was not that the students did not care at all about the credibility of their sources. When I asked Jenny, the TA for Rich's class, whether the students voiced any particular frustrations during study hall, she said,

> I guess finding reliable sources. A lot of them found things or statistics by some random person. I think that was hard, because some of the stuff that they found just sounded ridiculous. I don't think it was an article that had been published, it was just some stats. (Jenny, 9/1/13, Lines 45 - 47)

I asked her more about what she meant by "ridiculous" and she said that the author of the article was clearly biased.

[29] This occurred during a rebuttal by a pair of students in Rich's class. The topic was marijuana legalization and the students were describing a study conducted at the University of Auckland in which a link was established between marijuana use and car accidents. After the first student noted that this study "proved that there's a link between marijuana use and car accidents" (Helene, Second Debate, First Day, 7/31/13, Lines 72 - 73), the second student added that "when the research was conducted there was a control group and a group that was using marijuana" (Isak, Second Debate, First Day, 7/31/13, Lines 75 - 76). While this statement could be taken as purely descriptive, I coded it as a content cue because the statement's inclusion suggests that the use of a control group as part of the experimental design is a reason to trust the conclusions.

Class	Grounds	Backing	Content Cues	Peripheral Source Cues	Peripheral Information Object Cues
Tim (3 debates)	15	1	1	0	0
Rich (5 debates)	37	1	1	0	0
Both	52	2	2	0	0

Table 4-1. Grounds and Backing for Information Sources (Phi University)

Furthermore, a number of the sources used by the students fulfilled credibility requirements found in the information literacy literature (Rieh, 2010); almost half of the named sources were from the Federal government, established non-profit organizations, and scholarly institutions. Most of the sources, though, were of more doubtful provenance. I attempted to track down the remaining sources and determined that out of the 19 sources cited, 6 were from advocacy groups for one or the other side of the issue, while 3 were from news outlets with a well-known political bias. Out of the remaining sources, half were of indeterminate origin perhaps due to a student misreporting the name (Figure 4-2). While I do not argue that governmental or scholarly sources should be accepted without reservation, the importance of backing is particularly pronounced for the sources in those sources of indeterminate origin as can be seen by the fact that the majority of those sources are actually organizations with a stated bias. Crucially, even though Tim provided a motivating example of how special interest groups can mislead with statistics through the selective use of data, none of the students who used these sources said anything to the class about whether the sources might be biased nor were they asked to do so by either instructor.

Source	Description
Concerned Citizens across the United States	Indeterminate
The Death Penalty Information Center	Anti-death penalty advocacy group
The Kansas Coalition to Abolish Death Penalty	Anti-death penalty advocacy group
NewAmerican.com	John Birch Society publication / Radical right wing organization
AmericanNews.com	Conservative news website
NORML	Marijuana legalization advocacy group
Huffington Post	Liberal news website
Marijuana: Reassessing the Gateway Effect	Indeterminate (described as a book)
Center for Addiction and Substance Abuse	Substance abuse advocacy group
DeathPenalty.org	Anti-death penalty advocacy group
American Jurisdiction	Indeterminate
National Alliance on Mental Illness	Mental illness advocacy group
Drug Cases & Health	Indeterminate
American Medical Association	Professional organization
Amnesty International	Human Rights NGO
Mexican Institute of Competitiveness	Research center and think-tank
DrugAbuse.com	Commercial website for treatment programs
MarijuanaToday.com	Indeterminate
MarijuanaNation.com	Indeterminate

Figure 4-2. “Other” sources used by students at Phi University

Mathematical Knowledge and Information Seeking

Case-Specific Observation 1.2: Lack of mathematical knowledge appears to have limited the students' ability to find information at times, but there was little evidence of these difficulties in the debates.

Past research into information problem-solving would lead one to expect that students' content knowledge would limit their ability to identify and evaluate relevant information (Walraven, Brand-Gruwel, & Boshuizen, 2008). While there is evidence that this held true for the students at Phi University, these issues were actually brought to the attention of the teachers. In my interview with Rita, she spoke about some of the mathematical difficulties that her students encountered,

> I wish we had done more on stats because [...] a lot of stats that they got had like p-values and z-scores and like more detailed statistics. And what we went through was just like the bell-curve, skewed and things like that. So I don't think even if they did find like a great resource, I don't think they were really able to fully extract the math from it because they didn't understand a lot of the math that it contained. (Rita, 9/1/13, Lines 88 - 92)

She went on to say that there was one group who knew about z-scores and p-values and they used those two concepts as part of the argument they presented before the class. Rita revisited the importance of the students' mathematical knowledge when I asked her about what she would propose changing in future iterations of the activity, she said "I think we should do this activity again next year but I do think it would be nice if maybe someone like you or [Tim], who knows about statistics [...] could read over their arguments and like do a proofread beforehand." (Rita, 9/1/13, Lines 106 - 108).

A critique of the statistics used by the students was not practical while the debates were in progress since the requirements of the mathematical task meant that the students were presenting a chart or graph and not a mathematical argument. Furthermore, most of the graphs presented straightforward longitudinal data such as amount of marijuana seized annually from 2000 to 2010, or a pie chart indicating the racial breakdown of inmates on death row; these simple diagrams were not very amenable to critique. These observations suggest that a teacher can include mathematical work as part of an information-based problem without necessarily addressing the importance of that mathematical work for judging the value of information sources.

Information Problem-Solving Difficulties

Case-Specific Observation 1.3: Students encountered some difficulties seeking out and evaluating information. These difficulties were not noticed by the teachers.

There was evidence that students encountered some of the difficulties that are well-documented in the information problem-solving literature (Walraven, Brand-Gruwel, & Boshuizen, 2008). As noted in chapter 2, Walraven et al. (2008) found that students have difficulty specifying search terms, judging search results, and judging sources. My semi-structured interviews (Weiss, 1995; see Appendix A for the interview protocol) with the TAs were partially intended to gather further information about difficulties that their students encountered. Tim's TA, Rita, said,

> Yeah, I think they had a really hard time with that. A lot of them couldn't find stats online. But I think, I referred some of them to the library, but I don't think they used the library at all. They didn't use any books, it was all strictly online and what they could find. I wish I was a better resource like to know how where to help them look for things. (Rita, 9/1/13, Lines 36 - 39)

Rita's conjecture is consistent with Connaway, Dickey, and Radford's (2011) claim that convenience tends to be prioritized when people engage in information-seeking tasks regardless of the context. When I asked Rita whether the students had any other difficulties related to the work that they were doing for the project, Rita said that they did not need any help with writing up their arguments and reiterated that "they were complaining because they couldn't find anything" (Rita, 9/1/13, Lines 80 - 81). The students would ask Rita for "'what sites do you think we should look at?' or where to go to get resources" (Rita, 9/1/13, Line 82). This attitude, the idea that there is one particular website that has the perfect information for answering a given question has been documented in studies with secondary school students (Fidel et al., 1999; Wallace et al., 2000).

Rich's TA, Jenny, corroborated the problems that Rita described although Jenny was also able to provide some more information about how students were working with the websites and one another. Jenny was concerned that the students were using Wikipedia too much and subsequently cautioned them about their use of websites,

> So I told them to try to be careful about the websites that they use because not every website is a 100% reliable. As they were presenting you could see that some stats conflicted each other because they came from two different websites and a website may not actually have been a good website to get stats from. You've got to be careful with that, and I tried to warn them of that. (Jenny, 9/3/13, Lines 63 - 67)

Beyond that, she noted that students would often ask her whether a site was "okay". She also described how they would work with their partners,

> Jenny: But the ones that really worked on it mostly used the internet. They were using each other too. But they were just kind of like collaborating that way. [...]
>
> Interviewer: What do you mean by "using each other"?
>
> Jenny: Like for their partner, they would ask where would you find this on the internet. Because it was a partnered assignment, two people were together. So, just like the people who were supposed to be working together, they would collaborate on each. Usually one would have a laptop and one would be doing something else. [...] So one person would be would be working on the graphs, because he wanted graphs on those and the other person would be like finding the facts.
>
> (Jenny, 9/3/13, Lines 23 - 40)

While both TAs said that they wished that they had been better prepared to help students with their information seeking, they were more concerned with the students' content knowledge and whether they were able to extract statistics from the sources that they encountered without making mistakes.[30]

[30] See Case-Specific Observation 1.2.

When I asked Tim about his thoughts on the students' information seeking, he did not express any concerns about the students' ability to find what they needed,

> I don't know, I imagine they got their stats from the internet for the most part. and probably a few, Google death penalty statistics and you can get a lot of stuff. Maybe part of the lesson here is that it's not hard to find numbers. They did it, I give them a lot of credit for not blowing it off. Part of the competition aspect of it, it's not something that I've utilized in my classes, I'm not a competitive guy, it doesn't motivate me, but I sure do see how it motivates other people and they really get motivated when there's some sort of competition when there's something on the line. [...] So the question was how do they prepare? So I don't have a good answer for you. I imagine it was mostly Googling. (Tim, 8/14/13, Lines 203 - 213)

Tim's comment in this final interview seems to suggest that he was more concerned with whether the students would put in the time to find the information and not worried that they would have trouble doing so. Tim went on to make note of a student that particularly impressed him, partly because she went beyond the internet to research her topic,

> There was one student, H____, who is, she was in the other section, but she wrote to me the night before the debate and said can I present my arguments to you? I said sure, I said I'll meet you at the room and so she met me in the classroom and she had a lot of well-thought out arguments and graphs. She told me that she had been to the law library of all places, and had asked the law librarian for data about the death penalty. The law librarian says, well we don't really have any stats here, but I was really pretty impressed with her that she went and did that. (Tim, 8/14/13, Lines 214 - 219)

Notably, Tim brought up this anecdote as an example of why he was impressed with the work that the class had done as a whole and not as an exception to the rule. The existence of this disconnect between the students' experience of the information seeking task and Tim's impression further suggests that the teachers were not directly addressing that part of the assignment.

Statistical Literacy as a Goal

Case-Specific Observation 1.4: In their framing of the students' task, the teachers focused on two knowledge elements of statistical literacy (the creation and interpretation of graphs, and critical skills) and one dispositional element (the adoption of a critical stance).

While the information seeking and information evaluation aspects of rational dependence were largely elided in the debate problem, Tim was concerned with his students' ability to critically appraise quantitative claims and his approach reflected a theory about how students might learn how to do this. Tim and Rich decided early on that they would encourage their students to mislead their peers with graphs and that the onus would be on the peers to call each other out if it looked like anybody was being misleading. As a result, the graphs became a focus of the subsequent discussions and feedback from the instructors. Furthermore, the students were required to create the graphs themselves. As stated by Tim,

> I made the decision at some point that I didn't want them to just download graphics off the internet because I was worried that if they did that, they would download a bunch of fancy graphics that they didn't really quite comprehend and then it would be too much information for anybody in the audience to comprehend too. And so I figured the way around that is that I would have them

> do it, they read the section on how to present data, that's section two of that chapter, how to present data, ideas on how to present data, and so let's make them do it. I think that was a good decision. (Tim, 8/14/13, Lines 73 - 79)

Tim focused, in this statement, on the comprehension of the students, both those who are presenting and those in the audience. He was concerned that the students might not "comprehend" the statistics that they would present and that the audience would have the same trouble. Tim recounted a story during his final interview that elaborated on this. He began by saying that "I think what I had in the back of my head, in my subconscious was when I was in college I took a course in Shakespeare" (Tim, 8/14/13, Lines 24 - 25). He went on to relate how he and his fellow students attempted to act out parts of the plays before going on a trip to England to actually watch them being performed. In summary,

> [Performing the plays ahead of time] added a whole new dimension to watching it for me. Because suddenly you realize that the people performing it have had to make choices all along, sure you say the words that are written, but you have to make tons of choices about how to present it, because we'd been forced to confront it. And so it wasn't as simple as the data, if you will, of Shakespeare, it was also, there was a big layer of presentation of a lot of choices. And so I think that's sort of what I had in the back of my mind for them, that if they were forced to make those choices then maybe they would realize, suddenly have a much better appreciation for what the numbers mean, for what's going on here. (Tim, 8/4/13, Lines 32 - 39)

While Tim stated that he wanted his students to think about what goes into the creation of the graphs, Rich was more explicit about trying to get students to contemplate how graphs might be used to mislead people. In the question and answer period after the very first debate, he prompted students to say whether they thought the graphs were "true" or "deceptive." When one student suggested that one of the graphs might have been misleading, Rich responded as follows:

> You think it was skewed? You think it was deceptive? Okay. Do you think any of the graphs weren't deceptive? I mean do you think they were true? Like the one up there now, do you think that's okay? [Lisa] mentioned she liked the cost of the death penalty. Did you like that graph? Do you think that's true, the way they got it set up? (First Debate, First Day, Rich, 7/31/13, Lines 133 - 141)

Subsequently, after a brief digression, another student asked, "So it's a bad thing to have a deceptive graph?" (First Debate, First Day, Rich's Classroom, 7/31/13, Line 184). To which Rich responded,

> No. Yeah, I mean you can, can't you make numbers look any way you want? Well with statistics you can manipulate things any way you want. So sometimes it isn't bad to have a bad graph if you're trying to prove a point. You're not actually lying you're just making the picture different that's all. (First Debate, First Day, Rich's classroom, 7/31/13, Lines 186 - 189)

This idea, that students should simultaneously be on the lookout for misleading representations of statistics while suggesting that manipulating the presentation of data is not necessarily a bad thing if it is in the service of making a point, recurred at the end of the day when a student caught that another group was presenting a pie chart that appeared to indicate that 100% of the population of the United States were on death row. Rich congratulated the audience member on catching the error and when the student who provided the graph said that she had copied it from somewhere else, he used this as an opportunity to say something summative about the day's work,

> But it looks good doesn't it? It does look good! So I mean, you can do things -- does the top one total to 100? So if you found that, which is fine, obviously you copied it from somebody who made it originally. So you can do anything you want with statistics, you can manipulate things or you could - You've just got to watch where you're getting the stuff too, because it might be deceiving when you get it. So, you do that. (Third Debate, First Day, Rich's classroom, 7/31/13, Lines 266 - 277)

Rich's statements provide a sense of what he meant when he encouraged his students to mislead with statistics. The key is his claim that if you use a "bad graph" to try to "prove a point" then "you're not actually lying" and that "you're not actually lying you're just making a picture different that's all" (First Debate, First Day, Rich's classroom, 7/31/13, Lines 186 - 189). Rich distinguishes between manipulations of a graph, such as adjusting the scale in order to exaggerate a rate of change, from charts that have incorrect information such as the pie graph that was mislabeled. Rich did not present an entirely consistent point of view on this topic. His statements to the students signal that there is such a thing as graphs that are not "bad" and that these graphs would presumably be more objective in some sense. Rich also put his students on watch for diagrams that they encounter in other venues. "Watch where you're getting that stuff too, because it might be deceiving when you get it." (Third Debate, First Day, Rich's classroom, 7/31/13, Lines 277) His statement provides an initial sense of what it meant to develop a critical sense and also foreshadows the idea that it might have different meanings for different teachers, a theme that I return to in the other case reports.

Student Engagement as a Goal

Case-Specific Observation 1.5: The teachers highlighted student engagement as a positive outcome of the debate.

While the development of a critical sense was important to the teachers at Phi University, student engagement was an even more important outcome. During our conversations after the activity had been completed, the teachers both said that the level of student engagement was sufficient reason to use the activity in future iterations of the course. In my interview with Rita, the TA for Tim's section, she stated that the debate activity energized the class. When I asked her why this was the case, she said that "I think bringing in this almost competition into the course work was good for them" (Rita, 9/1/13, Lines 4-5) especially given its position near the end of the shortened summer semester. Rita also suggested that the students might have been more motivated because they were able to choose topics that interested them. She went on to note that the topics were not only interesting, they were also relevant: "They hate that they have to take it sometimes because they think that they'll never use the math that they learned, but with the debates I think, they all learned really interesting things about math and how it could apply to practical life" (Rita, 9/1/13, Lines 14 - 16). Rich's TA, Jenny, expressed similar sentiments,

> I think that it was a good idea only because no math classes really have debates in the middle of class and so because it's not - Because it was a new math class it helped keep the students engaged. Because statistics, I don't know, to me it can be kind of a boring topic and I feel like the debate kind of brought it to life, it's like

> now I understand why stats can be, it can be skewed, it can make things in your favor, you can just kind of alter it any way you want. And I feel like this debate kind of liked reinforced that concept. (Jenny, 9/3/13, Lines 108 - 112)

Elsewhere in the interview, Jenny noted that the students appeared to respond particularly well to the debate format. She said that she heard students commenting on how they loved to debate and then suggested, just as Rita had, that competition helped engage the students and encouraged them to work hard.

In my final interview with Tim, he expressed some concern that his approach in this course “doesn’t test very well”, but he also said that “I do have expressions on their faces to know they engaged with it and I think they’re going away with a little bit different attitude toward mathematics, I hope” (Tim, 8/14/13, Lines 191-192). His goals for the activity, as he expressed in this last interview, did not exactly align with the more conceptual goals reflected in his story about performing Shakespeare; instead he stated, “what I hope they got out of it is A) there’s a lot of interesting math out there, and B) you can engage with it sometimes without it being procedure-based or symbol manipulation” (Tim, 8/14/13, Lines 193). This concern with student engagement points to a focus on beliefs and dispositions about mathematics (Gal, 2001) rather than the development rational dependence.

Appraisal of Student Work

Case-Specific Observation 1.6: The teachers chose not to evaluate the content of the student presentation, choosing instead to give students full credit based on a holistic appraisal of the effort that the class had put into the activity.

While a focus on rational dependence would suggest that the students' ability and inclination to seek out and compare information sources should be rewarded by the instructor, this did not turn out to be the case at Phi University. I observed Tim and Rich discuss how to assess the students' work with the TA, Jenny, who would be doing the actual grading. After agreeing that the students had surpassed their expectations with respect to the amount of time and effort they had put into the debates, they decided that all students should get full credit, while Jenny would look across the feedback written down by the audience members and use this to compile a brief summary of what the students did well and where they could improve. In an effort to determine how Tim was informally assessing his students' work, I asked him whether there were some groups that he felt had done better than other groups and, if so, why. Tim said that "there were people who were on the ball and were able to pick at their opponents statistics" (Tim, 8/14/13, Lines 63 - 64) and said that he might decide to grade on the comprehensiveness of the rebuttals along with the amount of statistics when he next did these debates. However, he reiterated that he was very pleased with how well all the students had performed.

When I asked Rita, the TA who was not charged with grading the students' work, about student difficulties she said that,

> I think we should do this activity again next year but I do think it would be nice if maybe someone like you or [Tim], who knows about statistics, well, I don't know, I could read it too. But if someone could read over their arguments and like do a proofread beforehand. So that, because sometimes, not saying that I would have any idea, but [Tim] probably could catch the flaws in the argument better than I could or you probably can. Because like some of the arguments were great and they put a lot of work into it but they totally misunderstood one part. (Rita, 9/1/13, Lines 106 - 113)

Rita's suggestion was interesting because she was not necessarily arguing for a more punitive grading scheme, rather, she suggested that this "proofread" be used formatively to improve the students' arguments before being presented to the rest of the class. When I interviewed Jenny, she agreed that Rita's suggestion might be beneficial, but she also said more about why she was in favor of giving students full credit for the work that they did,

> The reason that I voted for them all to receive an 'A', because [Tim] kind of asked for my opinion, and the reason I did that was because people were kind of frustrated. The course itself is kind of difficult for these students, and so a lot of them are just frustrated and I felt that and [Rita] felt that and so, like they kind of needed a grade-booster and if you're going to make something the grade-booster it might as well be the debate [...] because when you have a frustrated group that just wants to give up, they're very difficult to carry near the end. (Jenny, 9/3/13, Lines 136 - 145)

Jenny went on to suggest, though, that she would be in favor of rearranging for the course as a whole so that students were being graded only on completion for the homework assignments and thus the teacher would be free to grade the debate on the quality of the presentation.

Summary of the Phi University Case

The class observed at Phi University demonstrates that information-based problems do not automatically lead to a space for rational dependence in the classroom. On the face of it, a debate might appear to be an ideal context for judging the credibility of sources against one another, but the structure of the task left no room for any work of this sort. We also saw that the students may have benefited from instruction that attended more to their information problem-solving practices since they were having difficult determining which sources to use and they ended up using many that were demonstrably biased. Instead, these teachers further problematized the role of rational dependence with their idea that students can develop a critical sense by creating their own misleading charts. In the face of a case like this, we will see that it might make more sense to ask how such a task serves to satisfy the teachers' responsibilities with respect to mathematics while still providing students with a reasonably well-motivated reason to seek information outside of the classroom. The problem is that the end result may not leave much room for rational dependence.

Rho University: Case Narrative

Introduction

Rho University presents a stark contrast to Phi University in terms of the students' opportunities to develop rational dependence. Rather than engaging in a debate, the students at Rho actively compared sources according to their respective credibility, discussed this credibility assessment with peers, and were directed to attend to specific mathematical content as they did so. My case-specific observations suggest that this type of informal discussion may be more productive of rational dependence than the debates that took place at Phi University. The mathematical work required of the students, however, was very cursory, and operated from a different sense of what it means to be critical of a source. Anne, the teacher at Rho, had students look for the presence of specific types of mathematical backing for a source's claims and argued that its absence cast doubt on the credibility of the source. This is another example of a teacher who turned credibility assessment into a type of mathematical work, although very small changes in the structure of the problems was associated with different types of connections between the mathematical work and the credibility assessment.

Background and Context

The Quantitative Reasoning course at Rho can be used to fulfill the university's quantitative reasoning requirement in the place of more traditional mathematics courses.

According to the teacher, most of the students taking this course were uncomfortable with mathematics and were now meeting the requirement so that they could graduate. Out of all the instructors with whom I spoke, Anne was probably the most enthusiastic once I described the concept of information-based problems. In fact, she explained that she had already made some efforts to include problems of this type in her course and had been looking for the opportunity to do more. She was frustrated because most of the course followed a more traditional format and she hoped that collaboration with me would provide her with some ideas that would make her class more compelling to her students.

Preparation

After looking through the syllabus together, Anne chose the section on correlation and causation for the first information-based problem. The assignment that she eventually designed had students locate three online resources and provide the following information for each source: the author, reasons why the resource is credible, and whether they provide a correlation coefficient.

Group	Size of group	Topic
First Session		
Group 1A	4	Autism and Vaccination
Group 1B	4	Autism and Vaccination
Group 1C	3	Autism and Vaccination
Group 1D	3	The Mozart Effect
Second Session		
Group 2A	5 (one arrives late)	Gun Control
Group 2B	4	Marijuana Legalization
Group 2C	3	Healthcare Reform

Figure 4-3. Small Groups at Rho University

Anne felt there was room for two such problems in the term and ended up situating the second problem as part of a unit on polling data. In this case, the students were looking at polls and they were only allowed to use articles that included a confidence interval. The in-class portion of the activity followed the same format in both cases. Students were asked to form small groups according to the topics that they had chosen (see Figure 4-3) and then they were asked to discuss the data sources that they had found collectively and to try to decide as a group on several sources that were the most credible. After the students talked in small groups for half of the lesson, the plan was that the entire class would gather together in order to discuss what the separate groups had concluded and to possibly come to a consensus about which sources were most credible.

Narrative of the Information-Based Problems

The implementation of the problem largely went as planned. The students met in small groups dictated by which topic they had chosen. Anne interjected on occasion but she spent most of the time observing the different groups without interrupting their work. After having had about 20-30 minutes to engage in these discussions, the groups came together for a whole group discussion in which they shared their results with one another. In practice, the whole group discussion took the form of a series of monologues in which a representative from each group shared what their group had concluded. Anne expressed disappointment that there was not more of a dialogue during this part of the lesson and said that she would work over the summer to develop a better strategy for managing the whole group discussion when she next assigned these problems.

Case-Specific Observations

I begin reporting on the observations (see Figure 4-4) associated with this case by focusing on the credibility arguments that the students made during the in-class portion of the activity because these arguments are so crucial to the practice of rational dependence.

Case-Specific Observation 2.1: The students were able to make much more sophisticated credibility arguments during their in-class discussion than they had in their written reports.
Case-Specific Observation 2.2: In the first session, students were searching for articles and then looking for a correlation coefficient within the articles, but they rarely found a correlation coefficient.
Case-Specific Observation 2.3: In the second session, students were searching for articles with confidence intervals and they were usually successful in finding those.
Case-Specific Observation 2.4: Some groups made use of the tools at hand (e.g., smartphones, laptops) to corroborate information that they had already found or to look into the validity of something reported by an absent student.
Case-Specific Observation 2.5: Students preferred to work with information resources that contained mathematics that they could understand.
Case-Specific Observation 2.6: In the first session, the teacher prioritized the identification of a particular piece of mathematical content, the correlation coefficient, to the exclusion of any discussion of the credibility of sources.
Case-Specific Observation 2.7: The teacher addressed the credibility of sources much more often in the second session than in the first session.

Figure 4-4. Case-Specific Observations for Rho University

The amount and quality of these arguments far exceeded those at either of the other two cases and I suggest that it is crucial that these students were required to discuss the credibility of their sources and encouraged to come to a consensus about which sources were most credible. The next two findings address the way in which students' mathematical knowledge presented in their discussion of credibility and in the teachers' assessment of the students' work. Finally, I describe how the teacher's management of the discussions about the credibility of sources was affected by a small change to the assignment requirements and how it subsequently evolved from the first session to the second.

Role of Credibility Arguments

Case-Specific Observation 2.1: The students were able to make much more sophisticated credibility arguments during their in-class discussion than they had in their written reports.

Anne and I were initially disappointed by the written work that he students submitted. For each of the three resources located by the students, they had been asked to name the author of the piece and describe why they believed the author was credible. Unfortunately, the majority of student responses to this question were more superficial than we had anticipated. Some of them simply described the source (e.g., "He is a writer for the Huffington Post") without providing any further explanation as to why the source ought to be seen as credible. Others offered a superficial description of the contents of their source. For example, a student would write that the reported claim was based on a research study and then describe the study's conclusion. In retrospect, I believe these students may have been answering the question as if it had been asking them why they chose their source and so the reason they felt that the fact that it was a research study reporting relevant results was a sufficient reason. All of this led me to worry about the discussion that the students were going to have with each other during class time.

Fortunately, the in-class discussion had a level of sophistication that belied the students' written work.

For example, one student had only written that a source was an author for *The Huffington Post* as their sole reason for finding the source credible. During the in-class discussion, the same student said that their source "was credible because [the author] is a staff-writer, I received this information from the Huffington Post and he is also the health editor for CBS" (Elena, First Session, Second Group, 2/6/14, Lines 48 - 51). The students' extensive use of credibility markers during their first discussion can be seen in Table 4-2.

Class	Grounds	Backing	Content Cues	Peripheral Source Cues	Peripheral Information Object Cues
First Session	40	37	11	25	8
Second Session	32	17	13	9	0
Both	72	54	24	34	8

Table 4-2. Grounds and Backing for Information Sources (Rho University)

They used content cues 11 times, peripheral source cues 25 times, and peripheral information object cues 8 times. This meant that they provided justification (i.e., backing) for almost every source (i.e., grounds) that they cited (i.e., grounds) In the example above, the student is demonstrating that they recognize that it is important to establish that the author is a journalist and that he has direct experience reporting on health issues.

These explanations usually arose as part of a dialogue among students. For example, the following exchange occurred when a member of group 1B explained that there was no correlation coefficient in one of the articles that she had found:

> Donna: Your person that did that article? Was that a credible source? [addressed to Gina]
> Gina: Yeah, it was from a scholastic journal or something. It was um published in a journal of child neurology and um it was done by like a Ph.D.
> Donna: Okay, credible researchers.
> Gina: Two doctors -
> Faith: [unintelligible] Ph.D., I'd say it was credible.
> Gina: I think they were from Northern Iowa.
> Donna: Credible researchers?
> Gina: They were, I can't remember what department they were in, I think it was actually the psychology department which is weird, but they weren't math, but yeah.
> (First Session, Second Group, Lines 106 - 115)

As the student was questioned, she noted where the article was published, along with the credentials and institution of the authors -- all examples of peripheral source cues and not part of her written submission.

Anne remarked on the high quality of the students' discussions about credibility when I asked her about how she might alter the structure of the activities in our final interview. She said,

> I saw them looking back through their work and reporting on what they found, also I liked their discussions deciding which articles were most relevant or maybe most credible, I liked them doing that kind of activity and I'm trying to think about how to broaden that activity. I like that decision-making and how logical they are most of the time. (Anne, 4/3/2014, Lines 29 - 32)

In fact, her observations of these student conversations led her to consider making more extensive modifications to the activity structures so that students are encouraged to "talk through their decisions and justify them". She described her thinking as follows,

> I have a much different sense of what students know when they're reporting out orally and also when they're making their decisions together, I was thinking 'okay, so let's take a broader view of what that activity is and a lot of it is discussion and decision-making and justifying their decisions and even outside of this specific activity, how can we do this in the day-to-day classwork and I would have to change a lot of how I approach problems in this class, but I'm ready to revamp this course anyway and so it might be doable. But that's one of the things that I really enjoyed watching, them talking through their decisions and justifying them. (Anne, 4/3/2014, Lines 48 - 54)

Her comment about taking a "broader view of" the activity is particularly suggestive. While I have focused on credibility assessment, Anne's comments imply that she was treating decision-making and justification as a more generalizable practice.

Perhaps most significantly, Anne said that the oral component of these information-based problems helped her see particular students in a new light,

> There are a couple of students in the class who have had trouble with exams and have struggled sometimes with the regular assignments, and they have both really shined in these activities in terms of being able to explain out loud what they have found, why they thought it was good information, that sort of thing. And they clearly understood the math content that they were learning which I don't see -- I know they are math anxious and so I know there are ways that their exams scores aren't going to reflect what they know in the same way that another way of assessing them would. (Anne, 4/3/2014, Lines 75 - 80)

Anne had apparently already known that these students' exams were not good reflections of their ability but had not found another way for them to demonstrate their knowledge. The discussions allowed Anne to see that "they clearly understood the math content that they were learning."

Mathematical Content as a Token of Credibility: The First Problem

Case-Specific Observation 2.2: In the first session, students were searching for articles and then looking for a correlation coefficient within the articles, but they rarely found a correlation coefficient.

This observation and the next both deal with the way that the requirements of the two information-based problems affected the students' success at information seeking. Just prior to the first information-based problem, Anne introduced the concept of correlation coefficients (or r-values as she usually referred to them) as a measure of the strength of a linear correlation between two variables. As noted in the case narrative, one of the requirements of the first problem was for the students to search for a correlation coefficient in the sources that they located. When it came time for the students to present to one another, it turned out that only one student had found a correlation coefficient. This was consistent with the terms of the assignment as the students were only directed to look for a correlation coefficient after they had collected the sources.

As the groups discussed what they found, some students expressed concern and frustration that they had not encountered more r-values in their sources. Their frustration is captured in an exchange that occurred towards the end of the discussion:

> Adelle: I kind of expected to find more r-values and correlations and stuff.
> Corrina: It was really hard.
> Adelle: This is surprising.
> Corrina: it was hard to find articles that wasn't just people saying, 'My kid --'
> (First Session, First Group, 2/6/14, Lines 339 - 342)

In a similar vein, a member of group 1B found an article that

> I did have data on, and it was a p-value not an r-value, it was the lymphocytes of the population of children with autism spectrum disorder and their unaffected siblings. It's like they're talking about the hypersensitivity of the vaccines to the b-cells of the body and how that can trigger autism. And the author was from a journal, it was from a journal of toxicology, so that's pretty credible. It had like, it was a primary literature piece, it had a methods and materials section, it had an abstract and that stuff (Faith, First Session, Second Group, 2/6/14, Lines 58 - 63)

Her comments demonstrate that the student was not treating the presence of a correlation coefficient or other mathematical content as the sole indicators of credibility; she was also using information object cues (Hilligoss & Rieh, 2008) in the form of the different section headings typical of a "primary literature piece." Nonetheless, the student made a point to say that she had located a "p-value not an r-value" and proceeded to clarify that she had gone to Anne to get feedback on the piece and that Anne had told her that the p-value was the same as the r-value.[31] Two of the students I interviewed after the first session commented on their inability to find articles that contained r-values. The lack of r-values stood out to them because Anne had put so much emphasis on them. In fact, one of the interviewees suggested that Anne ought to have required that they find r-values if they had such importance.

I asked Anne whether her focus on the correlation coefficient during the first activity was part of a larger learning goal for the students. She responded in the affirmative, referring initially to the confidence intervals that had been the subject of that day's class,

> I would like them to know that if somebody is reporting polling results that they should report a margin of error because there is a margin of error and we talked a lot about why that is. How samples aren't perfect and how if you want to extrapolate from a sample to a population, you've got to account for that. And for correlations, you have, as well, that if somebody is claiming a correlation they should be backing it up with data, with statistics with something that justifies where there conclusions are coming from. So I want my students to be critical readers of things that talk about statistics and to know what should be included in there. And I recognize that in the mainstream media that it's unlikely that they're going to report an r-value, but very often when mainstream media is reporting, well not polling results, but when they're reporting a correlation it's from a scientific journal, like this came out in Nature or Science or whatever. (Anne, 4/3/14, Lines 222 - 231)

There is an interesting combination of content and dispositional goals reflected in this statement. While Anne wanted students to understand the purpose of both the margin of error and the

[31] Later when the groups were reporting out to the rest of the class, the same member of 2A said "Then we had two articles, one had a p-value which is the same thing I guess as an r-value, I found that out from [Anne]" (Faith, First Session, Final Discussion, 2/6/14, Lines 165 - 166)to which Anne responded, "it's not exactly the same thing but it tells you whether it's a significant finding" (Anne, First Session, Final Discussion, 2/6/14, Line 168). It is unclear whether the student misunderstood Anne or not.

correlation coefficient, the larger concern was for students to be “critical readers”. Anne revisited this goal later in the interview, saying that “one of my broader objectives is that they are critical consumers of math that they encounter in the world and kind of figure out what should be in there and whether it is or not.” (Anne, 4/3/14, Lines 240 - 242)

Mathematical Content as a Token of Credibility: The Second Problem

Case-Specific Observation 2.3: In the second session, students were searching for articles with confidence intervals and they were usually successful in finding those.

In the second session, Anne altered the instructions for the information-based problem so that students were now able to successfully collect sources containing the targeted mathematical content. For this problem, the students were required to locate information resources containing a confidence interval instead of being asked to search for the confidence interval only after they had found relevant resources. As it turned out, this requirement was easily met by most of the students by adding “confidence intervals” as a search term. As described by a member of group 2C,

> I just legit googled confidence intervals and healthcare. The only challenge that I faced was picking which one I actually wanted to use because I found so many articles. (Hannah, Second Session, Third Group, 3/27/14, Lines 87 - 90]

Only one student failed to find confidence intervals and when she brought this up with her peers, they reiterated that they did not have any trouble and that this was because they used the term "confidence interval" as one of their search terms.

Anne remarked that students had a much easier time with the second problem, although she did not attribute this greater success to the requirements of the assignment:

> They were certainly able to find what they needed on-line. They had better content but they also had better direction from me in terms of what they needed to be looking for. That they needed to have stuff that had a plus or minus. They were very concerned when they couldn't find articles that said 'confidence interval', that didn't have those words. They said, 'I couldn't find any!' and I would say 'No, no, no, the plus or minus. They give you a margin of error, there's your confidence interval right there.' (Anne, 4/3/14, Lines 151 - 157)

Anne asserted that students had "better content" but also that they had received better instruction from her. While Anne's comment suggests that students may have experienced some difficulties that were not in evidence during their conversations, there remains a distinct contrast between the outcomes of the two tasks and how these outcomes influenced the students' opportunity to practice rational dependence. For the first problem, students were left with sources of information that they were told not to trust while the sources for the second problem were declared much more acceptable since they all included confidence intervals.

Using Tools in the Classroom for Information Seeking

Case-Specific Observation 2.4: Students made use of the tools at hand (e.g., smartphones, laptops) to corroborate information that they already found or to look into the validity of a claim reported by an absent student.

The practice of rational dependence rests on the students' ability to make use of available technology in order to corroborate or pursue the claims that they encounter. There were two notable incidents from the first and second sessions respectively where students demonstrated that they were able to find information by making use of their laptops and smartphones. During the first session, the members of group 1A used a laptop and several smartphones to look up a couple of the articles that had been cited by one of the group members. The decision to search for the article was spurred by Adelle who said to Corrina that "I like your first article because it has an r-value and a graph" (Adelle, First Session, First Group, 2/6/14, Line 329). Another student wanted to see the graph and Adelle volunteered to look on her laptop using Google. They subsequently found the listed article but it did not contain a graph; this led Corrina to realize that it was not the article that she had thought it was. This was a frustrating turn of events for the students, but they were able to discover that the group member had made a mistake about the article in question and the group subsequently found another article that had a relevant graph.

The episode that occurred during the second session was both more successful and has more implications for the kind of information-seeking that students may be able to accomplish in the classroom. Since the group in question, 2C, consisted of three students and only one had completed the individual portion of the information-based problem, Anne gave them written work submitted by an absent student and told them to survey that student's sources. The episode of interest occurred as the students reviewed one of the articles. Anne was observing them as they spoke and interjected at one point,

> Hannah: And, let's see, her second article says No increase in Public Pressure for Healthcare Reform. The article states that while there is still a high level of concern regarding the healthcare reform, that number is not increasing. Between 2004 and 2005, the percentage increased by about 6%. Polls were conducted via telephone interview with 1014 national adults age 18 and older. It has a 95% confidence interval with 3% margin of error. This survey had practical errors in the wording of the question, it read, "What would you say is the most urgent health problem facing this country at the present time?"
> Bob: What? I'm confused?
> Hannah: Yeah, I don't like that one. This survey is from Gallup Polls, and I'd probably need to read this myself in order to kind of really fully understand because it isn't really -
> Anne: Oh, read the original? Is there a link? Can you use your device?
> Craig: It's just Gallup.com/Polls.
> Anne: Well then maybe you'll find it easily enough because it's a pretty timely topic. Wow, you all have your - [observing that all three students have portable devices for searching on the internet]
> Craig: Yeah, let's see who gets there faster.
> (Second Session, Third Group, Lines 138 - 158)

One of the students later clarified that they were confused by the claim that there were problems with the wording of the question. The students took Anne's suggestion and found the original poll within three minutes. After looking at the poll, the students conjectured that the absent student had read a note in the survey methods section stating that "question wording and practical difficulties in conducting surveys can introduce error or bias into the findings of public opinion polls" (Saad, 2007, November). This is a standard disclaimer that Gallup includes at the end of all their reports, but the student may have understood it to mean that the questions for this particular poll were worded badly. In our interview Anne said,

> It was just funny to me how they were immediately on their Smartphones and getting the information and I didn't have to give them a computer. The world is at their fingertips. (Anne, 4/3/14, Lines 40 - 41)

This gives an idea of Anne's impression of the information problem-solving that the students were able to accomplish here.

Mathematical Knowledge and Information Seeking

Case-Specific Observation 2.5: Students preferred to work with information resources that contained mathematics that they could understand.

This observation reinforces what I found at Phi University, namely that students are hesitant to use resources that contain mathematics that they do not understand. The irony evident in Anne's class was that these were often the articles that the students found most credible. During the first session, a student from the first group, Adelle, spoke very highly of the credibility of a research study both due to content cues ("it actually showed their different groups, their variables, and then their control group") and peripheral information source cues ("it was all people with MDs, PhDs, Masters working on it together") but she ended her explanation by saying that "it was like really difficult to understand with all the terminology" (First Session, First Group, 2/6/14, Lines 28 - 31). At a later point in this same discussion, Adelle took a cynical view of the usefulness of that article,

> And the first one that I have where it is an actual study and everything is really good to have. It had a bunch of numbers and things, I just couldn't decipher it very easily. But, um, I think those two are really good if you want to throw a bunch of facts in somebody's face. (Adelle, First Session, First Group, 2/6/14, Lines 130 - 134)

She went on to say that "the third one is the one I like the most, it's easy to understand, it makes sense" (First Session, First Group, 2/6/14, Lines 134 - 135), in reference to an article published by the Centers for Disease Control and Prevention (CDC) that summarized some existing studies. This article, while "easy to understand", apparently could not serve to support an argument in the same way that the first article could because it did not contain r-values or "a bunch of numbers".

Students understood the claim being argued by an article even if they could not follow the mathematical argument supporting that claim. For example, when a member, Donna, of the second group described an article that she found, she said,

> They actually said that there was no correlation between the vaccines and risk of autism. And they did use scientific and mathematical evidence but I didn't understand any of it. None of it was labeled r-value. There was other things mentioned but I didn't know how to evaluate that because we haven't covered that in class so I didn't know what it was. But that's what they based their decision on. (Donna, First Session, Second Group, 2/6/14, Lines 3 - 7)

The student, in this case, understood the claim being made and noted that the authors provided "scientific and mathematical evidence" to support their claim, but was unable to evaluate that evidence due to a lack of mathematical background. This is in contrast to the first article that she had shared with her peers which was about a court case in which the judge had found in favor of a family who had sued the federal government. The student said that she found it to be a credible article but also noted that "they didn't provide any mathematical statistical data to help their case" (Donna, First Session, Second Group, 2/6/14, Line 44). This statement highlights a tension arising from the classes focus on mathematical content as a marker of credibility. The articles that contained statistical arguments were often the most difficult for the students to understand. The articles that students could better understand often contained less mathematical content, at the same time the students were less enthusiastic about those articles that did not contain the mathematical backing that Anne told them to seek out.

Students appeared to be much more confident speaking about the mathematics contained in their resources during the second session. This is reflected in Table 4-6, where it can be seen that students in the second session used content cues as backing for information sources more often than in the first session, despite the fact that there were more than twice as many uses of backing in the first session. These content cues most often referred to the sample size used in the poll; others referred to the confidence intervals and the locations that were being polled. When I interviewed her, Anne said that she felt that the students were better able to handle the mathematics in the second information-based problem session. She suggested that this might have been because

> We'd done the probability unit and then three days of the confidence intervals in total. [...] They were certainly able to find what they needed on-line. They had better content but they also had better direction from me in terms of what they needed to be looking for. That they needed to have stuff that had a plus or minus. (Anne, 4/13/14, Lines 126 - 132)

I asked her to speak a little bit more about her direction and she elaborated as follows:

> They were very concerned when they couldn't find articles that said 'confidence interval', that didn't have those words. They said, 'I couldn't find any!' and I would say 'No, no, no, the plus or minus. They give you a margin of error, there's your confidence interval right there.' (Anne, 4/13/14, Lines 132 - 135)

Anne's assertion that there were students that encountered difficulty understanding some of the articles was supported by an exchange that she had with a student at the very end of the class. The last group was reporting out to the class, and Anne asked a last question of the speaker for the group,

> Anne: So you mentioned that one of the additional challenges you had was narrowing down what you were finding. So were you finding additional articles that also reported the statistics well and had similar qualities to them as the ones that you used?
> Hannah: Yeah, and then some of them, it was kind of over my head. So I had to choose the one that I could decipher better. Because I mean if I can't understand it then I can't make you understand it either. (Second Session, Final Discussion, Lines 56 - 62)

Hannah’s comment brings a different perspective on the challenges entailed when students are confronted with mathematical content that is beyond their ability to interpret. If part of their goal is to make somebody else, possibly their teacher, understand the mathematical arguments contained in the sources that they are consulting, then they are forced to restrict their consideration to those sources that they are able to interpret.

Mathematical Content as a Token of Credibility: The Teacher’s Perspective

Case Specific Observation 2.6: In the first session, the teacher prioritized the identification of a particular piece of mathematical content, the correlation coefficient, to the exclusion of any discussion of the credibility of sources.

I have discussed some of the ways that the structure of the two information-based problems may have affected the students’ work, but Anne’s interactions with her students also varied dramatically from the first session to the second. Anne’s introduction to the in-class discussion for the first problem emphasized both credibility and mathematical content,

> Okay, so you’ll get in a second a sheet that gives you some prompting questions for going through the articles that you found, kind of talk about them a little with each other in terms of what the content of the articles was, talk about the credibility and kind of the credibility in terms of the credibility of the sources you found and think about which kind of sources would be the most credible, if you had to stand up and [unintelligible] based on what the sources would be. Each of

> the groups will have either 12 or 15 well depending on absences there might be less or fewer articles to think about and kind of think about which ones of them claim that the claim was true and which one's didn't. Whether any of them mention r-values. A lot of them didn't, they would say that something is correlated but didn't mention that. And then thinking about which one of them makes the most compelling article. So if I'm a math person and I sort of only believe the math stuff that they're talking about, which one of them made the most compelling math argument and which one made the least compelling math argument. (Anne, First Session, Introduction, Lines 1 - 12)

Anne began her introduction by directing students to the "content" and "credibility" of the articles. She only devoted a single sentence to the r-values before speaking more generally about whether the articles contained "compelling math arguments". Based solely on this introduction, one might predict that Anne would direct students to consider "content", "credibility", and "math arguments" at least as often as correlation coefficients, but a view of her actual management of the lesson tells a different story.

As can be seen in Table 4-3, half of Anne's interactions with her students were focused on classroom management issues. While content was addressed much less often, Anne discussed the credibility of sources much more frequently in the second session. Why was there a difference between the two sessions? During the first session, when Anne spoke about content, she was largely reacting to the fact that students had difficulty locating an r-value.[32] For example, when a student who was looking into the connection between autism and vaccination said that they could not find articles that contained a correlation coefficient even in those documents that originated with the government, Anne commented that "It's amazing to me that they do that. They should

[32] The students' side of this is addressed in Case-Specific Observation 2.2.

be backing it up with numbers [...] especially big organizations like the CDC" (Anne, First Session, Final Discussion, Lines 40 - 46). Similarly, after a student said that the only number that they had found in an article was a frequency rate for autism occurrences, Anne added that "it's always shocking to me that people can make humongous claims and not have the data for someone like me" (First Session, Final Discussion, Lines 70 - 71). The few comments that Anne made about the content of the articles implied that it was inherently problematic for a claim to be made about the correlation between two variables without a correlation coefficient to back it up.

Session	Classroom Management	Credibility	Content	Off-topic	Total
First	7	0	5	1	13
Second	12	7	4	2	25
Total	19	7	9	3	38

Table 4-3. Anne's Interactions with Students during the Two Information Sessions

In my final interview with Anne, I asked her why she focused so much on the correlation coefficient in the first session. Her response helped shed some light on her priorities,

> I want my students to be critical readers of things that talk about statistics and to know what should be included in there. And I recognize that in the mainstream media that it's unlikely that they're going to report an r-value, but very often when mainstream media is reporting, well not polling results, but when they're reporting a correlation it's from a scientific journal, like this came out in Nature or Science or whatever. And so students could then, if they're interested, know that there is a journal article out there that most likely will give them more statistics than the mainstream media will. (Anne, 4/13/14, Lines 231 - 237)

Anne both prioritized the idea that students ought to become "critical readers" while suggesting a strategy for information seeking that she did not actually communicate to her students during the class. The strategy suggested was that they could look up research articles referenced in the mainstream media in order to find the backing, in the form of a correlation coefficient, for claims about the connection between two variables.

In the second session, the presence of confidence intervals may have actually resulted in fewer opportunities for Anne to encourage a critical attitude in her students. This is because it was the absence of correlation coefficients that usually occasioned those comments in the first session. Nonetheless, my subsequent interview with Anne provided evidence that she still cared about the development of a critical attitude in her students. When I asked her about what lesson she wanted her class to draw from their work on the second information-based problem, she said,

> I would like them to know that if somebody is reporting polling results that they should report a margin of error because there is a margin of error and we talked a lot about why that is. How samples aren't perfect and how if you want to extrapolate from a sample to a population, you've got to account for that. (Anne, 4/13/14, Lines 225 - 228)

Why did she not speak to her students explicitly about the importance of the confidence interval in the same way that she spoke about the correlation coefficient? While I do not have an immediate answer to this question, it may be helpful to look at what Anne *did* emphasize during her interactions in the second session.

Teacher Work and Credibility

Case-Specific Observation 2.7: In the second session, the teacher addressed the credibility of sources.

This session is particularly important to this study. It was the first time that I witnessed a teacher make the pursuit of rational dependence, in the form of credibility assessment, a major part of their interactions with their students. Anne addressed the credibility of information sources many times during the second session despite the fact that she never did this during the first session. This included her letting students know that she thought that certain sources (e.g., Gallup and Pew Research Center) were credible, suggesting that a particular polling question might give people an incentive to lie, and reminding students to consider the credibility of sources. Anne's comments were either about the wording of the polling questions, e.g., suggesting that a question about marijuana use might be written in such a way that respondents would have an incentive to lie, or about the credibility of the organizations sponsoring the polling, e.g., letting students know that Gallup and Pew are credible polling companies. The idea of credible and less credible sources was on her mind during this session. As she disclosed in the interview afterward, she took great interest in one group's discussion of a USA Today poll,

> There was that one group today that thought that USA Today should be a credible source and I would not cite USA Today for anything probably because I think of it as a junk newspaper that they put in hotels. But the students recognized that they

> were missing stuff and I don't even remember what -- oh yeah, it was the question, they didn't include the question that was asked, and the students noticed that. And so I was like, 'that's good!' You're recognizing that what you thought was this really credible source was possibly not including information that would help people know that they are credible. So for sure, I would very much like students coming out of this class, one of my broader objectives is that they are critical consumers of math that they encounter in the world and kind of figure out what should be in there and whether it is or not. (Anne, 4/3/14, Lines 233 - 241)

She was gratified that the students worked out for themselves that USA Today might not be the most credible source and explicitly hoped that future iterations of the activity could produce more "critical consumers of math".

While it is difficult to determine whether or not the structure of the second problem led Anne to consider students' credibility assessment more carefully, it does not appear that Anne's increased attention to credibility in the second session was a reaction to any increased attention on the part of the students; it appears to be quite the opposite, in fact. If anything, it would appear that the topics (both mathematical and non-mathematical) of the first session had provoked the students to talk more about the credibility of the claims that they encountered. While students used sources as grounds for claims 40 times in the first session versus 32 times in the second session, they were more than twice as likely to discuss the credibility of those sources in the first session (see Table 4-3). Nonetheless, the students appeared to recognize that credibility assessment was an important theme of the discussion. Anne summarized what students had said that they learned from the class as follows: "So you learned, question your sources, question the article whether they give you complete information, don't just take people's opinions" (Anne, Second Session, Final Discussion, Lines 273 - 274). This last quote echoed what students had said to her and it is notable that there was no analogous statement made at the end of the first session whether by the students or by the teacher.

Summary of the Rho University Case

This case suggests that opportunities for the practice of rational dependence can be developed in the mathematics classroom but that this needs to be done in a very explicit way. The students at Rho University were told to discuss the credibility of their sources with one another and to come to a verdict about which sources were the most credible. In the resulting conversations, the sophistication of students' thinking about credibility was much more evident than in their written work. It may be that the need to argue the legitimacy of information sources is so alien to students that it requires the give-and-take of an oral discussion for them to be able to become explicit about their rationale for their choices. This case also suggests other ways that the structure of a task might influence students' engagement with an information-based problem. Most markedly, a small alteration to the instructions for the problem altered both the mathematics that the students had the opportunity to encounter as part of their information seeking and altered the way that the students approached the sources that they found. Furthermore, the teacher shifted her focus from mathematical content to credibility between the two problems and it is possible that this was also influenced by the structure of the assigned problems. The evidence that the teacher's actions and the students' work do not simply come together in academic tasks but that these tasks also provide feedback that helps direct the teacher-student interactions is explored further in the cross-case analysis.

Delta University: Case Narrative

Introduction

We have seen how complex the relationship between mathematical content knowledge and rational dependence can be in the previous two cases. Students may shy away from using sources if they contain mathematical arguments that are too intimidating, but sources that contain sophisticated mathematical arguments are often seen as the most credible. The information-based problems used in this case were more mathematically demanding and the teacher had a better opportunity to assess his students' mathematical ability but this may have worked against opportunities for the development of rational dependence. This does not mean that these students did not consider the credibility of their sources at all. Indeed, one of the most striking episodes from this case demonstrates the dangers of an isolated critique of a source's credibility that does not look towards the larger epistemic community.

This case also presents yet another approach to the critique of mathematical content in these sources. It also demonstrates that the development of a critical stance is not necessarily the same thing as the development of rational dependence. In particular, we see below that this teacher wanted his students to be critical of the information that they collected but that this did not mean that the students were to seek out the relevant epistemic community or compare the credibility of sources. Instead, he wanted students to focus on the validity of the mathematical arguments contained in the sources and the credibility of the numbers themselves. This approach is congruent with other mainstream approaches to quantitative literacy (see Steen, 2001) and so this case serves as an example of how what can happen when such an approach is pursued in the mathematics classroom.

Background and Context

Ivan, the teacher at Delta University, is a tenured mathematics professor with over 15 years experience teaching mathematics at all levels and several years experience teaching the *Mathematics in Today's World* course. As it was with the other two cases, Ivan had virtual carte blanche over what he chose to include in the course and he expressed some discontent about how the students had reacted to the class in the past. He saw the introduction of information-based problems as a new way to approach topics with which he was currently feeling dissatisfied. There were nearly 40 students in his class, twice the students that were at either of the other locations. Notwithstanding the greater number of students, Ivan appeared to have at least as warm a rapport with his students as the teachers did in either of the other cases.

Preparation

Ivan expressed great interest in the project from the beginning of our e-mail correspondence. After I gave examples of information-based problems, he said that they would be a great fit for his class. We had solidified the idea that there would be one or two activities introduced to the course and before the term began, he came up with an activity where students had to form groups of three or four, pick a divisive topic, find a relevant poll or research article, and end by assessing its sampling methodology. The students were not instructed to compare sources and so this case serves as an important theoretical contrast with Rho University.

For the second assignment, Ivan had his students look into calculations of conditional probabilities. In so doing, they could choose between a number of different topics including murder rates, life expectancy, job prospects, and automobile accidents. Having picked a topic, the students were then asked to collect data in order to calculate a conditional probability that was not already provided by the sources. For example, one group that chose to look into murder rates decided to compare their respective chances of being murdered given their age, gender, race, and location. This last part of the problem was important to Ivan, he did not want students "to just take a number straight out of a source", instead he wanted them to present something "more personalized that would require you to do a little calculation" (Ivan, 4/17/14, Lines 2 - 4).

Narrative of the Information-Based Problem

The presentations followed a set format where a group would come up to the front of the room and hook their computer up so that they could display their slideshow presentation. There were a few technical problems that may have led Ivan to attend more to keeping time and managing transitions between presentations than he otherwise would have. Most of the presentations took approximately 5 minutes followed by an opportunity for questions from the class. Usually Ivan would allow students to ask questions first and then he would weigh in with a question of his own. Aside from asking those questions, Ivan's role primarily involved keeping time and making sure that technical issues were resolved in a timely manner. When I interviewed Ivan after the final class, he expressed some hope about what the students might take away from the experience:

> I'm hoping, there's always the hope, that for some of them, something connected, they learned something and were actually interested in something and they could pursue this. It changed their point of view about some of the material. So you always hope that you get a fraction of the students where a light goes up. (Ivan, 4/17/14, Lines 23 - 27)

Case-Specific Observations

As with the other two cases, these case-specific observations (see Figure 4-5) begin with a focus on student work and then address what the teacher was doing in the classroom. The first three observations all address whether students were given the opportunity to pursue rational dependence, much like Phi University, there was not very much scope for credibility arguments in the student presentations. More dramatically, one episode, a presentation on a scientific paper about vaccines and autism, highlights the dangers of criticizing the validity of a claim without attending to the larger epistemic community. The last two case-specific observations address how the teacher intervened as the students were presenting and suggests a third way of incorporating mathematical work into an information-based problem -- in this case, making the mathematical work the object of the task.

Case-Specific Observation 3.1: Students' credibility arguments were mostly confined to the first information-based problem and those arguments were about the content rather than the sources.
Case-Specific Observation 3.2: Students' adoption of a critical attitude could be used to forward an ideological agenda.
Case-Specific Observation 3.3: A number of the groups made mathematical errors and betrayed statistical misconceptions during their presentations; this appeared to be the most prominent outcome of the presentations from the teacher's perspective.
Case-Specific Observation 3.4: The second information-based problem provided an opportunity for students to compare different sources of information, but the work presented by the students was focused on calculating probabilities rather than information-seeking.
Case-Specific Observation 3.5: The teacher's interventions focused on the students' analysis of the mathematical content found in their sources.
Case-Specific Observation 3.6: The teacher was concerned with developing students' critical stance as realized through the asking and answering of critical questions.

Figure 4-5. Case-Specific Observations for Delta University

Role of Credibility Arguments

Case-Specific Observation 3.1: Credibility arguments were mostly confined to the first information-based problem and those arguments were about the content rather than the sources.

As noted above, the first information-based problem asked students to take either a research study or a poll and to review it critically with a particular focus on the sampling methodology. This resulted in a greater proportion of backing to grounds than any of the other problems (see Table 4-4). Almost all of these pieces of backing evidence were observations about the sampling method or other features of the polls' or researchers' methodology (for example, the phrasing of questions). There was only one group that questioned the credibility of their source, perhaps because many of the information sources were government-based or large polling firms such as Gallup. While a number of other groups were critical of the polls or research that they located, the remaining criticisms were all focused on the methodology used and not on the information source.

Assignment	Grounds	Backing	Content Cues	Peripheral Source Cues	Peripheral Information Object Cues	Critical
First (8 presentations)	11	20	19	0	0	13
Second (12 presentations)	19	3	0	1	2	1
Both	30	23	12	1	2	14

Table 4-4. Grounds and Backing for Information Sources (Delta University)

Why did the students focus on content cues to the exclusion of peripheral source cues and peripheral information object cues? First, Ivan modeled the type of analysis that he wanted during the class in which he gave the students their first information-based problem. While he would later tell me that he was disappointed that students did not adhere more closely to that model, it is nonetheless the case that he focused entirely on the methodology of the poll in question and did not include a critical look at who had authored or commissioned the poll. Second, the students had been asked to acquire a single poll or research article and the absence of multiple sources to compare with one another may have kept students from looking critically at the nature of the sources, just as the presence of competing claims could have forced them to attend to non-methodological aspects of those sources.

The task for the second set of presentations was the calculation of conditional probabilities based on data collected from outside sources. It may be due to their focus on the mathematical work that there were only three instances of students bringing up backing for the sources that they used.[33] Two of these occurred with group 2E (see Table 4-4) who were reporting on their attempt to devise a formula for the probability that an individual will become an alcoholic. In order to see how the conditional probability varies according to gender, they "read an interview with [Dr. Shuckit] on the PBS website, a really nice website" (Sierra, Second Session, Fifth Group, 4/17/14, Line 31) and they also collected data on the influence of genetics

[33] I explore this more thoroughly in my write-up of Case-Specific Observation 3.5.

on alcoholism from “the NIAA website, a government website” (Sierra, Second Session, Fifth Group, 4/17/14, Lines 56 - 57). I took the modifiers in both cases to indicate perceived backing for the sources, particularly as they are both features (i.e., the quality of website, the presence of .gov) that are commonly seen as markers of credibility by students (Rieh & Hilligoss, 2008). Most of the cited sources, however, were included without backing.

Even when the teacher challenged group 2F because they were citing murder rates that were improbably high, the students did not attempt to provide any backing for their source, instead they simply repeated “that’s what it said”, “that’s literally what is said”, and “we were using the data that we found” (Olivia, Second Session, Fifth Group, 4/17/14, Lines 53 - 61). The group expressed no interest in critically examining the source of their information. Shortly thereafter, Ivan told them to “be critical” because “that makes no sense, we agree that it makes no sense” (Ivan, Second Session, Fifth Group, 4/17/14, Line 63). Even with this prompt, however, the students still did not use any peripheral source cues, instead they eventually determined that they had misinterpreted what the source was stating.

The Dangers of a Critical Attitude

Case-Specific Observation 3.2: Students' adoption of a critical attitude can be used to forward an ideological agenda.

Ivan's primary goal with both of the information-based problems was to instill a "critical sense" (Ivan, 4/17/14, Line 150) in his students. He described this as "something that should immediately click that says 'something fishy going on here'" (Ivan, 4/17/14, Line 149) when a student encounters a mathematical claim that does not make sense. I explore what this means more deeply below,[34] but at this point I want to look at a possible unintended consequence of this message. This episode was not typical but it serves to illustrate a potential danger of encouraging students to examine published research with a critical eye.

Ivan had demonstrated what he wanted students to do by displaying an article on the board and discussing where it met and fell short of a proper experimental design. As it happened, group 1A followed this format exactly. The students described the article that they would go on to critique:

> Taylor: we ran across this new article and it's this one up here, the project by the CDC, government funded, and the claim of it is that there is no causal relationship between vaccines and autism rates in children. With this being said-
> Michael: Only 3 of the 8 managed care organizations were chosen for the study. A thousand, roughly, children participated. 256 had autism and 752 did not. And which I thought the eligibility for being selected was that you had to be born

[34] See Case-Specific Observation 3.6.

> January 1st, 1994 to December 31st and you had to be previously enrolled in one of the NCOs from birth until your seventh birthday. Currently enrolled at the same time of sample selection, and you had to live within 60 miles of the study. You had to be between 6 and 13 years old at the time the study was selected and had to live with your biological mother since birth and, lastly, you had to speak good english. And you were excluded if you had any of the links to autism.
> (First Session, First Presentation, 3/3/14, Lines 22 - 33)

After spending time describing the different sections of the article, Taylor criticized the choice of sample size by saying,

> It has 1008 participants, and I don't know about you guys but I feel like that's pretty low for a sample size. You're trying to sample a huge autism outbreak and you want to find out what causation or correlation is, you're not just going to sample a thousand from a 60 mile radius. You're going to try to get a nice randomized sample. It never says in any of the articles how it was randomized. It never -- it just says that they were picked from the 1008 and it says they were picked from a 60 mile radius, so you wonder how they got these people. It never explained in the actual research article. (Taylor, First Session, First Presentation, 3/3/14, Lines 45 - 51)

According to Taylor, the problem with the sample size is that it "feels [...] pretty low" given the claim that was being made. This concern could be indicative of the common misconception that a larger population requires a larger sample size or that the sample size should be thought of as a fixed proportion of the population (Castro Sotos et al., 2007; Huck, 2009). The student's subsequent concern about how "it never says in any of the articles how it was randomized" could also be an honest concern although they did not describe what would count as sufficient evidence of proper randomization.[35]

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[35] This concern is similar to a criticism expressed by the third group of students in their analysis of a poll on gun control. I address this concern, that any evidence of non-randomness is problematic when sampling, in the next section.

It was immediately after her critique of the sampling method that Taylor used this evidence to level an accusation at those who funded the study:

> And it never said about the 256 people that did contract autism from these vaccines, they never talked about, even though they did, why it wasn't a cause. Also that kind of led to a sample bias because it's such a small sample size and, I think, well what we thought, was that maybe the government could be trying to cover up something because they didn't want us to think that they're vaccines which are regulated through the government, they wanted to make everything seem okay, but this study just seemed a little bit fishy. With all the, 'you can't be in the study if you're linked to autism', you can't be in the study if you don't live within 60 miles, and only taking a thousand and some people, I think that - Definitely a larger sample size would be more accurate and not have bias and it was very problematic to put so many restrictions on who could be in the study or not. (Taylor, First Session, First Presentation, 3/3/14, Lines 51 - 61)

While "sample bias" was one of the concepts that had been covered in the lectures that led up to these presentations, these students were not using it in the proper sense. They said "that kind of led to sample bias", but the referent of "that" is not apparent. The speaker may have been suggesting that the various restrictions related to recruitment resulted in a sample that was not actually random and that it was designed to be biased by excluding people whose inclusion would reveal a causal connection between autism and vaccination.

During my interview with Ivan after the class session, he expressed great frustration at how that particular presentation had played out. The students had satisfied the terms of the assignment with respect to the tasks that they were asked to engage in (i.e., describe and critique the sampling methodology of a study), but he felt that they had misapplied the statistical concepts that they were being taught. They had critiqued the sample size without having grounds to do so and complained about the restrictions placed on the sample without giving a reason for why it would be problematic. Ivan stated that he was frustrated because the students did not draw on what had been covered in the previous lectures when they criticized the paper. Further, while he did not say so explicitly in class, there is evidence that he disagreed with the conclusion that the students were arguing. During the questioning period, he contested a claim that was made about the chemical thimerosal being used as an additive in vaccines by pointing out that thimerosal had not been added to vaccines in the last ten years. This is notable because it is the only time that he called into question a point of fact that was not mathematical in nature. Further, he told me after the class that he was aware that the students had “an agenda” (Ivan, 3/3/14) but he did not know how to intervene.

There are two different ways to look at this episode. On the one hand, it could be argued that these students were doing their best to meet the terms of the assignment in good faith and that they made a few mistakes because they misunderstood some of the mathematical content that they had been taught. On the other hand, if the students were already opposed to vaccination and wanted to use their presentation to promote that viewpoint, then they may have been selective in their critique of the article in question and intentionally sought to tear down its methodology. I do not know whether either or both of those perspectives are the correct one, but it is clear that Ivan felt that both held true and this bothered him greatly.

Making Mathematical Errors Visible

Case-Specific Observation 3.3: A number of the groups made mathematical errors and betrayed statistical misconceptions during their presentations; this appeared to be the most prominent outcome of the presentations from the teacher's perspective.

While the students in the other two cases encountered difficulties due to their limited mathematical knowledge, it was only at Delta University that the students' mathematical misconceptions were made evident to the teacher. These errors were consistent with existing research on students' misconceptions about probability and statistics (Huck, 2009). For example, the students had been asked to examine the sampling strategies used in polls and research papers for the first presentation, and some of the groups presented work that evidenced a misunderstanding of certain aspects of the way that sampling works. The second set of presentations all needed to include calculations of conditional probabilities and there were several groups that either made a miscalculation or misinterpreted what the resulting probabilities meant.

Two groups (1A and 1C) who presented during the first day leveled complaints about the sampling methodology employed by the studies or polls that they were analyzing. The first group's exhibition of a well-documented (Castro Sotos et al., 2007) misconception about how to determine the right size of sample for a study is documented above.[36] The other group, 1C, was concerned with whether the sample used by the poll was truly random because the pollsters were calling households and they chose whom they were going to speak with by asking for the adult whose birthday fell closest to the day on which the call was made. The students complained that this "didn't seem very random" (Alvin, First Session, Third Group, 3/3/14, Line 30). Ivan probed them more about this during the questioning period at the end of the presentation. The interaction is of interest due to Ivan's approach and the students' reaction. I focus on the students' perspective in this section and review the same episode from Ivan's perspective when I report on Case-Specific Observation 3.6:

> Ivan: The birthday, think carefully about this, so you phone a house. Your point is to - and the phone number was chosen randomly, because you want a random sample. In the house there are more than one person. You need to interview one because to interview two then these people are way too connected to each other. How do you choose the one? You seemed to indicate that, and somebody before you, that you don't like the idea of the closest birthday. Think carefully, how would you do it? You want to maintain this randomness. Why is the closest birthday not a good thing?
> Haseeb: That's a good question, but there's always going to be that question if your survey's, I don't think any survey's going to be 100% random. If you look at birthday studies, there are months that have more popular birthdays. And, my boyfriend does birthday studies and why some months are more popular for birthdays and if you want to go off into that, then I think that would be why. There are months that have more birthdays than others.
> Ivan: So how do you do it? You have three people in the house and you need to pick one, how do you do it?
> Haseeb: I think you should be just like, person with the darkest hair color.That's more random than, I don't know [laughter]

36 See Case-Specific Observation 3.2.

Ivan: No, it's not an easy question to answer, I'm not saying it is. But you guys keep criticizing this birthday choice.
Alvin: It just doesn't seem that random to me if you put a restriction on it, if you have a list and you split like this, then I feel that's more random.
Ivan: Yeah, but you can't. You've already called the house, there are 3 people there, you need to pick one.
Haseeb: I mean it's not the worse thing they could have done, nothing's going to be random 100%. But I guess you're right, how are you going to find a random person?
Ivan: It's one of the best ways, if you think about it. But thank you!
(First Session, Third Presentation, 3/3/14, Lines 75 - 108)

In response to Ivan, Haseeb argued that birthdays are distributed differently throughout the year and that picking the darkest hair color might be a better strategy.[37] Another student, Alvin, added that "it just doesn't seem random to me when you put a restriction on it." As it turns out, Haseeb was probably correct about the distribution of birthdays (Knapp, 1982) but that concern misunderstands the purpose of the sampling strategy. It is not that true randomness needs to be achieved within each household but, rather, that there needs to be a way to pick household residents that will not bias the responses to the survey.[38] . Alvin appeared to be touching on that same issue, a lack of randomness, by referring to a "restriction".

During the second assignment, a particular misreading of probabilities was repeated by two different groups. The first example occurred when group 2F was presenting on murder rates.

[37] The students were correct, of course, that picking a birthday does not result in a random person -- that is to say, there is not, by definition, an equal chance that any occupant of the household will be chosen using this method. There has, however, been research that has provided evidence that picking the last birthday does not lead to bias in survey responses (Lavrakas, Shuttles, Steeh, & Fienberg, 2007).

[38] As it happens, there has been research carried out that provides some evidence that the birthday method is successful in that respect (Lavrakas, Shuttles, Steeh, & Fienberg, 2007)

After introducing themselves, they immediately displayed a slide which the first speaker narrated as follows:

> Most of our statistics are taken from CityData.com and [the State website] And what we found was that females age 20 to 24 have a 19% chance of being murdered; African-Americans have a 53% chance, Caucasians 44, and that's all in the State [...] and we took the average of some of these numbers to find that a White female has a 33% chance of being murdered and a black female has a 30% chance of being murdered. These graphs were taken from [the State website]. (Olivia, Second Session, Sixth Presentation, Lines 3 - 6)

The students went on to calculate a final probability by taking an average of the probabilities that they listed above and the murder rate for the county as seen in Figure 4-6. The students followed this with a similar calculation for a nearby urban center in order to compare the two locations. Once the group had reached the end of their presentation Ivan challenged them on these numbers and they protested that they were using the numbers that they had found in their source. After Ivan pressed them further, focusing on the 53% murder rate that they had reported for African-Americans, the students conceded that there was something wrong with this statistic and Maranda suggested that the 53% might refer to the percentage of murder victims who were African-American.

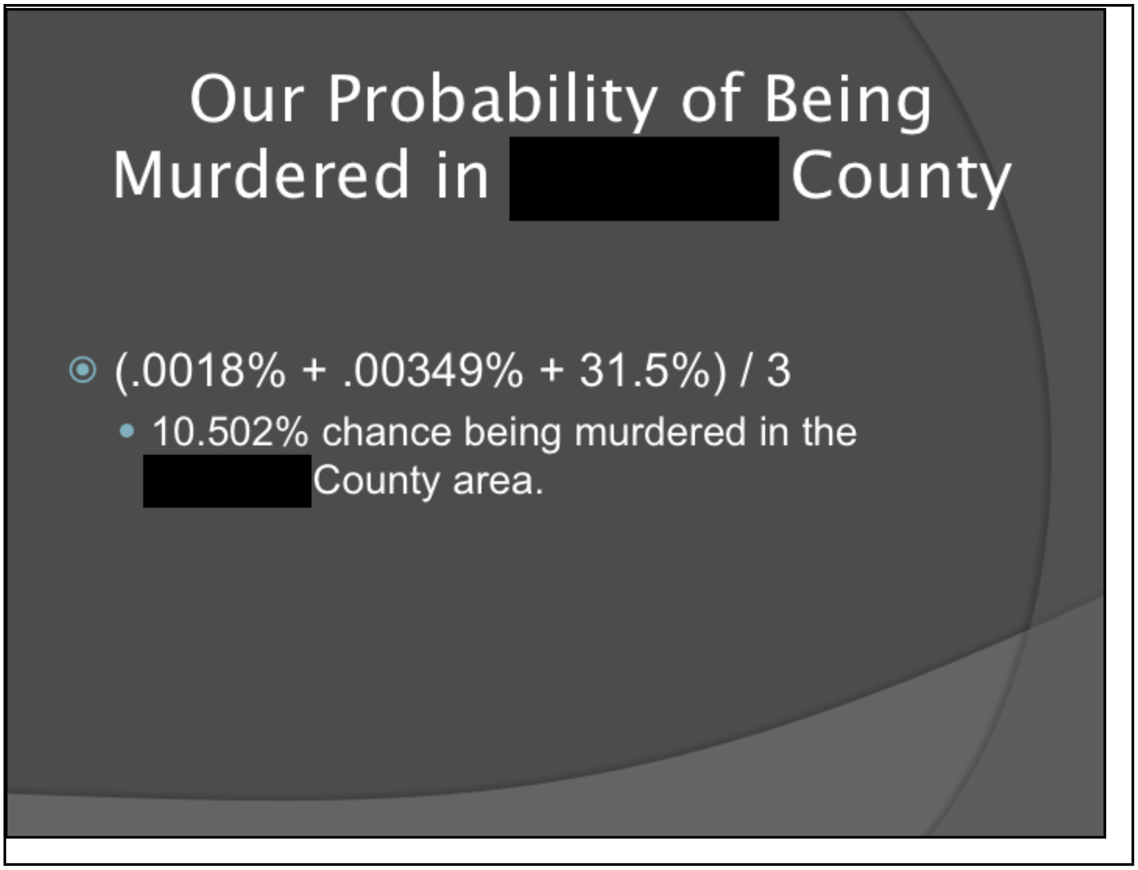

Figure 4-6. Slide presented by Group 2F

The next group made the same mistake. They had also chosen the topic of murder rates and decided to make the topic more personal by calculating the probability that they themselves would be murdered within the next year given their age, gender, race, and city of residence. The students made a claim about the murder rate for men and women respectively as seen in Figure 4-7. Ivan interrupted after they had presented a couple more slides:

> Ivan: Go back two slides. Somebody make a comment before I do.
> Audience Member: 87.7%?

> Ivan: Yeah, you actually wrote this down? [Addressing the presenters] You have a 90% chance of being murdered, really? Let's find out what's wrong here. Where did this 80% come from? Or this 13%, that's ridiculous. What's the problem here? (Second Session, Seventh Presentation, 4/17/14, Lines 19 - 25)

A student in the audience was able to identify the mistake that the speaker had made. She said "Well, it's you're saying it's out of the 6309 Americans, a whopping 5000 were male victims, so yes that's a fact, but it's out of that, it's not out of the total population" (Audience Member, Second Session, Seventh Presentation, 4/17/14, Lines 44 - 45). This last student had apparently noticed that the presenters were confused about the sample space in question, mistakenly using the number of murder victims when it should be the population of the state.

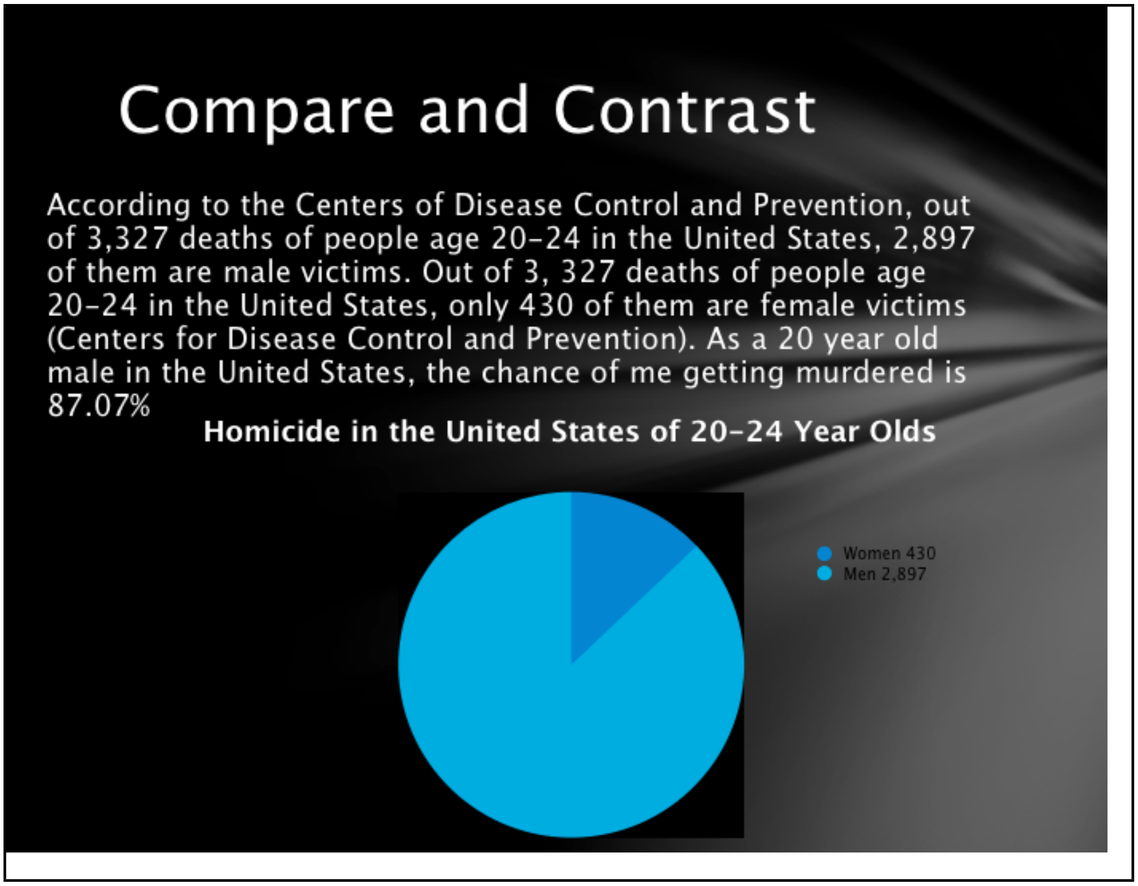

Figure 4-7. Slide presented by Group 2G

Mathematical Errors and Information Problem-Solving

Case-Specific Observation 3.4: The second information-based problem provided an opportunity for students to compare different sources of information, but the work presented by the students was focused on calculating probabilities rather than information-seeking.

This observation documents a lost opportunity for the students to practice rational dependence. The first information-based problem focused on a single source and so students had no need to compare sources with one another, but the second problem presented an opportunity for that sort of information problem-solving work as the students had to locate data that they would then use to calculate a conditional probability. They would potentially have to find multiple sources of information and use that information to calculate something about the world that was not directly provided by the information sources. In other words, they would have to engage in information synthesis (Eisenberg & Berkowitz, 2001).

Many of the groups provided evidence that they had synthesized information from multiple sources during the second set of presentations but there was no indication that they were critically comparing sources with one another. The sources that they used were all internet-based and ranged from newspaper articles on the topic in question to government websites at the city, state, and federal level. As seen in Figure 4-8, all groups except one were citing information from multiple sources and so it would be fair to expect that they would need to make some judgments about the respective credibility of these sources.

Group	Topic	Number of Sources	Type of sources
2A	Life Expectancy	5	CDC, Insurance, News, Non-Profit
2B	Murder Rates	4	City, State, Real Estate
2C	Murder Rates	3	City, National, News
2D	Murder Rates	2	City, State
2E	Alcoholism	4	National, News, Non-Profit
2F	Murder Rates	4	City, State
2G	Murder Rates	3	CDC, News, Educational
2H	Murder Rates	1	State
2I	Murder Rates	6	Real Estate
2J	Job Prospects	4	National, State, University
2K	Motor Vehicle Accidents	Unavailable	Unavailable
2L	Terrorism	4	National, News, Academic

Figure 4-8. Questions and Types of Sources used for the Second Information-Based Problem

Why, given the use of multiple sources of information, did the students say so little while presenting on the second information-based problem about how and why they chose their sources? In order to explore this question, it may be instructive to compare the two information-based problems. The first problem asked that students look critically at the methodology behind a study or poll. While this did not lead students to compare sources with one another, it did result in appraisal of the content of the source's arguments including questions about whether the authors might be biased. There was, on the other hand, no motivation built into the second problem for students to engage in a similar critique. Questioning the methodological underpinnings of the numbers that they found would not have helped them get any closer to completing the calculations required of them, and there was nothing in the assignment that would give them reason to seek out other corroborating or conflicting sources. This is despite the fact that the students usually had to consult multiple information sources in order to find the data necessary for the assignment. Ivan's description of his framing of the assignment accords with this:

> That was also a requirement. You were not supposed to just take a number straight out of a source, you needed to somehow come up with a subset or something more precise, more personalized that would require you to do a little calculation. And some of them did this perfectly well, others just extracted a number, so I'm going to take points off for not actually following the protocol I had requested. (Ivan, 4/17/14, Lines 1 - 5)

Indeed, Ivan only remarked on the sources if they were absent from the presentation entirely and he did not question the students about their choices or whether they had privileged one source above another. This provides further evidence that Ivan's focus was not on fostering rational dependence as that would require him to press students to think more deeply about the sources that they were choosing, instead his priority appeared to be determining whether the students had understood the mathematical topics in question.

Quantitative Data as an Information Seeking Goal

Case-Specific Observation 3.5: The teacher's interventions focused on the students' analysis of the mathematical content found in their sources.

This observation provides further evidence that Ivan was prioritizing the students' mathematical knowledge over and above the source evaluation that is part of rational dependence. I have already described Ivan's reaction to group 1A's critique of the research article claiming that there was no causal connection between vaccination and autism. His reaction is notable here because he never suggested that recourse to other authorities might repair their error; instead, his actions suggested that the students' analysis would have been more just if they had a better understanding of the mathematics involved. Ivan also reacted, albeit not as strongly, to group 1C when they questioned the "last birthday" method for picking whom to speak with when conducting a telephone poll. Rather than directly contradict the students' claim about the poll's lack of randomness, Ivan encouraged the students to try and put themselves in the position of the pollsters and asked them what they would do if they had to "maintain this randomness" (Ivan, First Session, Third Presentation, 3/3/14, Line 94). One of the group members continued to insist that the poll was not really random because "there are months that have more popular birthdays" (Astrid, First Session, Third Presentation, Lines 98 - 99) and so Ivan pressed her again to say what she might do instead. While she suggested that the pollster could ask for the person who has the darkest hair, Ivan did not appear to take that response seriously and finally concluded the exchange with the unequivocal statement: "It's one of the best ways, if you think about it" (Ivan, First Session, Third Presentation, 3/3/14, Line 121).

Ivan had a much better opportunity to correct a misconception when it occurred during the second assignment because the error in question was repeated by two different groups. The students in Group 2F were presenting on murder rates when they offered some grossly overstated probability figures for being murdered.[39] Once the group had reached the end of their presentation, Ivan challenged those numbers:

> Ivan: Go back please. Let's think about this one. So your conclusion here is that you have a ten percent chance of being murdered in _______ County. Think about what that means. You have ten friends and one of them is going to die.
> Olivia: Yeah, why not?
> Ivan: You think that's reasonable?
> Paige: Sure.
> Ivan: How many people in your high school, how many graduated?
> Paige: 500
> Ivan: 50 of them are dead. What do you think went wrong here?
> Olivia: I don't know.
> Audience member: Wait, where did the 31% come from?
> Ivan: Very good!
> (Second Session, Sixth Presentation, 4/17/14, Lines 58 - 78)

[39] See Case-Specific Observation 3.3.

At the instigation of this student, they went back to the first slide on which they reported that "African Americans have a 53% chance of being murdered". Ivan commented on this part of the slide:

> Ivan: African Americans have a 53% chance of being murdered, really? So a half of African-Americans are killed everywhere?
> Paige: But that's what it said! Why would it say that?
> Ivan: Because you misread it? That's one possibility.
> Olivia: That's literally what it said.
> Ivan: And you accepted this at face value [...]?
> Olivia: Well, no, but we were using the data that we found.
> Ivan: Yes, but be critical! That makes no sense, we agree that it makes absolutely no sense.
> (Second Session, Sixth Presentation, 4/17/14, Lines 81 - 94)

Ivan did not make a conjecture about why the probability figure might be in error, rather he focused on trying to get the students to recognize that the figure was absurd and thus to motivate a reexamination of the number. The students finally conceded the point and Maranda suggested that the 53% might refer to the percentage of murder victims who were African-American. Ivan promptly agreed that this was probably what was actually going on and encouraged the next group to begin their presentation since time was running short. The next group made the exact same error but Ivan immediately spoke up and prompted somebody in the audience to explain the mistake that the speakers had made.

Ivan took one last opportunity to address the issue during the next group's presentation. They had also investigated murder rates but they produced a much more believable number. In the course of their presentation they displayed the percentage of murder victims in the state who were African-American and White respectively. After the presentation was completed a student in the audience asked why they had not talked about the percentage of people in the state who had been murdered. One of the presenting students responded that "it wasn't interesting" (Evan, Second Session, Eighth Presentation, 4/17/14, Line 45) because the number was so small. Ivan immediately responded:

> That's a good point, the numbers are so small once you divide by the population of [the state], which is your real probability of getting murdered! Not 40% or 90%, instead .00095 or so. (Ivan, Second Session, Eighth Presentation, 4/17/14, Lines 46 - 47)

That would be his final word on this particular misreading of statistics during this class session.

In our interview after the class was over, Ivan described how he would approach the grading of these presentations and this led him to express his frustration with some of the errors that he had noticed:

> And then the conclusion, and people who conclude that they have a 90% chance of getting murdered, I'd give 0 on that part even though I really feel that it should be a negative number. [pause] Why would you even bother to turn in work [sighs] anyway [...] when you have students like some of these groups the problem is that it sort of colors your whole picture of the class and your attitude. I mean, I feel angry after a presentation like this, actually angry, and so I have to try to calm myself and say well you have to ignore this and focus on the next one with a fresh start. (Ivan, 4/17/14, Lines 6 - 14)

In light of these strong feelings, I asked him whether this experience made him hesitant about using these types of information-based problems or whether he would at least approach them differently. He responded as follows:

> Every time you try to readjust, but no, I don't want to stop doing things like this just because they're hard and sometimes they're annoying. I mean it's much easier to give them idiotic little tests like multiple choice just to verify that they can reproduce or mimic what they've done in the chapter, I don't see much value to that. I mean part of their grade is based on that. But I don't want it to be the whole of their grade, even for an elective course. I'm hoping, there's always the hope, that for some of them, something connected, they learned something and were actually interested in something and they could pursue this. It changed their point of view about some of the material. So you always hope that you get a fraction of the students where a light goes up. So no, I'm not going to change. (Ivan, 4/17/14, Lines 19 - 27)

These quotes establish that Ivan felt that these mathematical mistakes were a very prominent part of what transpired in the classroom from his perspective and that he, nonetheless, felt that information-based problems will serve a valuable role in the course going forward. The larger question that I address in the next chapter is whether Ivan's mathematical goals and the goal of rational dependence are in conflict with one another.

Assuming a Critical Stance

Observation 3.6: The teacher was concerned with developing students' critical stance as realized through the asking and answering of critical questions.

Even though Ivan attended to his student's mathematical knowledge to the exclusion of any consideration of how they were finding or comparing their sources, he still valued his students' development of a critical stance. In my final interview with Ivan, he tried to explain to me what he wanted his students to get out of this work:

> This is what numeracy or math literacy is about. First and foremost, being able to see numbers and graphs and tables and it should make sense. If it doesn't make sense then something should immediately click that says "something fishy going on here'. That critical sense, or appraisal. (Ivan, 4/14/2014, Lines 147 - 150)

Here Ivan offered a definition of a numerate citizen as somebody who should be "able to see numbers and graphs and tables and it should make sense." Two aspects of disciplinary literacy are at play here: the derived mathematical literacy that allows an individual to assess basic mathematical work, and a critical attitude that motivates the individual to make that assessment in the first place. Ivan elaborates on this by saying that if a number, graph, or table "doesn't make sense" then the numerate student should quickly notice the problem.

Session	Classroom Management	Credibility	Content	Off-topic	**Total**
First	10	2	8	1	21
Second	14	5	13	2	34
Total	24	7	21	3	55

Table 4-5. Ivan's Interactions with Students during the Two Sessions

A closer look at the types of comments made by Ivan throughout the two sets of presentations (See Table 4-4) helps support the idea that Ivan truly did care about fostering his students' critical stance. Further, it suggests that he connected that critical stance to the students' ability to harness their content knowledge by asking appropriate questions about their sources. Ivan's questions highlighted numbers that did not "make sense" and uncovered the mistakes made by the presenters that led to those numbers. In the fourth presentation during the second session, for example, the students were using data to model the probability that a given individual might have of becoming an alcoholic. As a student made a calculation error by treating the affect of having an alcoholic parent and the affect of having an alcoholic extended relative as independent probabilities (see Figure 4-9), Ivan spoke to the group,

> Can you go back two slides? Question, [Chelsea] you're multiplying by 6 and 2, what's the assumption here? We didn't talk about this much, but you're assuming independence and that's unlikely to be the case. This is way much higher than it is. [...] this is important, when you multiply probability you're assuming independence, you cannot do this when they're not independent. (Ivan, Second session, Fifth presentation, Lines 66 - 73)

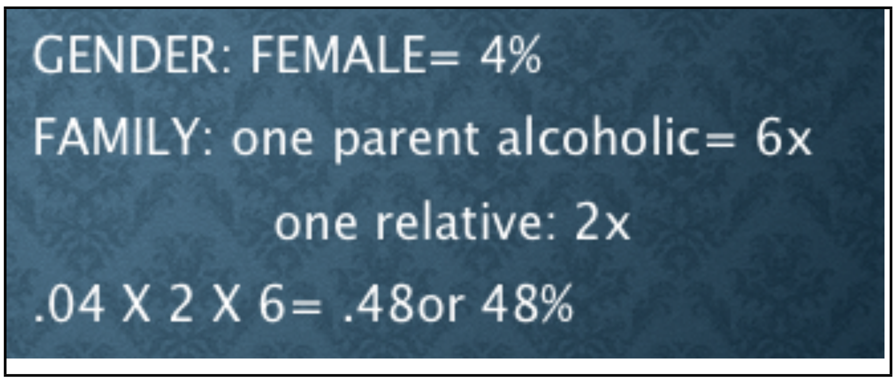

Figure 4-9. Excerpt from slide presented by group 2E

A similar interaction occurred earlier that day when the second group presented. Group 2B displayed the slide in Figure 4-10, which they were using to describe the state of the educational system in the city for which they were calculating the murder rate. Breanna narrated this slide and immediately after she moved to the next slide; Ivan said "Go back, you have three columns, I don't understand the three columns what do they represent?" (Ivan, Second Group, Second Presentation, 4/17/14, Lines 61 - 62). After some discussion about the time-frame to which the table referred, Tamara first said that the second row listed the number of schools before saying that 8000 must refer to the number of students, this led to the following exchange between Ivan and Breanna:

Ivan: The second row still doesn't make sense to me. Are we counting schools or are we counting students. If you're counting students the first two columns don't make sense, if you're counting schools the last column makes no sense.
Breanna: Okay, they're counting schools, that's what they're counting, schools.
Ivan: So they're 8000 schools?
Breanna: No, originally I think it was 336 schools that was 20 years ago. Now with the charter schools and everything else there are over 3477, actually I don'tknow, the 8000 I think is the students. The number of students that they had.
Ivan: So that, that whole row makes no sense.
Breanna: Right.
Ivan: It's either schools or its students but you can't have both.
Breanna: Okay, we just have to redo it then.

(Second Session, Second Presentation, 4/17/14, Lines 98 - 116)

Ivan was unable to get to the bottom of the mistake that the students had made when they created the table but he was able to get the students to understand that they had, in fact, made a mistake. This conversation between the members of group 2B and Ivan lasted over two minutes from the time that Ivan first asked them to go back to the table to the time that Breanna conceded that they would need to change it. In a class where Ivan had been very concerned with keeping time so that every group would have a chance to present and where the average presentation lasted about five minutes, the fact that he would not let the conversation go until the students recognized their mistake is a good indication that he was serious about the importance of getting students to critically question any numbers that they encounter.

	20 years ago	10 years ago	This year
Student/ teacher ratio	23:1	22:1	16:1
Total public schools	336	3,477	8,000
Total private schools	64	860	2,522
Total post-secondary schools	19	199	805

Figure 4-10. Slide presented by group 2B

Summary of the Delta University Case

Delta University serves as a particularly instructive case because it suggests that information-based problems can be introduced to a mathematics classroom without losing the opportunity to engage in real mathematical work. In fact, it is possible that Ivan was able to detect student mistakes and misconceptions that he would have missed without the information-based problems. Unfortunately, the focus on students' mathematical work may have led to missed opportunities for promoting the students' rational dependence. These teachers profiled in each of the three cases had to manage the way that mathematical work appeared in the information-based problems and Ivan's solution was to create a mathematical problem that used information-seeking as a resource.

. The second information-based problem, in particular, incorporated information-seeking into the mathematical work in a manner unlike either of the other cases. As the students collected quantitative data in order to carry out a mathematical calculation, there could have been an opportunity for the students to compare the credibility of the sources of that data or to share sources with one another just like the students at Rho University. Instead, these students appeared to take the validity of their data for granted. The students' credulity frustrated Ivan, but he did not suggest that they could have mitigated their risk of using incorrect numbers by corroborating what they found across sources or any other practice related to rational dependence. Instead, he continued to prioritize mathematics as a means of double-checking their work.

Summary of the Chapter

The three cases reported in this chapter suggest that providing opportunities for rational dependence in a mathematics classroom is not as simple as assigning a problem that requires students to seek out and use outside sources of information. The dramatic difference between the students' use of credibility arguments at Rho University as compared with the two other cases implies that structure of the activity may play an important role. The students at Rho University only began to make sophisticated credibility arguments when they were required to discuss their choice of sources with their peers. On the other hand, while the formal debate at Phi University appeared to be an ideal venue for such discussion, the rationale for the students' sources never were called into question in that context.

These reports also help draw connections between the structure of the problems and the teachers need to incorporate mathematical work into the information problem-solving process. Each of the teachers resolved this dilemma in different ways and this had implications for the students' opportunities to practice rational dependence. This also meant that the students' mathematical knowledge played a different role in each case. The students at Delta University, for example, were given problems where the product was entirely mathematical and so the teacher was better able to attend to the students' disciplinary knowledge even as he attended less to the their information-seeking and evaluation of sources than either of the other two cases. The teachers' all expressed different perspectives on what it meant to them for their students to critically appraise claims that they encounter in the media and their assignment and management of the information-based problems reflected this.

In the next chapter, I look across all three of the cases in order to compare the way that students in the three cases drew on their disciplinary literacy in general, statistical literacy in particular, and what their information problem-solving process looked like. This comparison suggests that the academic tasks embedded in these information-based problems determine whether students have the opportunity to engage in rational dependence. Furthermore, the analysis of the teachers' work in the subsequent chapter better articulates how the genesis and management of these tasks are a natural outgrowth of the teachers' management of the dilemmas that inevitably arise when novel problems are introduced to the mathematics classroom.

CHAPTER V

Students and Rational Dependence: Cross-Case Observations

In this chapter I discuss whether and how students were able to move towards rational dependence by working with information-based problems. In the previous chapter, I presented the case-specific observations that form the basis for this cross-case analysis. The students in all three of these cases were given the liberty to seek out sources on their own and to make judgments about which of those sources to use -- an opportunity that is rarely present in a mathematics classroom. By looking across the three cases, I am able to describe how the students made use of this opportunity and how the structure of the tasks used in the three cases influenced their work. These observations serve to complicate what it means to have an opportunity to practice rational dependence in the context of a mathematics classroom.

Students are able to engage in credibility assessment with their peers in the context of activity structures like small-group discussion. However, these discussions may be compromised by the students' lack of mathematical knowledge, so that even as students cooperatively develop ideas about whom to trust, they may fail to make use of sources that are making mathematical arguments that they do not understand. This is further complicated if the teacher wants their students to treat mathematical concepts as markers of credibility. These examples highlight a larger theme which is that information-based problems vary in the demands they make of the students and in their consequences for the practice of rational dependence.

Research Question: How do undergraduate students in a quantitative literacy-focused course work with information-based problems introduced by their teacher?	
	Cross-Case Observation 1.1: The students in these cases largely followed a typical information problem solving process but they did not engage in any credibility assessment unless they were specifically told to do so, and
	Cross-Case Observation 1.2: Evidence of sophisticated credibility assessment only appeared when students were called on to discuss the credibility of their sources with one another.
	Cross-case Observation 1.3: Greater opportunities for credibility assessment were presented when the targets of the students' information seeking were sources rather than the quantitative data contained in the sources.
	Cross-case Observation 1.4: The problems that presented students with opportunities to use and synthesize information were not the same as those that presented opportunities for credibility assessment.
	Cross-case Observation 1.5: Students were mostly to fulfill the terms of the assignments that they were given but there was evidence of satisficing.
Research Question: How do they use their content knowledge when working on those problems?	
	Cross-case Observation 2.1: The dispositions component of statistical literacy were present when explicitly demanded by the problem and absent when not so demanded.
	Cross-case Observation 2.2: Students successfully drew on elements of a statistical knowledge base throughout the three cases, but those information-based problems in which mathematical work was prioritized presented a greater opportunity for revealing gaps in student knowledge.
	Cross-case Observation 2.3: The students' mathematical knowledge sometimes conflicted with the practice of rational dependence. On the one hand, if the students are not asked to use the mathematics in question, then it may only serve as a superficial marker of credibility rather than providing insight into the argument contained within the information objects. On the other hand, if a source contained mathematics that the students did not understand, then they might not use that source.

Figure 5-1. The Cross-Case Observations Addressing the Work of the Students.

My specific cross-case observations are presented in Figure 5-1 and elaborated below. The first set of observations explore the connection between the information problem-solving process and the students' opportunities for rational dependence. In particular, I look at when and how students were able to assess the credibility of the sources that they found. Then I look at how different elements of statistical literacy featured in the work of the students and elaborate on the ways that students' mathematical knowledge or lack thereof came into conflict with their opportunities for rational dependence.

The Information Problem-Solving Process and Rational Dependence

Gaps in The Information Problem-Solving Process

Cross-Case Observation 1.1: The students in these cases largely followed a typical information problem solving process but they did not engage in any credibility assessment unless they were specifically told to do so.

In elaborating on this observation, I describe the information problem solving process as I witnessed it carried out in the three institutions and I use this description to specify how certain elements of the model were missing from this work, particularly the credibility assessment stage. While I did not have the opportunity to shadow students as they engaged in information seeking, I was able to draw some tentative conclusions based on my observations of the in-class activities, interviews with the TAs at Phi University, interviews with three students at Rho University, and discussions with teachers at all three locations. First, there are points where the *information seeking strategies* and *location and access* stages support one another. The information seeking strategies stage consists of brainstorming to "determine the range of possible sources" (Eisenberg & Berkowitz, 2001, p.1) and deciding on priorities between those possible sources. The location and access stage includes finding the sources as well as the required information within those sources. Both of the TAs at Phi University as well as the students whom I interviewed at Rho University described an information seeking process that almost completely eschewed any sort of brainstorming and instead began with the inputting of keywords or a phrase into a search engine. The students would then fluidly move between deciding on sources based on the description, looking within the sources, and then moving back out to the search results to look across more sources.

Similarly, the *use of information* and *synthesis* stages occurred interchangeably and would sometimes be followed by or happen concurrently with the first two stages. These last stages include the extraction of information from a source (e.g., taking notes, copying and pasting, or simply reading and remembering), organizing the information extracted from all the different sources, and presenting that information to others. While the presentation of information necessarily occurred last in the sequence, the extraction and organization of information appeared to be an iterative process. As an example, Rita, one of the TAs at Phi University, described students in her study hall working in teams where one would be drawing up the graphs that they would use the next day even as the other student extracted information from online sources and told the first student what to draw. There was no evidence that students engaged in the reflective evaluation of their information-seeking process that is the *evaluation* stage and that stage is deemphasized in Figure 5-2 in order to represent this.

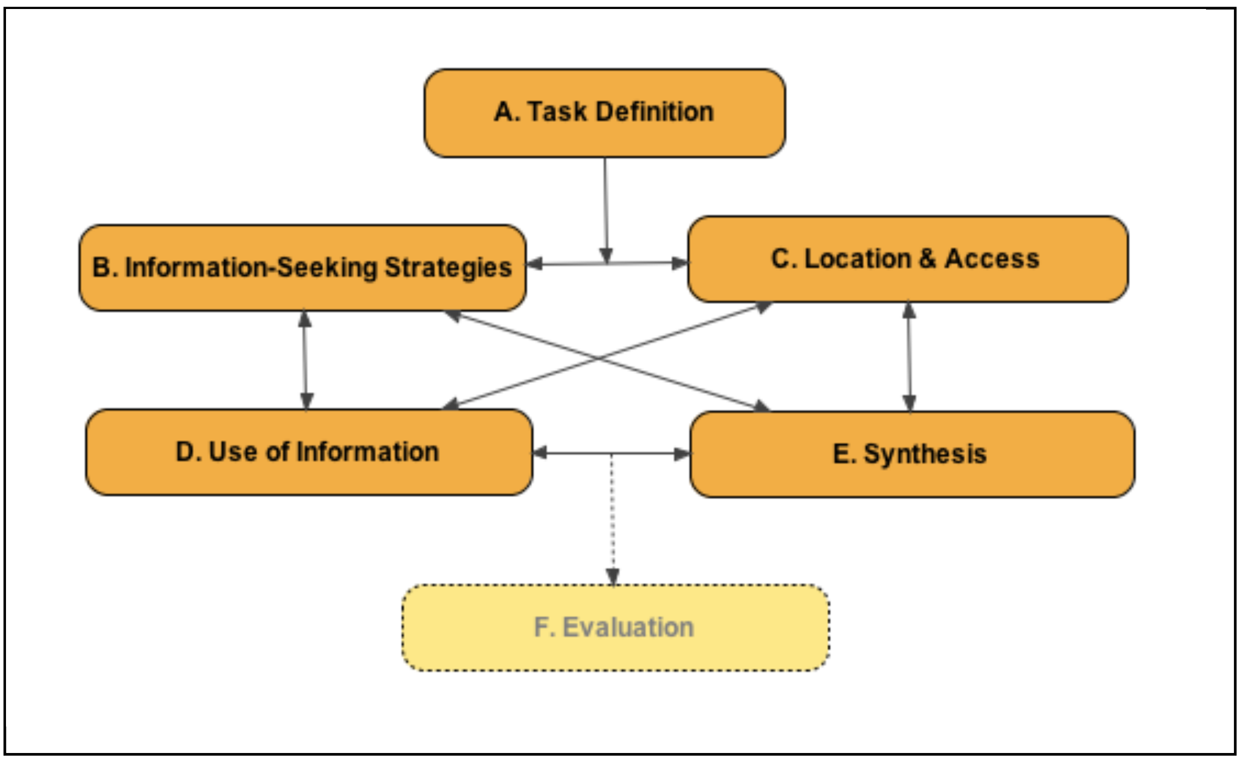

Figure 5-2. Information problem solving process (adapted from Eisenberg & Berkowitz, 2001)

The information seeking strategies stage includes the adoption of strategies for determining which sources to consult. A crucial part of this process is the assessment of credibility of sources (Rieh, 2002). Aside from the question of whether the source is actually pertinent to the topic at hand, credibility has been argued to be the crucial determinant of whether one source should be prioritized over another (see Norris, 1995). This, of course, is not always the case in practice. Researchers on information seeking behavior have found that students have a tendency to prioritize convenience and availability of information over other factors such as the credibility of sources (Connaway, Dickey, & Radford, 2011), a set of behaviors that will be address in Cross-Case Observation 1.5.

A Context for Credibility Assessment

Cross-Case Observation 1.2: Evidence of sophisticated credibility assessment only appeared when students were called on to discuss the credibility of their sources with one another.

The basic premise behind an information-based problem (Walraven et al., 2008) is that these are problems that require individuals to go beyond their own knowledge base. The need to rely on the knowledge of others is intended to open up room for the practice of students' rational dependence but, as we have seen above, the information-based problems each presented different opportunities for the practice of rational dependence. In particular, while credibility assessment is crucial to the development of rational dependence, sophisticated credibility assessment only occurred at Rho University. By sophisticated credibility assessment, I refer to the judgments about the quality and credibility of sources that research has found experts make much more often than novice information seekers (Brand-Gruwel et al., 2005). This finding suggests that the number of judgments can serve as a rough proxy for sophistication. Furthermore, my experience with the credibility assessments produced by students at Rho University motivates me to draw a distinction between those statements that simply reiterate the provenance of a piece of information, such as often happened in the written work that these students turned in, and statements that include backing that fall into one of the categories identified by Hilligoss and Rieh (2008) (e.g., peripheral source cues, peripheral information object cues). Please note that in comparing the number and quality of credibility assessments at different locations, I am not making any claim about the ability of the respective students to engage in this type of work. Rather, my conjecture is that the difference in credibility assessment between the cases and the information-based problems at these sites has more to do with the opportunities and motivation for practicing these skills.

In light of all these ways of assessing the credibility of sources, it is particularly striking that the amount of credibility assessment at the three locations contrasted so greatly. To be more precise, the students included backing for their sources 54 out of 72 times at Rho University, 2 out of 52 times at Phi University, and 23 out of 30 times at Delta University.[40] At first glance, it may appear that the two salient groups are Rho and Delta University where they both had a ratio of source to backing of at least 3:2, and Phi University where students hardly provided backing at all, but if we look more closely at the two separate assignments at Rho and Delta University

[40] See Figures 4-1, 4-8, and 4-11.

we can produce a better point of comparison. During both discussion sessions, the students at Rho University provided backing for their grounds more than half the time and almost all of the time for the first session. At Delta University, on the other hand, there was a dramatic difference between the two problems with students only including backing for sources 3 out of 19 times for the second problem. Thus, the two cases where there were very little backing were the debates at Phi University and the second set of presentations at Delta University.

The information-based problems at Phi University took the form of debates and so it might appear counterintuitive that the students would actually be *less* concerned with providing backing for their sources there than in other contexts given that the immediate goal of the in-class portion of the work was to successfully defend the claims that they made. To understand why the students did not provide much backing for their choices, it helps to look more closely at how the debates actually played out. The debates were formal and so one group would present their argument complete with charts and graphs that they had created themselves and then the other group would counter with their own presentation. These opening arguments were followed by short rebuttals by each group. While the majority of groups included citations for the sources that they used in the opening arguments, none of the students in either class ever defended their choice of sources. Further, the students' rebuttals never called the sources cited into question either. The teachers did not make any critical comments about the sources that the students were using either and this is despite the fact that they both had referred to the "misuse" of statistics as a theme that had motivated these debates. Rich who, as documented in the last chapter, spoke up on a number of occasions about how statistics can be misused, did not address possible motivations for that misuse; instead, he encouraged the students to look critically at the diagrams themselves. Taken together, it appeared that students' and teachers' both took the existence of a source to be sufficient justification for a claim without any further backing needed. The teachers wanted students to examine diagrams critically since those diagrams could be potentially misleading but this type of examination did not extend to an examination to the validity of the mathematics that informed the diagram or the intellectual authority of its source..

Just as the debates at Phi University put a focus on the features of the graphs that the students constructed rather than the sources of the data for those graphs, the second activity at Delta University focused on students' conditional probability calculations. The students were generally very good about including references to the sources for the data that they used; and, when they failed to do that, Ivan reminded them. But critical comments made by both the teacher and the students were focused either on the validity of the calculations or the question of whether the students were correctly presenting the data that they found. There was never any question about whether the sources they were using might be problematic or whether some sources might be better than others. These presentations were also similar to the debates at Phi University in that they had already been created by the students and did not allow for any discussion beyond the questions posed after the presentation was over.

There were three other sessions (both discussion groups at Rho University and the first set of presentations at Delta University) where students provided backing for at least half of the sources that they cited. If the *types* of backing are taken into consideration, the two discussions at Rho University are the only occasions in which students commented on the intellectual authority or biases of the source more than once in a given session. As described in chapter 4, the first set of presentations at Delta University were a special case inasmuch as the students were tasked to evaluate the methodology employed by a single source and so the critique was focused on the mathematical content rather than peripheral source and peripheral information object cues (see Table 4-1).

The sessions at Rho University saw students employing all three different types of backing for their sources. Students justified their choice of sources to one another by talking about the background of the authors (e.g., their profession, their institutional affiliation, credentials, whether it was a "dot-gov" website), the features of the information object (e.g., the presence of a methods section and graphs), or corroboration from other sources. These are all elements of credibility judgments that have been identified by prior research into credibility assessment (Rieh & Danielson, 2007) and so their absence from the other sessions was more notable than their presence at this session. What was unique to the information-based problems assigned at Rho University that these would be the only occasions during which students made use of all three types of backing? For one, these were the only problems that required students to justify their choice of source to one another. In fact, as noted in the last chapter, the students did not even provide backing of this sort when they submitted their initial written work. This suggests that the default of these undergraduates was to provide a source but that, without being put in a position to defend their choices, they felt that the citation itself was sufficient justification for the assignment at hand. The fact that the students at Rho University were able to engage in more sophisticated credibility assessment when given the time and motivation to do so suggests that undergraduate students possess the necessary dispositions and skills, and that they only lack tasks that will call forth their effort.

The next section addresses the ways in which the students reduced the demand of the information-based problems, here the focus is on the extent to which students assessed the credibility of the sources that they found. As documented in the individual case reports, students were generally good about citing sources but if students had not been specifically told to compare the relative credibility of different sources, as was the case at Rho University, then there were very few occasions where students said anything about why they chose the sources that they did. If one were to entirely judge from the presentations at Phi University and Delta University, it would appear that these students felt that the citation of a source was sufficient to justify a knowledge claim and that the sources themselves needed no justification. The students at Rho University, however, demonstrated that they were capable of considering the credentials, histories, and achievements of sources, and that they could use this information to judge that some sources were more believable than others. This suggests that evidence of credibility assessment has more to do with opportunity afforded by the activity structure than with the characteristics of the students.

The Object of the Search: Source Versus Data

Cross-case Observation 1.3: Greater opportunities for credibility assessment were presented when the targets of the students' information seeking were sources rather than the quantitative data contained in the sources.

Learning to live with the expertise of others (Norris, 1995) involves locating the sources of that expertise and judging between them in a reasoned way. By looking across the three cases presented in the last chapter, I have found that the target of the information-based problems influenced whether and how students were able to engage in those practices. In particular, students had an easier time accomplishing their information seeking and were able to discuss the comparison of sources with their peers when the information sources were the target of their search. The students had much more difficulty, and their knowledge of the relevant mathematics appeared to be more of an obstruction, when they were told to search for specific information rather than the sources containing that information. In the next section, I elaborate on how the structure of the problems was related to the students' opportunities to synthesize the information once they had found it.

The information problem-solving process begins, according to the Big6 model (see Table 3-1, Eisenberg & Berkowitz, 2001) with *task definition.* This refers to how the object of the students' information-seeking task is defined. While it might be most obvious to talk about task definition in terms of the topic to be searched for or question to be answered, the crucial aspect of the search task for the present purpose is whether the students were directed to seek out *information objects* or the *quantitative data* contained in those information objects. As a reminder, information objects refer to distinct documents or sources that can be characterized by their content, type, and presentation (Rieh, 2002). Quantitative data is the target of information seeking whenever the problem requires that the students provide a piece of information (for example, the probability rates for the second problem at Delta University[41]) rather than the source of that information.

Now I turn my attention to the three cases and how the choice of target presented opportunities for the students' exercise of rational dependence. When students were told that they would be describing and comparing the credibility of a set number of information objects, as was the case for both problems at Rho University and the first problem at Delta University, the product of the information-seeking task was well-defined in the set that the student would know that they were done once they had found the amount of relevant sources requested. While the students needed to make certain that each source actually addressed the topic, of course, they did not need to consider the mathematical content of the sources until after they had already been gathered. The second information-based problem at Rho University had an additional requirement for sources in that they needed to include a confidence interval,[42] but the students dealt with this by including the term "confidence interval" as one of their search terms. In the

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[41] See Appendix B

[42] See Appendix B

latter case, the students were also told that the article had to include a confidence interval. The students were largely successful with this search although some students needed to be informed by the teacher that the +/- symbol preceding a number represented a confidence interval.[43] The three students interviewed for the case also corroborated this observation; they input search terms describing the topic (e.g., "Pretty much Google, I just Google-searched autism and vaccines" (Carrie, 2/11/14, Line 4), "I just typed in exactly what it said on the sheet and lots of results came up" (Brittany, 2/10/14, Lines 5-6)) into a search engine and selected those sources that proved to be relevant from their descriptions.

On the other hand, when the students were told that they would have to make an argument using quantitative data, as was the case for the debates at Phi University and the second problem at Delta University, they had to search within sources to determine whether the required data was indeed present and further confirm that it was really the data that they needed. Rita and Jenny, the TAs for the Phi University class, both described students who were frustrated trying to find the information that they needed.[44] While the students' search was deemed successful on the whole, Jenny said that she wished that she had been a better resource with respect to online information seeking for the students in her section and Rita said that she found it necessary to give students feedback on whether the sites they were using were legitimate or not. Jenny further noted that "as they were presenting you could see that some stats conflicted each other because

[43] See Case-Specific Observations 2.2 and 2.3.

[44] See Case-Specific Observations 1.2 and 1.3.

they came from two different websites and a website may not actually have been a good website to get stats from" (Jenny, 9/3/13, Lines 64 - 65). Similarly, for the second problem at Delta University, Ivan recounted how he helped two different groups find the information that they needed in order to complete the assignment. These students had to draw on their knowledge of how to read probability rates in order to choose which numbers they needed for their presentation, and it is therefore unsurprising that some of the groups made mistakes on that front.[45] One might think that the difficulties encountered by these students suggest that teachers should scaffold students' rational dependence by having them seek out sources and leaving the more complicated work of assessing and scanning the sources for in-class work that can be better monitored. However, the students' frustration can be looked at from another perspective, the students who have to seek out data within these sources are being forced to engage with other aspects of the information problem-solving process even if they have less bearing on rational dependence, namely the question of what information to pull from the source and what to do with once it has been extracted.

[45] As when a group incorrectly presented a probability as though the it applied to the population of a city when it actually only applied to the number of murder victims, see Case-Specific Observation 3.3.

The Use and Synthesis of Information

Cross-Case Observation 1.4: The problems that presented students with opportunities to use and synthesize information were not the same as those that presented opportunities for credibility assessment.

The use of information and synthesis stages of the information problem solving process (Eisenberg & Berkowitz, 2001) includes the extraction of information from a source, coordinating information from multiple sources, and presenting the results to the intended audience. While rational dependence deals with decisions about which sources to use, the use of information and synthesis stages are important for the development of rational dependence as the reasoned use of the knowledge of others requires one to know what information to draw from sources and how to coordinate information from multiple sources. Looking across the three cases, I have developed a representation of information problem-solving demands as presented in Figure 5-2.

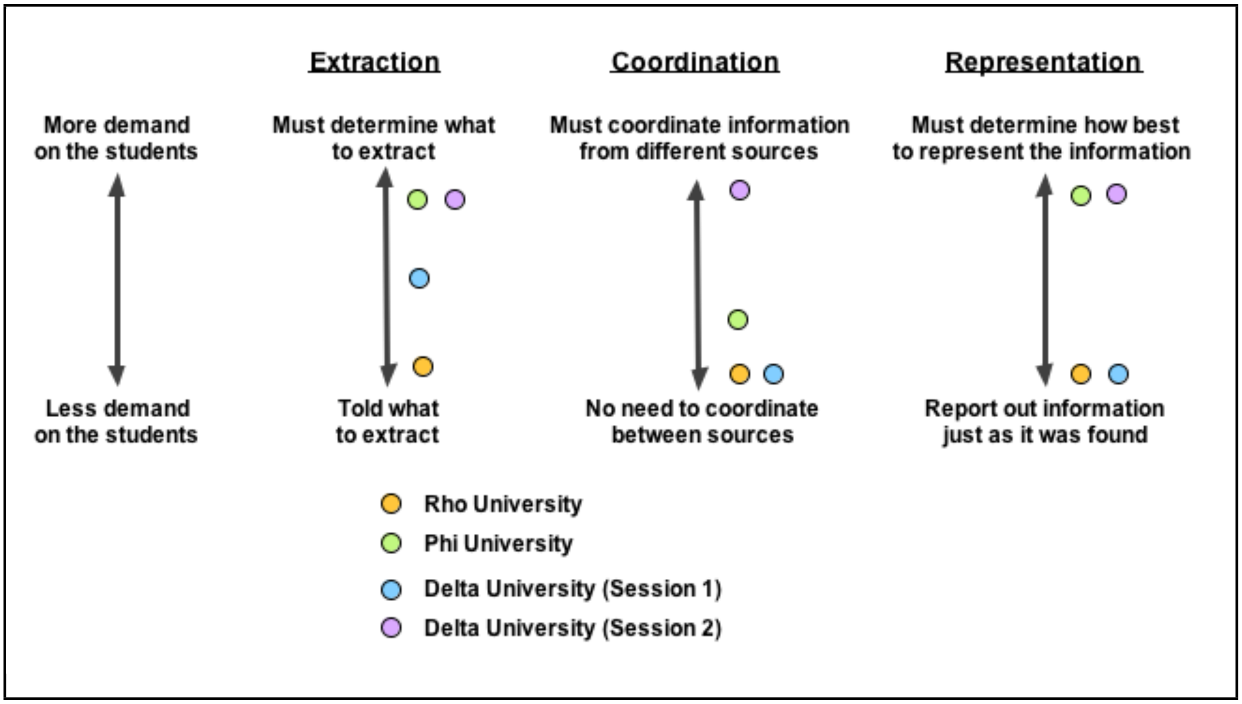

Figure 5-3. Relative demands of the information problem solving tasks

Extraction. The students at Phi University were largely left to their own devices when it came to deciding what information they would extract from their sources. They were required to create a chart or diagram but there were no further restrictions about where to find the statistics or even what type of statistics to use. The flexibility of these requirements was reflected in the arguments that the students presented which included everything from longitudinal statistics to polling results to courtroom verdicts. Both problems at Rho University, on the other hand, were much more specific about the exact information that the students needed to gather and this was reflected in the discussions that they had. While the students were able to talk reflectively about the way that they assessed the relative credibility of their sources,[46] the information that they had

[46] See Case-Specific Observation 2.1.

extracted from those sources was virtually identical across the different groups of students. The students had been told exactly what to report (i.e., the presence of correlation coefficients and confidence intervals) and they did as they were asked. The problems at Delta University occupied a middle ground with respect to extraction -- the students were told what mathematical work to do, but they had to determine for themselves which quantitative data from their sources would be necessary for that work.

Coordination. The students engaged in very little coordination across multiple information sources at any of the three sites. They drew on a number of different sources at Phi University but there was no attempt to compare, contrast, or combine the information found therein. While the students at Rho University were asked to compare their sources in terms of credibility, this did not require the students did not take the opportunity to coordinate information from those sources. The second problem at Delta University was the only problem that required students to synthesize information from multiple sources. For example, one group decided to calculate their risk of alcoholism and, in order to do so, they found figures broken down by gender from an interview with a physician on a National Public Radio website. Then they collected similar figures on the effect of having a family member who is an alcoholic and the effect of childhood drinking by consulting a health column published online in the *Globe and Mail* and an informational website produced by the National Institute of Health respectively. These students coordinated information from the three locations for their calculations, but there was no indication that they were weighing the credibility of these sources; in fact, the heterogeneity of their sources both in terms of type and format strongly suggests that they were picking the first source that contained what they needed.

Representation. The students were asked to attend to the ways in which they were presenting the information to their peers at Phi University and Delta University. The students at both of these location created presentations prior to the class meetings and had to be deliberate about the manner in which they represented the information. The students at Rho University, on the other hand, turned in a brief report to their instructor that described the sources that they found, but this was only tied to the in-class discussion through its role as a reference. The students were not asked to make a formal presentation to one another, instead they participated in a discussion.

The question now is whether and how the students had opportunities to develop rational dependence as a consequence of these latter stages of the information problem solving process. Part of the reason for including the representation of these demands in Figure 5-3 is so that I can better specify where and how these opportunities occurred. On the one hand, the students at Rho University were asked to do very little when it came to extracting, coordinating, and representing the information that they found. This complicates the opportunity that Anne provided for students to exercise rational dependence through talking about the credibility of the sources that they had found as they did not proceed to do much with those sources. On the other hand, the students in the second session at Delta University, had to gather and coordinate probabilities despite the fact that they were not provided with any scaffolding for how to locate and evaluate those numbers. They were, nonetheless, held accountable for the validity of the calculations that they performed with those numbers. The situation at Phi was similar although the students were held less accountable for what they presented in the end. This observation suggests some of the difficulties involved in putting together an information-based problem that involves the extraction and coordination components of the information problem-solving process. To provide these opportunities, an instructor can focus on a goal like at Phi University where students got to choose what sort of information to use to bolster their argument or a calculation like at Delta University where students had to find the data necessary to calculate a conditional probability.

Satisficing and Information-Based Problems

Cross-case Observation 1.5: Students were mostly able to fulfill the terms of the assignments that they were given but there was evidence of satisficing.

The phenomenon of satisficing, or the tendency of individuals to fulfill the immediate demands of a given task rather than coming up with an optimal solution, is well-documented (Prabha, Connaway, Olszewski, & Jenkins, 2007; Warwick et al., 2009; Zach, 2005) in the context of information seeking behavior and so it is to be expected that it would occur for these information-based problems. The more interesting question is *how* students satisficed in these situations and the extent to which they could get away with this behavior while staying within the terms of the assignment. I begin by providing characteristic examples of how this happened in each of the three cases. We will see that there were some assignments that were more conducive to satisficing than others and this was strongly affected by the sophistication of the mathematics required.

The students at Delta University surpassed the expectations of their teachers and the TAs. The evidence that they had gone above and beyond the call of duty was the sophistication of the charts that they included with their assignments and the fact that they had located and cited statistics found on the internet. One way to think about satisficing is to compare the work that the students did for the school assignment and the work that they would have to do if they felt the need to truly render a verdict on the issue in question. In the former case, they simply need to collect resources that have the superficial believability necessary to support their side of a debate, while in the latter case it would be in their interest to weigh the evidence on both sides of the issue and it would not be in their best interest to give credence to any arguments that have doubtful provenance or insufficient mathematical warrant. This was not the case for this assignment and so it makes sense that students did not take the time to critically interrogate the sources of their information or the processes involved in generating the numbers that they used to support their claims.[47]

The students at Phi University were similarly able to fulfill the terms of the assignment as given while engaging in a radically simplified information-seeking process, but there is a contradiction in this case. Both the evidence of the students' written assignments, the small-

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[47] See Cross-Case Observation 2.1.

group discussions, and the interviews that I conducted with three of the students suggests that the students found the sources that they used by simply typing the controversial topic into a search engine and seeing what appeared. The students, both in their class discussions and during my interviews, generally described a process in which they would pick some of the first websites that appeared and only then engage more critically with the credibility of the sources. Part of the issue here is that while the students were asked to find multiple sources that they would present to the class and to look across the sources critically, there was no criteria for the inclusion of the sources other than the topic itself. This was particularly evident for the first information-based problem where most students did not find an article that included a correlation coefficient even though this was supposed to be a target of their search. One could imagine a student looking for additional sources that contained correlation coefficients once they discovered that there were no correlation coefficients in the sources that they found, but there is no evidence that any of the students took this step. This satisficing is peculiar because these same students had no trouble discussing the relative credibility of the different sources that they found.[48] In fact, if one were to judge purely from those conversations, it might appear that the students had been spending time actively discriminating between sources in order to come up with the sources used for the problem. Unfortunately, this does not appear to be the case: Most of the students met the minimal demands of the information-based problems and, in doing so, vastly simplified what might otherwise have been a rich information seeking process.

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[48] See Cross-Case Observations 1.2 and 1.5.

The situation at Delta University allowed for a similar simplification of the task. For both information-based problems, students needed to locate only a limited number of sources, although the second information-seeking task was potentially much more difficult than the first. The first problem at Delta University was analogous to the first problem at Rho University in that students were asked to find an information source and to critically examine it. In fact, while students were asked to track down more than one source of information, they only needed to present on one of them and the quality of this information source only mattered inasmuch as the student would be evaluating it -- the student would not need to take the quality of the source into account as they were seeking information. They could simply choose the first relevant article that the search engine provided.

The second problem at Delta University, on the other hand, required that the students actually find data that they could use to perform a probability calculation. In order to calculate a more specific conditional probability, the students needed to locate information about the way that gender, race, location, or some other demographic characteristic that influenced the probability of dying in a car accident or by gunfire. However, there was no reason for the students to doubt the validity of the numbers once they had found them. The situation would have been different if the students needed to know the true probability in question. In that case, they might have wanted to double-check to see whether the numbers were corroborated or that the source was trustworthy. However, the students did not need to know the true probability and the tendency of some of the students to take the numbers at face value was demonstrated quite profoundly by the two distinct student presentations in which they calmly accepted homicide rates of greater than 50% without questioning the realism of those numbers.

As can be seen above, there were a number of distinct types of satisficing at play at these three different locations. They ranged from a lack of critical examination of sources to almost absurdly abbreviated information seeking tasks where students only collected the first links that appeared. These behaviors are understandable, but they are also unfortunate since it robs the students of an opportunity to develop the information seeking skills that could help them when they find themselves in similar situations with real stakes.

Mathematical Knowledge and Rational Dependence

Dispositions Towards Statistical Claims

Cross-Case Observation 2.1: The dispositions component of statistical literacy was present when explicitly demanded by the problem and absent when not so demanded.

In this section I focus on statistical literacy and specifically on the fostering of a critical stance towards statistics, which is where it most supports the development of rational dependence. In order to do this, I first draw some connections between Gal's (2001) model of statistical literacy as presented in chapter 2 and the disciplinary literacy model, based on Moje

(2007) and Norris (1995), presented in the previous section. These two models are quite consistent with one another as can be seen in Figure 5-4. Further, I will employ a distinction made by Norris (1995) that does not have an analog in Gal's model of statistical literacy; namely, Norris (1995) argued that the "skeptical disposition" needed in order to productively draw from the expertise of others should be aimed at the "believability of experts, not the evidence supporting scientific knowledge claims" (Norris, 1995, p.216). His argument is that students are unlikely to possess the requisite scientific knowledge to evaluate the evidence supporting a claim and so the onus should be shifted to those criteria that students could potentially be better equipped to gauge, e.g., the weight of consensus, prestige in the scientific community, amount of publications and research grants. We will see that the use of some information-based problems encouraged practices more aligned with Norris's skeptical disposition than others.

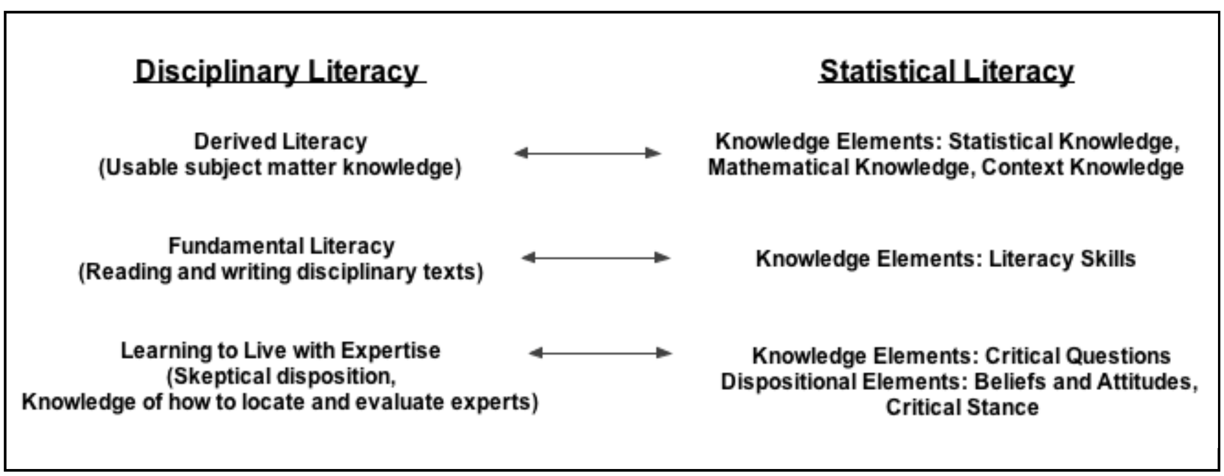

Figure 5-4. Comparing disciplinary literacy (Moje, 2007; Norris, 1995) and statistical literacy (Gal, 2001)

There were three different points during the cases in which students' dispositions towards quantitative claims were highlighted by their in-class work:

1. At Phi University, all of the groups were taking part in debates with one another and this necessarily led to some critical questions about the statistics being presented.

2. At Delta University, the first group that presented during the first session took an extremely critical view of the research article that they were analyzing.

3. At Rho University, the students had been asked, in both sessions, to look across information sources and decide which were the most credible.

I now compare what it was that students were actually doing in each of these three cases as they critically examined the arguments and articles before them and use this to better describe the relationship between the tasks and the dispositions that the tasks fostered.

At Phi University, the students made critical comments about their peers' contributions but they never questioned their choice of sources in the first place. These students were given a minute for a rebuttal after having made their opening arguments. While students would occasionally use their rebuttal time to include a piece of evidence that they had not had time to include in their opening argument, the majority of the groups directly engaged with the arguments that had been put forward by their opponents. These responses ranged from questioning the applicability of their opponents' claims (e.g., a pro-death penalty argument is based on a state with a different financial profile than the state in question) to offering contradictory evidence (e.g., presenting a survey that purports to show that firearms make people safer). At no point, however, did the students engage in the type of critical work advocated by Norris (1995); they did not question the believability of the sources used by their opponents nor did they weigh the credibility of sources against one another. The lack of this type of questioning did not appear to surprise the instructors and they never suggested that the students ought to be skeptical of their sources.

By way of contrast, the students at Rho University spoke about the believability of their sources throughout their small-group discussions. Students in both sessions made critical comments about the sources on a number of occasions, 25 times during the first session and 9 times during the second session.[49] These comments included references to the professional status, organizational affiliation, and experience of the writers. The students at Rho, or at least a subset of those students, paid attention to the source in much the way that Norris (1995) prescribed. They noted when sources corroborated one another, that an "article was published in a journal of child neurology and [...] was done by like a PhD" (First Session, Second Group, Line 107), or that a source was an advocacy group that might have a vested interest in what they

[49] See Case-Specific Observation 2.1.

reported. Interestingly, these students appeared to attend to the believability of sources more often when they had difficulty with the mathematics and less often when they were able to directly examine the validity of a source's mathematical arguments. There was no evidence during the first session at Rho University that the students were able to directly engage with the mathematics they found in their sources. Instead, the students' critique was limited to noting whether there was a correlation coefficient or *r*-value present in the articles. When they did encounter mathematics, they were not able to evaluate its validity. As one student noted, "they did use scientific and mathematical evidence but I didn't understand any of it" (Donna, First Session, Second Group, 2/6/14, Lines 4 - 5). The second session, on the other hand, was focused on polling data and the students had been given tools with which to critique the methodology of the polling companies. These critiques largely focused on the sample size, the way that the sample was chosen when this information was available, and whether the questions were phrased in such a way that bias might be introduced into the surveys. The students still attended to the believability of the sources, distinguishing between polls that originated at universities, governmental institutions, and private firms, but they spent comparatively less time on this than in the first session.

There was only one group at Delta University who looked critically at the believability of a source. The students had been asked to look up polls or studies related to a controversial issue and to present a critical report on one of those polls. The resulting presentations differed from the discussions at Phi University because the students almost never attended to the believability of the experts themselves (with one exception to which I return shortly) and instead focused entirely on the sampling strategies of the polls and research articles, e.g., the sample size, inclusion criteria, locations polled. The first group was the one that addressed the believability of their source. These students looked at a longitudinal study that was attempting to determine whether there was a connection between vaccination and autism rates. This was one of only two groups that looked at a research article rather than a poll and they took issue with most of the sampling decisions made by the researchers and expressed concern with those elements of the work, like the sampling strategy, that were not provided by the authors.[50] They concluded by assailing the believability of the source of the research article, speculating that the research may have been sponsored by the federal government in order to disguise its complicity in the autism epidemic through its use of unsafe vaccine regimens.

Why did the students' dispositions vary so widely between the three different locations? First, it should be noted that the very word "disposition" is probably misleading in this context. These students' actions were likely influenced, if not dictated, by the terms of the information-based problems that they were given. With this in mind, it is worth noting that Rho University, the only location where a sizable number of students engaged in those dispositions described by Norris (1995), was also the only location where students were specifically asked to assess the credibility of the sources. Why did students spend a considerable amount of time attending to the mathematics backing the claims contained in the information sources at both sessions at Rho

[50] See Case-Specific Observation 3.2.

University and at the first session at Delta University? Again, the students were specifically told to look critically at the sources that they found and were given some guidelines for doing so. In each of these cases, the teachers either provided a written handout on assessing the credibility of a source, demonstrated what this type of critical analysis might look like in front of the class, or both. The fact that students only gave evidence of these dispositional elements of statistical literacy when specifically asked to do so by their instructors means one of two things: the students are evaluating sources in this way regardless of the terms of the immediate assignment and they simply lack any motivation to talk about it unless required to by the assignment, or the students are not motivated to be skeptical of sources in the first place.

Revealing Student Mistakes

Cross-Case Observation 2.2: Students successfully drew on elements of a statistical knowledge base throughout the three cases, but those information-based problems in which mathematical work was prioritized presented a greater opportunity for revealing gaps in student knowledge.

Gal (2002) proposed that the statistical knowledge base component of statistical literacy can be divided into five categories as follows:

> 1. Knowing why data are needed and how data can be produced.
> 2. Familiarity with basic terms and ideas related to descriptive statistics.
> 3. Familiarity with basic terms and ideas related to graphical and tabular displays.
> 4. Understanding basic notions of probability.
> 5. Knowing how statistical conclusions and inferences are reached.
>
> (Gal, 2002, p.10)

A survey of the mathematical topics that were connected to each problem is provided in Figure 5-5. As can be seen in the table, though there was no coordination between the different sites, it happens to be the case that all of the categories described by Gal were covered by the selection of problems. This does not mean, however, that they were all covered in the same way or with the same degree of thoroughness.

Problem	Mathematical Topic
Phi University	Familiarity with basic terms and ideas related to graphical and tabular displays
Rho University First Session	Knowing how statistical conclusions and inferences are reached
Rho University Second Session	Knowing why data are needed and how data can be produced Familiarity with basic terms and ideas related to descriptive statistics
Delta University First Session	Knowing why data are needed and how data can be produced Familiarity with basic terms and ideas related to descriptive statistics
Delta University Second Session	Understanding basic notions of probability

Figure 5-5. The statistical knowledge base categories (Gal, 2002) targeted by the information-based problems

There is both a positive and a negative sense in which the students' engagement with the categories of the statistical knowledge base can be described. The positive sense is captured in Table 5-5; this describes those elements of statistical knowledge that the students would theoretically need to bring into play in order to address the information-based problems that they had been assigned. The question is whether and how the students actually had to draw on that knowledge. At Phi University, the students were required to create at least one diagram or chart representing some of the claims made in the course of their argument. As recounted in chapter 4, Tim had students do this because

> I made the decision at some point that I didn't want them to just download graphics off the internet because I was worried that if they did that, they would download a bunch of fancy graphics that they didn't really quite comprehend and then it would be too much information for anybody in the audience to comprehend too. And so I figured the way around that is that I would have them do it, they read the section on how to present data, that's section two of that chapter, how to present data, ideas on how to present data, and so let's make them do it. I think that was a good decision. (Tim, 8/14/13, Lines 73 - 79)

But how accountable were the students for the accuracy and insight of the data displays that they created? While students were asked to question what had been presented by their peers at the end of each debate and the debaters themselves presented rebuttals of their counterparts' arguments, the questions, with only a single exception, were never more critical than a request for clarification and the rebuttals, as documented above, almost never critically evaluated the content of the representations of statistical data. The one exception to the above was a student in the audience who successfully pointed out that a group had presented an incorrectly labeled pie chart. Interestingly, Rich, the instructor of the section in question, downplayed this error, making the assumption that the students had copied the pie chart correctly from their original source and using the incident as an opportunity to talk about how the students should "watch where you're getting the stuff" (Rich, Third Debate, First Day, 7/31/13, Line 277) rather than suggesting that the students might have not accurately labeled the chart.

The work of the students at Rho University entailed even less actual mathematical demands than the work of the students at Phi University. The students were asked to look in their sources for the correlation coefficient or for confidence intervals respectively, but they were not asked to do anything with those mathematical objects if and when they found them. This played out slightly differently in the two sessions observed. In the first session, the students were only looking for the presence or absence of the correlation coefficient and the only mathematical knowledge needed was the ability to recognize whether the correlation coefficient was present or not. There was some implication that the student should be able to interpret the correlation coefficient once they found it but this was rendered moot because there were almost no articles that contained one. In the second session, by way of the contrast, the students were asked to find an article that contained a poll and write

> A summary of the results that includes: the wording of the question that was asked in the poll, the number and type of people surveyed/polled (may be "general public"), the percentages reported in the polling results, and whether the article includes a confidence interval.[51] (If any of these items are missing, please say that in the summary.)
>
> (See Appendix C for the complete assignment)

Thus the students had to do at least a little more interpretive mathematical work than they had in the first assignment but it did not amount to much more than collecting readily available information. It could be predicted then that Anne would not find much to object to in the work provided by the students and this was indeed the case.

The class at Delta University presents a stark contrast with the other two cases in this respect. Both of the information-based problems were more mathematically demanding and the

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[51] This last part of the summary is a little misleading because Anne eventually required that the students locate a poll that included a confidence interval.

teacher was simultaneously less satisfied with the work that his students submitted. The first session at Delta was very similar in some respects to the second session at Rho University and so it furnishes a good opportunity to be more specific about what I mean by 'mathematically demanding'. The students at Delta University were also asked to look for polls related to a controversial topic although they were later given the option of examining a research article instead. The statement of the problem itself is as follows:

> Each group will find evidence of the status of public opinion in the form of public opinion polls (from editorials, articles, polling firms). Then you are to evaluate the poll. Are they valid? Are they good? What do they really show? How were the results presented? Etc (sic)

As can be seen in the statement, there are some crucial differences between the requirements of this assignment and the assignment that Anne gave at Rho University. First, the students are being asked to "evaluate" the poll rather than to provide a "summary". The guidance for this evaluation is fairly open-ended as the students are asked to say whether the results are "valid", "good", and then asked to say what they "really show". Ivan supplemented these instructions with an example of what this type of critical evaluation would look like. He presented a poll in front of the class the week before their presentations were due and talked through the sampling strategy, remarking on the sample size, the geographic criteria for the sampling, and focused, most particularly, on how the pollsters were carrying out proportionate sampling in order to generate a random sample that accurately reflected the demographics of the population that it was supposed to represent.[52]

As at Rho University, these students' presentations were descriptive but they looked more closely at the sampling strategies employed by the pollsters (e.g., was the sample convenient?, was it random?, if so, how did they achieve this?). The greater sophistication of their analysis was reflected in Ivan's response to their presentations. While Anne at Rho University had felt completely satisfied with the work that her students did, Ivan at Delta University, as reported in the case report from the last chapter, noticed errors on a number of occasions -- the students in the first group leveled a criticism at the sample size of the research article that they were reviewing which betrayed an ignorance of the Law of Large Numbers, the second group misunderstood the meaning of a 'convenience sample', the third group erroneously criticized a telephone poll for the method they used to pick a random member of the households they called, etc.

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[52] Proportionate sampling is when different subpopulations are selected in numbers relative to their proportion of the total population.

Type of Mathematical Task	Definition	Example
Identification	The student must locate and possibly relate elements of the mathematical content specific to the source.	Describe the sample size and confidence interval for a poll.
Evaluation	The student must assess a mathematical argument that appears in the source.	Determine whether the sample size of a poll is appropriate for the claims that it is making.
Calculation	The student must use quantitative data located in the source or sources to carry out some type of mathematical calculation.	Develop a valid sampling strategy for conducting an opinion poll about a citywide referendum.

Figure 5-6. Categories of mathematical tasks contained in information-based problems

While it is possible that similar errors were being made by the students at Rho University and just failed to attract Anne's notice, my review of the transcripts of these discussions did not turn up any, primarily because the students were not making evaluative statements about the statistical methods underlying the polls and instead providing descriptions more like the following:

> It didn't really say specifically where the sample was coming from, it just said 1028 adults nationwide in the US in a survey. Asked the question whether marijuana should be legal or not and they found that legalization had an approval rate of 58% and a disapproval rate of 39 and then there was 3% that were unsure and then the margin of error for that was +/- 4. (Jerry, Session 2, Group 2, 3/27/14, Lines 19 - 13)

The extent of the students' critique was the question of whether the location of the poll was appropriate (e.g., was it set in a limited number of states or nationwide?) and whether the questions would introduce bias.

The second session at Delta University required that the students do more mathematics and included concomitantly more mathematical errors which were again evidenced by Ivan's reaction to them. The students were tasked to look up a probability rate relevant to their lives (e.g., murder rate, car accident rate, hiring rate, rate of alcoholism) and personalize it in some way by finding the data necessary to see what the conditional probability would be for some more specific demographics (oftentimes their own). As I documented in the individual case report, student errors included misunderstanding the population to which probabilities referred and subsequently calculating incorrect averages, making unwarranted independence assumptions, and making arithmetic errors due to a failure to carry over information properly from an earlier part of the problem. Ivan was frustrated with these mistakes as well, although, as I documented earlier, he was eager to continue to use these information-based problems in future iterations of the course. These three cases demonstrate that the opportunity to engage in mathematical work in the context of an information-based problem can vary quite widely depending on the terms of the assignment. A rough taxonomy of the type of mathematical tasks described above is contained in Figure 5-6. I explore the interaction between the information seeking and mathematical aspects of the information-based problems in the final two sections of this chapter.

Conflicts Between Mathematical Knowledge and Rational Dependence

Cross-Case Observation 2.3: The students' mathematical knowledge sometimes conflicted with the practice of rational dependence. On the one hand, if the students are not asked to use the mathematics in question, then it may only serve as a superficial marker of credibility rather than providing insight into the argument contained within the information objects. On the other hand, if a source contained mathematics that the students did not understand, then they might not use that source.

The relationship between the students' knowledge of the mathematical content of the information sources that they found and their use of the sources as evidence for their own arguments was a complicated one. For one of the problems at Rho University, students said that they had difficulty finding sources with the required mathematical content after having been told that this content was an important marker of credibility. At other times, the students said that they had difficulty determining how to use those sources that contained mathematical content that they did not understand. This was particularly pronounced at Rho University and Delta University where students were given very specific directions about which type of mathematical content to target.

While both information-based problems at Rho University targeted specific forms of mathematical content, the instructions changed in an important way between the first and second problem. For the first problem, students were asked to locate information sources that reported on whether a correlation existed between two variables and only then look to see whether the authors provided a correlation coefficient to support their claim. For the second problem, students were asked to seek out articles that reported on a poll and told that the article needed to include a confidence interval. Practically speaking, this meant that most of the articles collected for the first problem did not contain correlation coefficients and most of those collected for the second problem contained confidence intervals. Students expressed surprise at how difficult it was for them to find r-values for the first problem.[53] A member of group 1A commented that "I kind of expected to find more r-values and correlations and stuff" and that "[this difficulty] is surprising" (Adelle, First Session, First Group, 2/6/14, Lines 339 - 341). When the group presented before the rest of the class, they repeated that "it was really surprising that we didn't find any like r-values" (Adelle, Final Discussion, 2/6/14, Lines 89 - 90). Group 2A found an r-value in one of their articles but this seemed, if anything, to support their feeling that most of what they found lacked proper statistical support. As they stated in their final presentation, "most of the articles were, didn't have any mathematical stats to support their claims, just the one I read had a strong correlation with an actual r-value" (Donna, Final Discussion, 2/6/14, Lines 27 - 28). The ensuing tension was highlighted by a comment made by a member of group 4A, "when we were looking at our articles it wasn't, there was math involved, but then some had pages of math that just kept going and going so it was really hard to try and comprehend" but "when we were

[53] See Case-Specific Observation 2.2.

finding ours we didn't find any r-values that specifically said r equals" (Selena, Final Discussion, 2/6/14, Lines 50 - 54). Thus, some of the students appeared to be using the r-value as a generic marker of credibility apart from whether they understood the mathematical arguments contained in the article. This approach has the potential to be problematic because the ease with which an individual can detect the presence of an r-value (i.e., by using a search function to find the term "r-value" or "correlation coefficient") means that they can decide that an article is not credible due to its absence without considering other markers of credibility, a number of which are arguably much more important. Conversely, a student might accept the claim made by an article even if the mathematics is invalid. The students at Rho University were both more critical of their sources than those at the other locations and simultaneously doing less mathematical work.[54] The adoption of a critical stance without accompanying mathematical insight was also seen during the incident at Delta University where a group presented a scathing critique of a research article on the connection between vaccines and autism.[55]

These incidents demonstrates that the practice of rational dependence which hinges on coming to know the contours of a broader epistemic community can be held hostage by the mathematical knowledge of the individual. We have already seen two different ways that this can occur. First, if students feel beholden to evaluate the mathematical arguments being used by otherwise credible sources then they might avoid using those same authorities if the mathematics

[54] See Cross-Case Observations 1.2 and 2.3.

[55] See Case-Specific Observation 3.2.

is too advanced for them to understand. Second, if the students feel empowered to evaluate a mathematical argument, then any number of gaps in their knowledge could lead them to fail to give the source the credence it deserves. These dangers do not mean that there is not a constructive role for a student's mathematical knowledge; rather they suggest that students need experience judging how and when to use that mathematical knowledge.

Summary of the Chapter

This chapter focuses on student work and begins by considering where opportunities for the practice of rational dependence arose during the information problem-solving process. I found that students had a greater opportunity to exercise rational dependence when they were directed to gather sources rather than quantitative data contained within those sources. It was only in the case when they were directed to look for specific quantitative data contained within those sources, however, that students appeared to be deliberate about which information to extract from their sources and compare information between sources. This highlights a theme that recurs in the data: Each problem only touched on certain aspects of rational dependence.

Similarly, opportunities to encourage students to be skeptical of quantitative claims or to engage in credibility assessment only happened when teachers explicitly incorporated them into the requirements of the problems. The students gave no evidence that they were exercising their rational dependence in that way unless the teacher created activities that fostered such an attitude, whether it be the open-ended discussions at Rho University or the analysis of the sampling strategy of sources at Delta University. The role of mathematics is further complicated in these information-based problems. The usefulness of a source is compromised when a student does not understand the mathematical argument that it contains and this danger is exacerbated when mathematical content serves as a marker of credibility. The place of the students' mathematical work will be explored further in the next chapter as I take on the teachers' perspective.

CHAPTER VI

Teachers and Information-Based Problems: Cross-Case Observations

In this chapter I shift my focus from the work of the students to the work of the teachers. The choices that the teachers have made both in terms of creating the information-based problems and managing the students as they worked on them has been lurking in the background throughout the previous chapter. A central theme of that chapter was the way in which the features of an information-based problem may create or remove opportunities to practice rational dependence. In this chapter, I argue that even as the teachers paid little attention to the information problem-solving skills necessary for the development of rational dependence, they nonetheless valued their students' development of a critical sense and had distinct ideas about what it meant to do that. Further, the teachers developed these problems as academic tasks (Doyle & Carter, 1984) that had to be responsive to the obligations inherent in their professional role while also providing students with the opportunity to seek out and evaluate information. Furthermore, the tasks were novel as the teachers had never before had their students seek out and evaluate information gathered from outside the classroom. Prior research has shown that the introduction of novel tasks creates tensions for the teacher centered on their need to account for the knowledge at stake while being responsive to the work of the students (Herbst, 2003). These three cases build on those findings by providing different visions of how these tensions can be managed and what sort of opportunities these decisions afford for the development of rational dependence.

Research Question: How does the teacher of a quantitative reasoning class work with students who are asked to solve a series of information-based problems?	
	Cross-Case Observation 3.1: The teachers experienced difficulty evaluating student work, and their feedback rarely addressed the students' information problem solving process.
	Cross-Case Observation 3.2: The teachers all prioritized the development of a critical sense, but the manner in which this sense manifested itself in the classroom varied dramatically.
Research Question: How and why do teachers' modify the initial information-based problems as they introduce them to their classes?	
	Cross-Case Observation 4.1: The teachers each had different strategies for embedding mathematical tasks in the information-based problems.
	Cross-Case Observation 4.2: The teachers' development of the information-based problems resulted in fundamentally different opportunities for information problem-solving across the three cases.
	Cross-Case Observation 4.3: The teachers' feedback and evaluation of student work reflect different ways of managing the tensions between the information seeking and mathematical aspects of these novel tasks.

Figure 6-1. The Cross-Case Observations Addressing the Work of the Teachers

The cross-case observations describing the work of the teachers appear in Figure 6-1 and elaborated below. The first set of observations address the feedback the teachers gave to their students and how the teachers decided to evaluate the students' work. I then describe the way that the teachers appeared to conceptualize their goals for the information-based problems particularly in terms of their students' development of a critical sense. The second set of the observations conceptualizes the teachers' implementation of the information-based problems as academic tasks and uses this to describe how different tasks were associated with different opportunities for rational dependence.

Teachers and Rational Dependence: Evaluation, Feedback, and Learning Goals

Evaluating Information Problem-Solving in a Mathematics Classroom

Cross-Case Observation 3.1: The teachers experienced difficulty evaluating student work, and their feedback rarely addressed the students' information problem solving process.

Information-based problems require, by definition, information problem-solving, but the teachers did not provide substantial feedback on that facet of the students' work in any of the three cases, instead the teachers' feedback was directed towards managing the classroom, evaluating mathematical work, or encouraging a critical stance towards the statistics that students found. More generally, the teachers said that they had difficulty evaluating the student work as a whole. Given this state of affairs, it is particularly striking that the teachers all expressed the desire to use information-based problems again. What sort of feedback did the teachers provide their students? What do they see their students getting out of these problems? I address both of those questions with this and the next cross-case observations. In this section, I focus on two different types of feedback, the feedback provided by the instructor in the moment and their plans for grading the completed assignments. I develop a classification scheme describing the extent to which students were held responsible for the sources that they found as this is the only aspect of assessment that addressed the students' development of rational dependence.

In-class feedback. As documented in chapter 4, most of the feedback coming from the teachers in all three cases had to do with classroom management. In fact, both Tim and Anne remarked that this management work was keeping them from attending more closely to the content at stake in the conversations. While the demands of classroom management have been well-documented (Doyle, 2006) at the K-12 level, it may be that the novelty of the classroom task led to more classroom management work than the standard college course. Tim said that the debates were so fast-paced that he was unable to evaluate the tables that students were displaying,[56] he primarily noticed whether the tables looked aesthetically pleasing and he did not want to comment on that in front of the class because he did not feel that the students should be held responsible for the quality of their drawings. Anne also stated that she was too caught up in trying to make certain that the small group discussions were staying on task to get involved with the content of those discussions. Nor did she moderate the whole-group discussion apart from managing the transition from one group to the next. She later remarked that she wished that she had been better equipped to moderate the whole group portion of the in-class discussion:

[56] Thus reflecting Doyle's (2006) *immediacy* as one of the 6 dimensions of the classroom setting that contribute to classroom management demands.

> In general, I just maybe it's just some of the newness of the task but I don't feel that I come up with questions on the fly as good as with regular math. I need more training in discussion leading. I really admire people who are good at discussion leading across contexts. I would do really good where if there was a break of half an hour and I could come up with questions for the class. (Anne, 4/13/14, Lines 210 - 214)

Anne explicitly said that the novelty of the situation leaves her unsure of where to lead her students. In particular, Anne's statement reflected a tension between her desire to give space for an open discussion between her students about the credibility of their sources and her desire to desire to be more directive about those same discussions. This idea, that the tensions introduced by novel tasks (Herbst, 2003) influenced the work of the teachers, will be revisited later in the chapter. Further, the fact that Anne chooses to ascribe skill in this area to a more generic "discussion leading across contexts" suggests that she does not conceive of information problem-solving as a distinct set of skills at this point.

The students at Rho University were held accountable for considering the credibility of their sources but they were not responsible for finding high quality sources. The recording of the session documents that Anne took the time to intervene on occasion, but her perception was that she was operating as a facilitator rather than an evaluator of student contributions. Anne's non-management interventions during the first session were largely focused on encouraging the students to note when a source failed to contain a correlation coefficient.[57] I have previously argued that the structure of the first problem, namely that students were only asked to look for

[57] See Case-Specific Observations 2.1, 2.6, and 2.7.

correlation coefficients after they had already collected sources, led students to collect a set of sources that did not contain the desired mathematical content. Anne did not, however, bring this up when I asked her about why she focused on the presence of the correlation coefficient and said instead that she wanted to encourage students to be “critical consumers of math that they encounter in the world” (Anne, 4/13/14, Line 245).[58] Anne’s feedback focused much more on the credibility of sources in the second session.[59] The students in this session had been asked to look up polls related to a controversial topic and to discuss the polls’ credibility with their peers. Anne gave students some feedback on the credibility of the institutions doing the polling but these comments provided the students with additional information about the polls (for example, noting that Gallup is generally considered a credible organization) rather than providing feedback on the information problem-solving process. Anne’s self-identification as a facilitator along with the nature of her comments attests to her struggle to find a way of situating the information problem-solving work so that it could be valued as a product of mathematics instruction.

Ivan’s feedback to the students at Delta University offered a sharp contrast to the other two cases. He kept the focus on the students’ mathematical work rather than on the information seeking practices that preceded that work.[60] This even held true for the first problem where the students were specifically required to assess the sampling methodology of a poll or research

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[58] See Case-Specific Observation 2.1.

[59] See Case-Specific Observations 2.6 and 2.7.

[60] See Case-Specific Observation 3.5.

article. Ivan took issue with a number of the statements made by these students but he always directed the discussion towards the validity of the mathematics involved rather than the nature of the sources and how the sources had been located. This approach bears some superficial similarity to the concern with misleading charts at Phi University in that both put attention on the students' representations of mathematics that they found in their sources. The teachers at Phi University, however, appeared to operate from the assumption that the students were correctly representing what they had found and that any problematic mathematics existed in the original whereas Ivan assumed, correctly as far as I could discern, that the errors were on the students' side.

Looking across the three cases, I can identify four different ways that teachers held students accountable for the sources that they found:

A) Relevance only. The information sources are only judged on whether they are relevant. For example, the students at Phi University were not held accountable for how they chose their sources as long as they addressed the argument that they were making. This is a minimal requirement in that students were always expected to locate sources relevant to their assigned topic.

B) Credibility and relevance. The students are held accountable for the credibility of their sources but they do not need to account for the process through which they assessed the credibility. This is how Ivan treated the second information-based problem at Delta University. He stated that he would be double-checking the students' sources although he did not specify how he would hold the students responsible for the sources that they chose.

C) Process and relevance. The students must describe the process through which they chose sources, but they are not held accountable for whether they have ultimately found credible sources. The students' account of the process is part of the product of the task and may either take the form of a written report or a discussion observed by the teacher. The Rho University case is an example of this: the students had to turn in a written assessment of the credibility of the sources that they found and also discuss the credibility of those sources in small groups, however the students were given just as much credit for a negative assessment as a positive assessment, they were not penalized if they were unable to find credible sources.

D) Credibility, process, and relevance. Students are held accountable for the credibility of their sources and they must also submit a product that includes an account of how they chose those sources. The first problem at Delta University was potentially a good example of this type.[61] The students were asked to gather sources and specifically told to evaluate the methodology of the poll or research paper that they found and told to do this with a source that they found to be "exceptionally good".

[61] While these were part of the written terms of the assignment, Ivan ended up allowing students to present critiques of low-quality sources thus shifting the assignment to category C in practice.

Final evaluation. The approach taken to giving credit for in-class work at the first two cases further attests to the teachers' difficulty locating a mathematical exchange value for that aspect of the problems. At Phi University, the students' commitment to the debates and the quality of their presentations impressed both teachers deeply and so they decided that all of the students should receive full-credit for their work. Anne, at Rho University, did not assign any grade to the in-class portion of the assignment but planned on giving students credit next time because, similar to the teachers at Phi University, she was impressed with how well the students engaged with one another:

> I for sure would have some points or something attached to the in-class activity because I feel like the students should get something from having the discussions And I'm not sure whether they would just be participation points or whether there would be a quality aspect to it too, but I feel like with them doing so well with the activity in general for the class level and the level of anxiety they have with math, I feel they did exceptionally well and so I feel like that somehow needs to be reflected in their grades. (Anne, 4/13/14, Lines 180 - 186)

Anne's difficulty establishing what that "quality aspect" might look like is attested to by the one example she gave of an interaction that particularly pleased her:

> There was that one group today that thought that USA Today should be a credible source and I would not cite USA Today for anything probably because I think of it as a junk newspaper that they put in hotels. But the students recognized that they were missing stuff and I don't even remember what -- oh yeah, it was the question, they didn't include the question that was asked, and the students noticed that. And so I was like, 'that's good!' You're recognizing that what you thought was this really credible source was possibly not including information that would help people know that they are credible. (Anne, 4/13/14, Lines 237 - 243)

Notably, Anne did not suggest, either explicitly or implicitly by her goals for the class, that her evaluation would involve any assessment of the mathematical work of the students. The continued tension between mathematical and information problem solving work when it comes to situations that afford the opportunity for the practice of rational dependence is attested by the fact that Anne most squarely focused on her students' assessment of credibility even as she felt least equipped to lead their discussions.

Ivan, on the other hand, focused on the mathematics and only brought up the importance of credibility assessment in the service of that work. He said that he would grade students down if they failed to demonstrate knowledge of the mathematical content that had been covered in prior classes and that he would assess this by examining the students' slideshow presentations. Tim could have done the same with the students' presentations at Phi University but he evinced no desire to do so. Ivan also said that he would be looking carefully at the sources that the students used in his class even though the validity of sources was not an issue that he brought up during the presentations at any point. When interviewed, he characterized a questionable source as "not exactly what I would have chosen" (Ivan, 4/17/14, Line 59) and suggested that the use of such a source indicated that the students were not putting enough effort into the assignment:

> I'm going to look carefully at where their sources are. Why'd they even bother to pick numbers. [...] This is to me a very good indicator. What did they do? I imagine, Google "Murder Rate", the first thing that pops up, Huff Post, oh yeah, let's extract this, put this here. No thought, no critical appraisal of anything, just 'here are numbers, he wants numbers, we'll give him numbers'. (Ivan, 4/17/14, Lines 62 - 65)

The contrast between the case at Delta University and the other two cases is stark both in terms of in-class feedback and the determination of final grades. Ivan was much more critical of his students‘ mathematical work, discovering various student mistakes and misconceptions which he took as indicators that the students had not been listening in class or not putting enough effort into their information-seeking. He wished that he could “take these students just one group at a time and go over the presentation and say, okay what is this and try and figure out whether it is a misunderstanding or whether they just don’t care” (Ivan, 4/17/14, Lines 143 - 145). Anne and Tim had not caught many mistakes on the part of their students and, while they both felt that they could better manage and assess student work in future iterations of these problems, they generally felt pleased with the immediate outcomes both in terms of class engagement and student dispositions. One possible explanation for these different attitudes could be that the teachers’ had different ideas about what was at stake in the information-based problems, an idea that I explore in the next section.

Three Definitions of a Critical Sense

Cross-Case Observation 3.2: The teachers all prioritized the development of a critical sense, but the manner in which this sense manifested itself in the classroom varied dramatically.

While the teachers did not spend very much time addressing their students' information problem-solving process, they were nonetheless concerned with an important aspect of rational dependence, the development of a critical sense:

> If [the students] were forced to make those choices then maybe they would realize, suddenly have a much better appreciation for what the numbers mean, for what's going on here. (Tim, 8/14/13, Lines 37-39)
>
> So you can do anything you want with statistics, you can manipulate things or you could - You've just got to watch where you're getting the stuff too, because it might be deceiving when you get it. So, you do that. (Rich, Third Debate, First Day, Lines 232 - 235)
>
> So I want my students to be critical readers of things that talk about statistics and to know what should be included in there. (Anne, 4/3/14, Lines 222 - 223)
>
> First and foremost, being able to see numbers and graphs and tables and it should make sense. If it doesn't make sense then something should immediately click that says "something fishy going on here'. That critical sense, or appraisal. (Ivan, 4/17/2014, Lines 149-152)

In brief, all of these instructors wanted their students to think more critically about how numbers are used by others, particularly when those numbers are used to support an argument. However, this goal was conceptualized differently in each of the cases.

The primary difference between the approaches boiled down to the work required to critically assess sources. At Rho University, the students were encouraged to distrust sources that did not include targeted types of mathematical evidence such as correlation coefficients and confidence intervals; thus, the students' job was done once they had identified whether the mathematical content was present. The students at Phi University and Delta University, on the other hand, were asked to do mathematical work as part of their critique. At Phi University, the students needed to develop a statistical chart so that they would have a better understanding of what goes into the creation of similar charts that they might encounter in other contexts and avoid being fooled by those intended to mislead. The first problem at Delta University required that students formulate a critique of the sampling design of a particular poll or study; this suggests that students should be able to evaluate the quantitative claims that they encounter in the sense that they can recognize numbers that do not make sense and that they can go further and evaluate the mathematical arguments underlying those claims. Ivan's reaction to the students' work on the second problem further suggests this conception of a critical sense as his main feedback to those students had to do with whether they were taking the time to double-check their work after producing numbers that were suspect. Figure 6-2 provides a schematic representation of the approaches advocated by the different teachers as evidenced by their enactment of information-based problems.

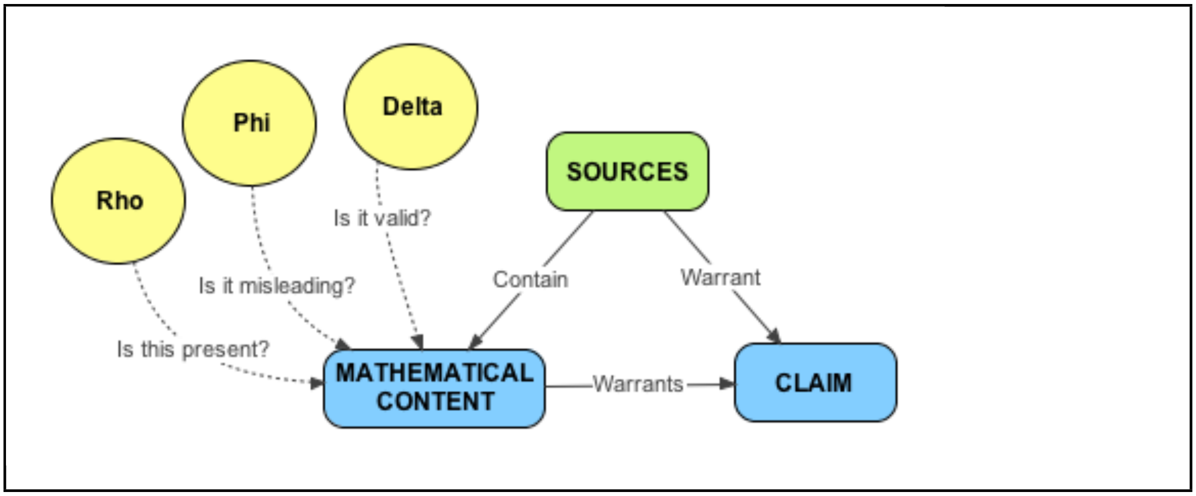

Figure 6-2. Different Ways of Being Critical of Quantitative Claims

A claim is at the center of this figure because the development of a critical sense was, in each case, characterized by the ability to critique quantitative claims. The differences all have to do with the way that this critique was accomplished. I have included a direct connector labeled 'warrants' between sources and claims because it is theoretically possible for an individual to accept or reject a claim based solely on the identity of the source even if this was not a perspective adopted in any of these three cases. These teachers all focused on the mathematical content but they each posed different questions about it. The students at Phi University were intended to be on the watch for mathematical content, largely in the form of charts and graphs, that might be intentionally misleading. The students at Rho University were supposed to watch for the presence of mathematical backing in the first place, with its absence constituting a good reason to be suspicious of the source. And the students at Delta University were supposed to interrogate the methodology used to make mathematical claims. It is notable that the students at

Phi and Delta Universities were encouraged to critique the mathematical content rather than simply checking for its presence. I further distinguish the approach at Phi University due to the presence of an implied mechanism for learning that was absent in the other case. Tim intended that those students would learn how to critique charts and graphs created by others by spending time creating their own. This demonstrates that the development of a critical stance is not so much a unitary goal but rather an umbrella that covers a number of different notions of what it means to critique quantitative claims and how those skills can be developed.

Information-Based Problems as Academic Tasks

The Role of Mathematics

Cross-Case Observation 4.1: The teachers each had different strategies for embedding mathematical tasks in the information-based problems.

The teachers with whom I collaborated were taking on a unique challenge when they decided to introduce information-based problems to their mathematics classroom. While they agreed that their students would benefit from an opportunity to engage in information problem solving, they had to continue to teach their students mathematics through these problems. I intentionally provided very little guidance on this front and the teachers at each of the three locations rose to the challenge in distinct ways. In order to describe the role that mathematical work played in these problems I describe the implemented problems as *academic tasks*, a term that encompasses both the perspective of the students as they try to meet the requirements of their assignment and the teachers as they manage the work of their students. I refer to academic tasks using the technical sense employed by Doyle and Carter (1984) where tasks are broadly understood as the "situational structures that organize and direct thought and action" (Doyle & Carter, 1984, p.130) in the classroom and more specifically as components of the curriculum that direct students to use *operations* on *resources* in order to achieve a *product* which is validated by a system of *accountability.* The different role of mathematics in each of the cases is clarified by articulating where it sits within the overarching academic task with respect to the component operations, resources, and product.

The mathematical aspect of the debates at Phi University was fairly circumscribed; it almost existed as a freestanding task of its own within the larger task of the debate. Tim had decided that his students would provide a statistical chart or diagram as part of their argument and that this would tie the problem into the unit on statistics that the class was in the process of covering. In particular, the students would have to create their own graphic rather than downloading it from elsewhere,

> I made the decision at some point that I didn't want them to just download graphics off the internet because I was worried that if they did that, they would download a bunch of fancy graphics that they didn't really quite comprehend and then it would be too much information for anybody in the audience to

> comprehend too. And so I figured the way around that is that I would have them do it, they read the section on how to present data, that's section two of that chapter, how to present data, ideas on how to present data, and so let's make them do it. I think that was a good decision. (Tim, 8/14/13, Lines 73 - 79)

I refer to the creation of graphics as an *almost* freestanding task because it still was predicated on some information-seeking in order to locate the sources containing the statistics that would inform the graphics. One way to put this is that the operations that were part of the debate task (for example, using a search engine, scanning search results) provided the resources that would be used for the mathematical task. I refer to the mathematical work as an academic task of its own because it theoretically could exist independently of its role in the debate as long as equivalent resources were made available. Conversely, a debate could have taken place without students having to make use of statistical diagrams. Nonetheless, by introducing this mathematical task, Tim was able to simultaneously avoid the introduction of graphics that could be too mathematically demanding for his students and to create a relatively well-defined mathematical task within the larger information problem-solving task which he would subsequently be in a better position to appraise as mathematical work.[62]

At Rho University, Anne also created a mathematical task that was part of a larger information problem-solving task, but in this case the mathematical work was necessary, at least as Anne conceived it, for the credibility assessment that constituted the larger task. As with the students at Phi University, the students at Rho were to submit a product that included the

[62] There was also the learning goal with respect to the development of a critical stance (see Cross-Case Observation 3.2), but here I am focusing on the teachers' creation and management of the academic task rather than the philosophical justification for the work.

mathematical work (i.e., the identification and interpretation of a correlation coefficient or confidence interval) alongside more ambiguous information problem-solving work (i.e., an assessment of the credibility of the different sources). It was also the case that the search for those mathematical markers could only occur after the students searched the internet in order to collect sources. Thus, we again have a situation where the information-seeking operations on the internet was used to provide resources for the students' mathematical work. There was one small but significant difference in the case of the second problem; those students were required to only collect sources that contained confidence intervals and so the mathematical operation of identifying a confidence interval became part of the information-seeking work. The subsequent classroom discussion constituted another part of the task, or perhaps a second task, which was much more ambiguous in terms of both its product and its operations. By breaking the information-based problems into two distinct activities, Anne was able to collect and evaluate concrete evidence of mathematical work with the written assignment and make that same mathematical work available as a resource for the students' discussions of credibility.

The first problem at Delta University was structurally similar to the mathematical sub-task at Phi University in that the students had to first find a source which they would then use as a resource for their mathematical work. The product at Delta University was the students' analysis of the sampling strategy used by poll or research article that they found. The second problem at Delta University was similar as well, but the use of sources was complicated by the fact that the students could not just pick a source and then analyze its contents. Instead, the students were held accountable for finding the data needed for their calculations which meant that their mathematical knowledge needed to mediate their information-seeking work in a way not seen in any of the other cases. By structuring the problems in this way, Ivan made the students' mathematical work the core of the product that they shared with the class. This was reflected in the type of feedback that Ivan provided for his students, he focused much more on the students' mathematical work than either of the other cases.[63]

These three teachers afforded me the opportunity to see some of the ways that a practicing mathematics teacher can dispense their obligation to teach the discipline to their students while assigning non-traditional information-based problems. In all three of the cases, the students had to engage in some initial information-seeking in order to collect sources that would serve as a resource for their mathematical work. In the first case, this work was its own mathematical task, contributing to the larger information problem-solving task but not strictly necessary for its completion. In the second case, the mathematical work was a distinct task but it also served as a resource for the following discussion. In the third case, the result of the mathematical work was actually the product of the information problem-solving task and the students' information-seeking and evaluation played a supporting role. In the next section, I address the role of the information problem-solving process in these problems.

[63] See Case-Specific Observation 3.2.

The Role of Information Problem-Solving

Cross-Case Observation 4.2: The teachers' development of the information-based problems resulted in fundamentally different opportunities for information problem-solving across the three cases.

Even though the teachers in these three cases conceptualized what they were teaching as information-based problems, they did not necessarily engage all aspects of the information problem solving process. As noted in the last section, the distinct feature of these problems when looked at as academic tasks is the use of the internet as a resource. Taking this perspective, the work involved in seeking out and evaluating information sources can be seen as operations available to the student.

Even though most of the problems began in the same way, students were asked to seek out a set number of relevant sources on the internet, an exception was the second problem at Delta University. In this problem, Ivan had the students seek out the quantitative data contained inside the information objects rather than the information objects themselves.[64] This type of information-seeking problem is more ambiguous and there is a greater risk of failure for the students since a) their success is predicated on locating the *correct* data and b) they need to apply mathematical operations to the data once they find it. The students were only held accountable for the numbers that they found if it appeared that those numbers had been misinterpreted,

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[64] See Cross-Case Observation 1.3.

otherwise the students did not have to account for how they sought out and chose the sources that they used. Both problems at Delta University were notable because the information-seeking aspect ended as soon as the initial resources were acquired. After that point, the students were engaged in an entirely mathematical task with the product being a presentation of their mathematical work.

The other students were made to engage more fully with the information problem-solving process but they were not held equally accountable for that work. At Phi University, the product of their task was a presentation that needed to contain arguments based on multiple sources, but the students did not need to give an account of how they found those sources or why the sources that they chose should be trusted above others. Tim wanted to give his students the opportunity to engage in the information problem-solving process but he only intended to give them feedback on their mathematical work. The problems at Rho University, on the other hand, provide an example of how a mathematics teacher can support their students' information-evaluation by making that process explicit in the classroom. Anne began this by asking students to write down what they thought of the credibility of their sources and extended it further by having the students discuss these credibility judgments in small groups.

Even if a teacher did not explicitly address part of the information problem-solving process, they still might hold a student responsible for it. Ivan, at Delta University had high expectations for his students when it came to their information seeking and he apparently saw how relevant it was for the mathematical tasks that they had been assigned. He complained that the students were not discriminating enough about the numbers that they had gathered,

> I do remember that the students who did very poorly quoted the Huffington Post. Not exactly the source I would have chosen and so I'm going to look carefully at where their sources are. Why'd they even bother to pick numbers. [...] This is to me a very good indicator. What did they do? I imagine, Google 'Murder Rate', the first thing that pops up, Huff Post, oh yeah, let's extract this, put this here. No thought, no critical appraisal of anything, just 'here are numbers, he wants numbers, we'll give him numbers'. I suspect, I'll look carefully. (Ivan, 4/17/14, Lines 59 - 65)

Ivan implies here that he would not accept the results of the students' mathematical work if the numbers did not come from a source that they had adequately "critically appraised" regardless of the validity of their mathematical work. He even emphasized that he will be looking carefully at the sources that his students used to support their claims, a step that was not taken by the teachers at either of the other sites. This highlights that the development of the academic task does not necessarily tell us all there is to know about the teachers' expectations of the students or the problem.

Information-Based Problems as Novel Tasks

Cross-Case Observation 4.3: The teachers' feedback and evaluation of student work reflect different ways of managing the tensions between the information seeking and mathematical aspects of these novel tasks.

For this cross-case observation, I draw on Herbst's (2003) argument for the existence of three tensions associated with the use of novel tasks in the mathematics classroom. Through his analysis of records of teaching, he found that each of the first three elements of Doyle's (1988) task framework are associated with a dilemma that emerges out of "the need for a teacher to reconcile *responsiveness* to what emerges from students' work on a task with *accountability* to an agenda for knowledge development" (Herbst, 2003, p. 198). First, the explicit product of a novel task may stand in for the most important knowledge at stake (for example, an opening argument in a debate may only serve as a vehicle for the evidence that students have compared multiple sources) which results in a tension between keeping the students' focus on that explicit product versus being responsive to the ideas that emerge from the students' ongoing work. Second, the operations of the task are associated with a tension between telling the students how they ought to interpret the directions that they have been given versus providing an opportunity for students to make sense of the demands of the task on their own. Finally, the resources of the task are associated with a tension between directing the students' attention to those features of the resources that are relevant to the specified task versus allowing the students to choose how they wish to use the resources available to them. In what follows, I look across those three elements of the mathematical and information problem solving tasks in order to make explicit the demands that these teachers had to manage as they introduced the information-based problems to their classrooms. In so doing, I take up Herbst's (2003) charge that these tensions be used to "look empathetically into the actions of teaching as those of people who must contend with complex, neither good or bad, demands placed on them by their position vis-à-vis students and subject matter" (Herbst, 2003, p. 232).

One of the most fascinating aspects of these cases is how explicitly the dilemmas are brought out by the structure of the tasks that the teachers' use. We have seen above how Tim, at Phi University, assigned a mathematical task that was somewhat independent from the larger information problem-solving task. By doing this, Tim could be said to be dealing with the tensions introduced by a novel task by essentially offering two tasks: the open-ended debate task where the students had flexibility over what evidence they chose to present and how they chose to present it, and the much more heavily-structured mathematical task where the students were directed to make a specified product using operations that they learned from the textbook. His students were allowed to determine what their own presentations would look like and to use whichever sources they saw fit in whatever manner they chose. This gave Tim the opportunity to be surprised by the students' work while still being able to hold the students accountable for the mathematics that they had been covering in class.

Anne navigated these tensions slightly differently. She included two distinct stages for the problems that she assigned: first the students had to complete a written assignment with a product that was highly specified and then the students used that product as a resource for a much more open-ended, in-class discussion with their peers. The written assignment served a similar function as the mathematical task in the first problem by providing Anne with a product that she could evaluate while still providing a venue for students to make their own choices about how to approach the sources they found. By making the assessment of credibility central to both of the tasks, Anne was introducing an activity for which she had no real model and the consequences of this could be seen in both the written and discussion portion of the information-based problems. For the written product, the students easily fulfilled the terms of the mathematical part of the assignment but many of the students failed to provide an adequate assessment of the credibility of their sources, at least in Anne's estimation. Many of the students simply recounted the institution to which the author belonged without providing any reason why that institution should be trusted more than another. For the second assignment, the open-ended discussion allowed the students to pleasantly surprise Anne as they exhibited much more sophisticated credibility assessment than their written work had suggested.[65]

At Delta University, Ivan only assigned a single task for each information-based problem and this task combined information-seeking and mathematical elements. Accordingly, his expectations were very unambiguous when it came to the mathematics that he wanted the

[65] See Case-Specific Observation 2.1.

students to present even though the mathematics was dependent on the students' initial information-seeking work. This is to say that Ivan never experienced the tensions that accompany the introduction of a novel task because he transformed the task into a more familiar one at least with respect to the work that the students' were expected to present in the classroom.

Critical Stance and Academic Tasks. I have taken two different perspectives on the work of the teachers up to this point. Earlier in the chapter, I observed that teachers in all three of the cases saw a critical stance as one of the major objectives of the information-based problems and described how their information-based problems reflected different conceptions of what constitutes a critical stance and how it is developed. I subsequently argued that the development and management of the information-based problems reflect different ways of managing the tensions caused by introducing novel information problem-solving tasks to a mathematics classroom. I believe that the synthesis of these approaches can help us come to a better understanding of how the information-based problems exist in the classroom and how they provide opportunities for the development of rational dependence. This is the case because the development of a critical stance, on the one hand, is the primary means through which these teachers approached the idea of how and when to depend on the knowledge of others in the classroom while, on the other hand, the evolution of the information-based problems as academic tasks reflects the manner in which the teachers were able to meet their obligations as mathematics instructors while still validating the goal behind the introduction of these novel tasks in the first place.

At Phi University, Tim gave students a mathematical task intended to help the students understand how people use numbers to forward their own agendas. This meant that Tim had not only given the students a task that he was in a position to guide and evaluate, he also would be able to help the students develop their ability to think critically about quantitative claims by giving them feedback on the task. This also meant that the larger information-seeking task served as motivation and context for the mathematical task rather than as an opportunity for the development of a critical stance in its own right. This perspective provides further insight into Tim's decision to give his students full-credit for their presentations and the fact that he wanted to give students credit for the amount of statistics that they used when he next assigned the information-based problem.[66] On the other hand, when I asked him about whether some of the groups performed particularly well despite his decision to give everybody the same amount of points for the assignment, he said that he admired those groups who were better able to rebut their opponents' arguments and suggested that he might give those students more credit next time. This last suggests that Tim was thinking of ways that the larger debate activity could serve as a venue for the development of a critical sense and not only as a way of fostering engagement.

In the case of Rho University, the assigned task was to seek out and evaluate the credibility of sources. By making students target correlation coefficients and confidence intervals as part of this task, Anne made the case for the role of mathematical knowledge when critically examining statistical or quantitative claims. While the initial written activity required that

[66] See Case-Specific Observation 1.6.

students use their mathematical knowledge in a very specific way as part of their examination of the credibility of sources, the discussion activity afforded Anne the opportunity to say more about why the identification of that mathematical content was important and to reassure herself that students were taking the intended lesson away from the information-based problems.

I have already noted that Ivan largely avoided the tensions inherent in introducing a novel information-seeking task to the classroom by turning it into a primarily mathematical task. This raises the question of whether Ivan saw the task as one that would help his students learn to better make use of the knowledge of others. This question is best answered by considering his two information-based problems separately. In the first instance, the students were required to critique the statistical methodology of a source and so the mathematical task could quite clearly be argued to be part of the information problem-solving process. Seen from this perspective, the students were being afforded the opportunity to practice an aspect of information-seeking, the aspect that fell most under Ivan’s area of expertise, and Ivan had the opportunity to give them feedback about whether their critique was well-founded. The second problem was less successful in this regard. Students needed to seek out and interpret quantitative data in order to accomplish the mathematical work required of them, but the task afforded them no opportunity to get feedback on whether they were effective in accomplishing that. In the end, the first problem that Ivan assigned, as well as the problems assigned in the other two cases, are set apart from this last problem because they all were able to isolate an aspect of information problem-solving process and transform it into a task that could be assessed and valued in the context of the mathematics classroom.

Summary of Chapter

I began this chapter by outlining the different ways that the teachers at the three sites provided feedback to their students and how they held students accountable for their work on the information-based problems. I found that the treatment of sources, in particular, was handled differently in each of the cases, a situation that has implications for whether students are given the opportunity to develop their rational dependence. While the information-based problems all required the students to seek out sources on the internet, not all of the problems held students accountable for how they chose their sources or whether their sources were high quality. I use the final chapter to explore what this means for the possibility to foster and observe rational dependence in the mathematics classroom.

In all of the cases, the teachers wanted their students to develop a critical stance with respect to the quantitative claims that they encounter outside of the classroom. These cases reveal that the nature and development of a critical stance can be viewed in a number of different ways and that this has implications for what tasks a teacher might choose in order to achieve this goal. At the same time, these teachers had to determine how to introduce tasks that would allow students to work with resources in the form of articles found on the internet over which the teachers had little control, while still producing work that satisfied their obligations as teachers of mathematics. The teachers were largely successful at accomplishing this balancing act and I further demonstrated how most of these academic tasks provided students with opportunities to develop their critical stance.

CHAPTER VII

Conclusion

This study was motivated by my desire to observe and analyze attempts to create opportunities for rational dependence in the mathematics classroom. In recent years, a number of mathematicians and reformers (Steen, 2001; Schoenfeld, 2001) have advocated for a shift towards quantitative literacy in mathematics instruction as a way of better preparing students for the mathematics that they will encounter in their everyday lives. I argued in chapter 2 that if this quantitative literacy instruction is to truly prepare students for mathematical claims outside of the classroom then that instruction would need to foster students' rational dependence, or their ability to depend with good reason on the expertise of others. This argument has been echoed by those information scientists (Grafstein, 2002; Kim & Sin, 2011) who suggest that the teaching of information problem solving benefits by being taught in the context of the academic disciplines that inform them. In my effort to observe what transpires when these wishes are granted, I identified quantitative literacy-focused classrooms at several undergraduate institutions and observed as the instructors introduced information-based problems to the curriculum. I conducted a multiple case analysis (Stake, 2013) at three of these sites in order to answer the following research questions:

1. How do undergraduate students in a quantitative literacy-focused course work with information-based problems introduced by their teacher? How do they use their content knowledge when working on those problems?

2. How does the teacher of the quantitative literacy-focused course work with students who are asked to solve information-based problems?

3. How are information-based problems affected by their introduction into a quantitative literacy-focused course?

These questions helped me account for how the information-based problems were enacted as academic tasks in the classroom environment: the problems, the students' work on the problems, and the teachers' management of that student work. Capturing a broad picture of these information problem-solving tasks was important because my goal has been to describe the circumstances under which rational dependence is supported in working classrooms rather than in a lab environment.[67] The analysis suggests that when mathematics teachers introduce information-based problems into their classrooms, they may end up limiting opportunities for rational dependence in order to maintain a focus on the tasks' mathematical value. Fortunately, the three cases encompassed a range of tasks which allowed me to more fully describe the features of the problems that limit or afford the practice of rational dependence.

[67] For work along the latter lines, see McCrory Wallace et al., 2000.

In what follows, I revisit the research questions that were the object of this study and summarize the answers offered by the multiple case analysis. As part of my response to the third research question, I present a scheme for assessing the potential for rational dependence in the academic tasks that were the object of my analysis. That scheme helps form the basis for a summative statement about what the differences between these tasks might mean for the opportunity to practice rational dependence. Next I review some of the implications of this work for research into disciplinary literacy and information problem-solving along with the practical implications for mathematics instruction in quantitative literacy-focused classrooms. Finally, I describe possible future research questions that emerged from this study.

Revisiting the Research Questions

1. How do undergraduate students in a quantitative literacy-focused course work with information-based problems introduced by their teacher? How do they use their content knowledge when working on those problems?

Advocates for the introduction of information-based problems to the classroom suggest that these problems will afford students the opportunity to seek out the knowledge of others and to make reasoned judgments about which sources to trust. In reality, I found that students did not normally provide reasons for their choice of sources even if, as with the debates at Phi

University, they were called on to defend an argument that they made with those sources. I also found that this was exacerbated when students were only made accountable for data within a source rather than the source itself, as when the students at Delta University were asked to calculate conditional probabilities but were not required to say anything about why they chose particular sources of data for finding those probabilities. Students only provided explicit credibility arguments when they were required to do so and their arguments tended to remain relatively unsophisticated, in the sense that they would only name the source without giving any further reason for trusting that source, unless they were made to discuss the credibility of the sources with their peers. In fact, this leads to one of the most encouraging outcomes of this work for those who advocate for information-based problems, small group discussions in which students came together to decide which sources were the most credible succeeded in eliciting wide-ranging and deep conversations about credibility.

The students' mathematical knowledge also influenced their opportunities to practice rational dependence in several different ways. First, the students avoided using sources that contained mathematical content that they were not able to understand. This hesitancy has the potential to undercut the students' willingness to rely on intellectual authorities: some of the sources that are generally considered most credible, academic studies in particular, were of limited use to those students because they did not feel equipped to make an argument with them. Second, when students were encouraged to treat particular pieces of mathematical content as markers of credibility, it led some of them to make decisions about the credibility of those sources without attending to the arguments that the sources contained. Third, the students were only held accountable for their mathematical work when the product of the assigned task was mathematical (for example, the evaluation of a sampling strategy or a conditional probability); when the instructor prioritized more general information problem-solving work as an outcome (for example, making an opening argument in a debate, assessing the credibility of sources), the students' mathematical work tended to either be trivial or left unevaluated.

2. How does the teacher of the quantitative literacy-focused course work with students who are asked to solve information-based problems?

My analysis of the work of the teachers in these quantitative literacy-focused courses suggests that they had different conceptions of how students ought to benefit from the information-based problems and that these different conceptions did not always support the students' practice of rational dependence. These teachers all spoke about the importance of source credibility in a way that echoed several elements of Gal's (2002) framework for statistical literacy: the students' development of a critical sense that allows them to interrogate statistical claims and a disposition to make use of that critical sense. The teachers steered students to critique the mathematical content of sources as a way of determining their credibility rather than using other canonical markers of credibility such as credentials, institutional standing, or whether the sources were corroborated by others (Rieh & Hilligoss, 2008). This focus on mathematics is natural in a mathematics classroom, but it can also interfere with the practice of rational dependence. A teacher directing students to attend to specific mathematical content may end up casting unwarranted doubt on those information sources that lack that content.

Further, the meaning, development, and practice of this critical sense differed across the three cases and that these differences influenced the extent to which students had opportunities to practice rational dependence. While all of the teachers kept the focus on mathematical content, their approach varied from simply checking for the presence of said content, determining whether a mathematical claim was valid, or assessing whether the source was actually being misleading in how they represented the mathematics involved. The first approach merely suggests that a source of information may be irresponsible by leaving out grounds for a quantitative claim while the latter is much more evocative of rational dependence since it suggests that one may need to assess the context in which a claim is being made and who is making that claim in order to determine whether there are good reasons to believe it. In the next section, I discuss how a consideration of this feature of the implementation of the implementation of an information-based problem may be used to assess the opportunities it holds for rational dependence.

Interestingly, there was a roughly inverse relationship between the attention these teachers paid to the mathematical work of the students and the attention that they were able to pay to the students' assessment of the credibility of their sources. The students at Delta University were given tasks that called for mathematical products and Ivan attended to student misconceptions throughout, sometimes halting students in mid-presentation in order to clarify the students' error or the misunderstanding of a statistic taken out of context. Anne, at Rho University, focused instead on various indicators of credibility, albeit primarily on the presence of correlation coefficients and confidence intervals, to the exclusion of any discussion of whether students were properly interpreting the quantitative claims they encountered. I do not claim that there is anything inevitable about the tendency of these teachers to either focus on mathematical work or credibility assessment but not both. I argue, instead, that the existence of these different foci on the part of the teachers suggests that the information-based problems present a challenge to a mathematics teacher who is responsible for teaching the content. A mathematics teacher must balance the goals of the information-based problem with their need to teach mathematics and the cases in this study demonstrate that there are a number of ways that this balance can be achieved. Unfortunately, the resolution often comes at a cost to either the mathematics or the opportunities to engage with information problem-solving process.

3. What form do the information-based problems take that are introduced into a quantitative literacy-focused course?

While the three cases examined in this dissertation establish that the use of information-based problems can create opportunities for students to work towards rational dependence in a quantitative literacy-focused mathematics classroom, the limits of this work can be understood as the product of constraints imposed by the teachers' need to honor the classroom's didactical contract. For example, a teacher can introduce an information-based problem and be able to claim that they are fulfilling their role as a mathematics teacher, if they can also provide evidence that their students have had the opportunity to learn something mathematical; otherwise it might reasonably be argued that there was no reason to introduce the problem to a mathematics course. Each of the teachers came up with different ways of resolving this dilemma, but those choices also had implications for their students' opportunities to practice rational dependence. As such, these choices provide the foundation for a framework that I use to describe how features of the information-based problems can afford students opportunities to practice rational dependence.

What follows is the beginning of a framework for assessing the opportunities for rational dependence that information-based problems can afford in the context of a quantitative literacy-focused mathematics course. This framework presents features of the problems that each afford or restrict those opportunities: the way that students are required to account for their use of sources,[68] what it means for students to take a critical stance towards quantitative claims,[69] and the relationship between the assessment of those quantitative claims and information problem-solving in the context of the academic task.[70] After describing the resulting framework (see Figure 7-1) in more detail, I discuss how such a scheme may be a resource for research and pedagogical purposes.

[68] See Cross-Case Observation 5.1.

[69] See Cross-Case Observation 5.2.

[70] See Cross-Case Observations 6.1 and 6.2.

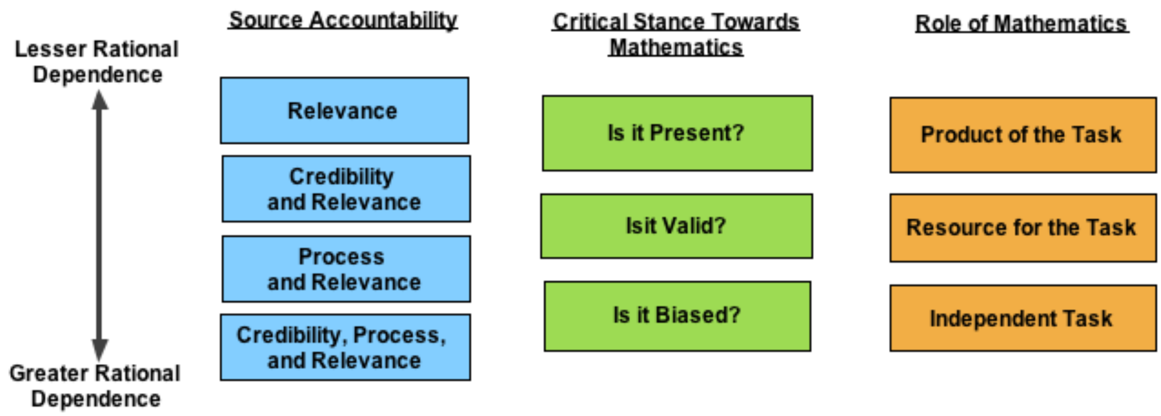

Figure 7-1. Opportunities for Rational Dependence in the Quantitative Literacy-Focused Classroom

First, I have observed that the information-based problems, as specified by these teachers, differed with respect to the way in which the students were held accountable for the sources that they found. This feature appears as the leftmost column in Figure 7-1 and contains four categories that I have ordered based on the degree to which the feature presents opportunities for rational dependence. The least conducive to rational dependence are those problems for which students are held accountable for finding sources that are *relevant* and nothing more. For example, students participating in the debates at Phi University did not need to say anything about the quality of their sources nor did they have to account for the process through which they decided on those sources.[71] Looking down the leftmost column, one can see that problems that

[71] See Cross-Case Observation 5.1.

require students to account for the process through which they assessed sources are ranked as more conducive to rational dependence than those problems that hold students accountable for the quality of the sources. This is because any consideration of the process of assessment forces participants to think about what makes one source more credible than another, while that process can be elided even when students are held accountable for whether the sources are credible or not. Ideally, an information-based problem would require students to reflect on how they chose their sources while holding them accountable for whether those choices were well-reasoned.

In the second column of Figure 7-1, I refer to the manner in which the teacher intends their students to take a critical stance towards mathematical claims. As these were mathematics classes, the students were expected to be critical of mathematical content in particular, but this expectation translated to different work in each case: the students were encouraged to watch for biased mathematical content, assess the validity of the mathematical argument supporting the claims, or check whether the claims were backed by a mathematical argument in the first place. The presence of mathematical content is positioned as least conducive to rational dependence in the figure because it does not say anything consequential about either the validity of the arguments put forward by the source or whether the source's claims are supported by a broader epistemic community. I positioned the validity of the mathematical argument used by a source as more conducive to rational dependence because answering that question gives a better sense of whether the sources' claims are supported. However, that approach fails to account for the possibility that the author of an article might present a mathematically invalid argument due to their lack of mathematical knowledge even if the claim is held to be true by those with expertise in the area. Indeed, it is commonly held that popular science reporting falls prey to this exact problem. The approach most consistent with the development of rational dependence is to determine whether a source has a bias and whether it represents a particular point-of-view with respect to the position it advocates. Asking students to specify the larger community to which a source owes its allegiance will better position the students to make informed decisions about whom to trust.

Finally, in the third column of Figure 7-1, I refer to the role of mathematics in these information-based problems. This role may be more or less consistent with the manner in which rational dependence arises in out-of-school contexts where the goal is to educate oneself more broadly about the matter in question rather than staking a claim on an article of mathematical knowledge. I position problems where the mathematical task is independent as the most consistent with rational dependence since this attitude treats mathematics as one tool among many. It is less consistent with rational dependence to give the identification of mathematical content a central role in credibility assessment, as occurred to a degree at Rho University in the way that the teacher prioritized the correlation coefficient, since this is not consistent with the way that credibility must be assessed in general. The role of mathematics that is least consistent with the practice of rational dependence is as the product of the task since this prioritizes mathematical work over any consideration of credibility at all.

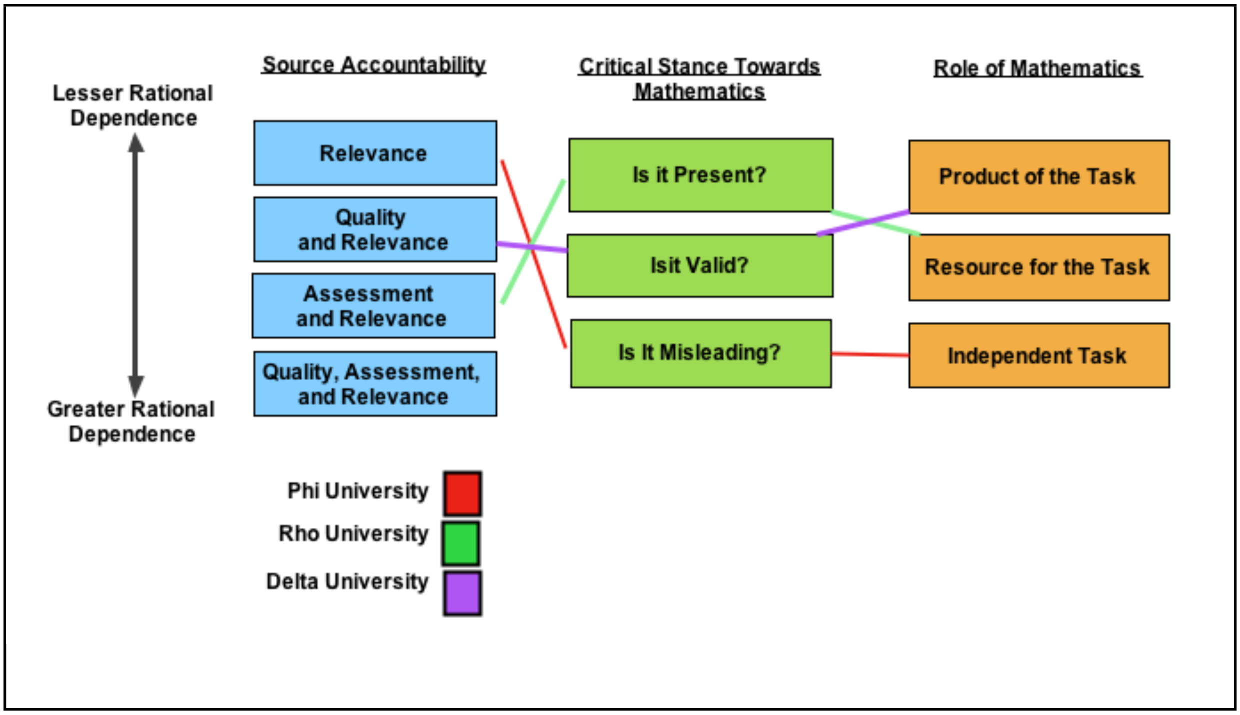

Figure 7-2. Opportunities for Rational Dependence in Each of the Three Cases

The three cases analyzed in this study are assessed according to these features in Figure 7-2. There are two important aspects of this assessment scheme as it presently stands. First, none of the cases are clearly the best or the worst with respect to rational dependence. For example, while the students at Phi University were encouraged to look across their sources using more than just the mathematics at play and were also encouraged to think about whether an author might be using statistics to mislead their readers, these students almost never defended their choice of sources and were never called to do so by their teachers. Second, there were some fairly serious limitations to the practice of rational dependence that applied to all of three of the cases. None of the students in any of the cases were held responsible for both the quality of the sources that they found and the way in which they assessed that quality. Further, the second two features only apply to mathematical content. This points to an unavoidable feature of information-based problems in mathematics classrooms: they must have mathematical value. This is as it should be, of course, but the assessment scheme suggests that this obligation to the mathematical content of the course can be met in a variety of ways and that the problems might be able to be adjusted in order to provide students with a greater opportunity to engage in rational dependence.

What Could Rational Dependence Look Like in the Mathematics Classroom?

In the previous section, I introduced an assessment scheme that partially characterizes the extent to which the information problem-solving tasks can afford students the opportunity to practice rational dependence. Now I am in a better position to sketch what a task might look like that maximizes those opportunities while maintaining its place in the quantitative literacy-focused classroom.

Credibility, process, and relevance. There were no cases where students were held responsible for both the credibility of their sources and for the process through which they assessed that credibility. The advantages of combining approaches can be illustrated by considering how it would work if the students at Rho University, who were asked to describe how they chose their sources as part of their written assignment, were also held accountable for the credibility of their sources. In particular, it would not be very practical for the teacher to assess every source individually, both because the teacher might not have enough information to be able to evaluate all of the sources and because source-specific evaluations would have more limited applicability for the students. The obvious solution then is for the evaluation to focus on the information-seeking process rather than the results of that process. Notably, Anne, the teacher at Rho University, never suggested critiquing the way in which her students sought out and decided between their sources. Instead, she spoke about her desire to be a better facilitator of the subsequent discussion and implied that the encouragement of a critical sense was a sufficient end in itself. This is also consistent with her observation that the students did not appear to have much trouble seeking out sources. I do not point out this attitude on Anne's part in order to be critical of her instruction. Rather, the fact that an experienced mathematics teacher did not see the credibility assessment process as something that she might actively critique suggests how important it is to scaffold this aspect of instruction for mathematics teachers. I return to the more practical question of how teachers might be supported in teaching such information-based problem when I discuss further implications of this dissertation study at the end of the chapter.

Are the quantitative claims biased? Out of the three ways of interrogating a quantitative claim represented by the cases in this study, the question of whether a quantitative claim is biased points to the source of the claim most directly and, hence, is most consonant with the practice of rational dependence. The question is partially a mathematical one in the sense that students could, as was the case for the debates at Phi University, look at a chart, a graph, or even a mathematical argument in order to determine whether it has been presented in a misleading way. However, it is also a broader question about the source of the claim and the communities to which that source belongs. After all, in order to definitively say whether bias exists, a student would have to look for corroboration from others and find out what outstanding debates regarding the issue in question are recognized by those with intellectual authority. That task, as specified, is a virtual impossibility even for teachers who have as much freedom in their use of curricula as those who took part in my study; the resources required would be too extensive and the object of the task would be too ambiguous. However, the small-group discussions about the relative credibility of sources carried out at Rho University suggest a way in which students could move in the direction of that sort of open-ended exploration while being held accountable for their work by the teacher. In that case, each student brought multiple sources to the table, as well as their own experience, and this led to wide-ranging discussions in which the students and teacher were able to talk about the mathematical backing for their sources' quantitative claims, possible sources of bias, and the authority of the backing institutions. This sharing of background knowledge between students and students, and students and teacher was a distinctive feature of the activity at Rho University that did not occur at either of the other two locations.

An independent mathematical task. The role of the mathematical task can also be used to describe how consonant the implementation of an information-based problem is with the practice of rational dependence. This means that the mathematical product of the task has not supplanted the information problem-solving work but it has not been short-changed either. In order to better explain why this approach may afford the best opportunity for the practice of rational dependence, I revisit Tim's debate activity at Phi University. By asking his students to create a statistical chart or graph, Tim introduced a mathematical task that could reasonably be conceived of as a genuine piece of a larger information problem-solving task. This meant that the problem could be justified as part of the work of a mathematics class without granting the mathematical work a significance in the information problem-solving task that it would not actually possess in the real world analogue of the problem.

This assessment scheme is not meant to be definitive, rather it is suggestive of the sort of framework that an observer can use to determine what sort of opportunities for rational dependence are offered by a given academic task. Further, none of the teachers were explicit about how they felt that their students' accountability for sources ought to be treated, rather this was a feature of the phenomenon that only emerged through the implementation of the tasks. Similarly, only one of the teachers was explicit about how and why they expected students to take a critical stance towards mathematical claims. As these features appear to largely emerge from the implementation of the information-based problem in the classroom, this assessment framework can help the researcher and the teacher think deliberately about whether they want their students to be able to have opportunities for rational dependence and how they plan to make that happen.

Implications for Research

The results of this cross-case analysis have implications for anybody who has an interest in what happens when an instructor attempts to broaden the scope of student work by introducing information-based problems to the classroom. As such, it is of particular interest to those in the information sciences who have advocated that this type of work should occur in classrooms where content is taught (Grafstein, 2002; Kim & Sin, 2011). Rational dependence, however, can be thought of in a broader sense inasmuch as more knowledgeable others do not necessarily have to be experts in a discipline, rather they could simply be more knowledgeable peers. From this perspective, the concept of rational dependence could serve as a useful lens for studying how students collaborate with one another in the mathematics classroom.

Research on Information Problem-Solving

This study has implications for research on information problem-solving as it provides an opportunity to see how students engage with an information-based problem when such a problem is introduced in a content classroom rather than through a library intervention or in a lab setting. Tools such as the SEEK Web Tutor (Wiley et al., 2009) and other uses of information-based problems in controlled settings (Kienhues, Stadtler, & Bromme, 2011) have contributed to our understanding of what students are capable of when given computer-assisted support and suggest some of the ways that a teacher using an information-based problem could help their students seek out and evaluate information sources. However, research carried out in such a setting cannot account for the pressures that a working teacher operates under and the present work provides some examples of how those pressures can influence the implementation of information-based problems.

This study both provides evidence that practicing teachers may modify information-based problems in order to satisfy their obligations as professionals and that the problems that they end up using may provide quite different opportunities for the practice of rational dependence than those generally advocated by information scientists. This work strongly suggests that further research into the use of information-based problems in such settings ought to be a collaborative endeavor with those who are more familiar with the disciplines in question. This could take the form of a design research project where the information scientist helps the mathematics (or science or history) teacher reflect on the information-seeking strategies and heuristics (Rieh & Danielson, 2007) that they themselves use when seeking out and evaluating information. The observations presented in this study provide some direction for choosing activity structures that may be associated with more opportunities for the practice of rational dependence: in particular, the experience at Rho University suggests that the use of small group conversations can support consideration of the relative credibility of sources.

Further, by locating these problems in a mathematics classroom, this work suggests ways that the practice of rational dependence, along with information literacy writ large, could be better delineated with respect to the role of the discipline. While work on information literacy primarily focuses on the process of seeking out information from credible sources (Eisenberg & Berkowitz, 2001), there has been little work on the specifics of how disciplinary knowledge is involved in that process. The classroom environment provides greater opportunity for capturing those details. For example, at Delta University I observed that several groups of students were able to locate the information that they needed for calculating probabilities but their use of that information was flawed because they made mathematical mistakes when interpreting the information. This suggests an important role for content knowledge at the extraction stage of the information problem-solving process. This has further implications for the role of rational dependence, even if it is necessary at times to depend on the knowledge of others, the rationality that one must employ is not limited to making judgments about where to find and whether to trust sources of information; it is also necessary for coming to a proper understanding of what is being communicated by information sources in the first place.

Research on Disciplinary Literacy Instruction

My analysis of these information-based problems suggest some ways that researchers could work with mathematics instructors to be more responsive to Norris's (1995) *learning to live with expertise* approach to disciplinary literacy. As a reminder, Norris argued that "students need to acquire the disposition to question, and to seek other opinions on scientific issues that matter in their lives and their community" (Norris, 1995, p.215). Crucially, he went on to argue that students' skepticism should be directed towards the credibility of the experts and not the actual evidence supporting their claims if only because it would be unlikely for the students to be in a position to judge that evidence. The cases studied as part of this dissertation study suggest that it is no easy thing to get students to seriously consider the credibility of sources that they encounter in a deep way.

The experience at Rho University suggests that students might be better able to discuss the credibility of experts if they are given the opportunity to discuss sources with one another and if they are forced to decide collectively on which sources to trust. While the discussions at Rho were limited due to the focus on particular pieces of mathematical knowledge, the assessment scheme developed earlier in this chapter can be used to help think about features that would make a task better represent the type of inquiry for which Norris is advocating while still fitting into the curriculum. More specifically, I argued at the outset of this study that the standard approach to conceptualizing quantitative literacy and its instruction was problematic because it did not account for the importance of rational dependence. I brought up a recently published textbook on the topic called *Case Studies for Quantitative Reasoning* (Madison, Boersma, Diefenderfer, & Dingman, 2009). The textbook consists of a series of 'cases' in which a student is confronted with one or more quantitative claims embedded in a newspaper editorial, advertising text or other real life text. While these types of problems provide some scope for developing students' fundamental and derived mathematical literacy (Moje, 2007), at least if the students' work is properly supported, they only demand analysis of the text at hand and do not require or even encourage the student to seek out other information sources.

An alternative approach could include a task wherein the students *start* with just such an editorial but where they work with the teacher to identify the relevant epistemic community and then work to determine whether there are others in the epistemic community who corroborate the claims that the editorial contains. This could inform a debate about the validity of those claims, but the experience at Phi University suggests that such a debate may simply result in a series of prepared speeches without any real dialogue occurring. Instead, the teacher could do as suggested above and have the students discuss the grounds for taking one side or the other and come to a collective final decision. After having generated and piloted a number of these scenarios, disciplinary literacy researchers could support their implementation on a broader basis and use that as an opportunity to study the process through which students come to trust in the expertise of others.

Research on Mathematics Instruction and Learning

This dissertation has implications for research on how to create opportunities for rational dependence in the classroom and these could be harnessed in the form of a design experiment (Cobb et al., 2003). By making use of the assessment tool provided in the last chapter, researchers could collaborate with teachers to develop tasks intended to maximize opportunities for rational dependence: tasks that make students accountable for the process that they use for locating and assessing the credibility of sources, pointing students towards the larger disciplinary community to which sources belong, and giving students the opportunity to use their mathematical knowledge as one among many tools for assessing the credibility of sources. The instructor in such a design experiment would also need to be supported both by helping them understand what it means for students to engage in rational dependence and by letting them know which activity structures are better suited to providing those opportunities. These last two aspects of the project are particularly important as this study has shown that, in the absence of that sort of intervention, it is easy for teachers to shift their focus to other outcomes such as student engagement. This could also provide an opportunity for greater scaffolding for the students. For example, in one of my interviews with Ivan at Delta University, we discussed the possibility of presenting students in his next term with anonymized versions of presentations made by students in earlier terms. The new students would be asked to identify mathematical mistakes and to interrogate Ivan about where the information came from. This would serve as a model for their own work.

This dissertation has been focused on the introduction of information-based problems as an opportunity for students to practice rational dependence in the mathematics classroom, but there are other conditions under which students in mathematics classes can and sometimes must depend on the knowledge of others and the concept of rational dependence may help clarify those situations as well. For example, the data from this study includes an episode at Delta

University where the presenting students made an error when making use of some statistics that they had found on the internet: they took the percentage of white residents in a county to be the complement of the percentage of black residents thus failing to account for the presence of other races. A fellow student brought the error to their attention. While this is a fairly straightforward transaction, it is significant that the student who noticed the error was not an intellectual authority and the students presenting at the board were not seeking out an authority. Rather, it was the act of sharing their work with peers, in enough detail so that such an error could be recognized, that allowed the classmates to help one another in that way. This incident suggests a facet of rational dependence that is not simply about making reasoned decisions about whom to trust, it is about making reasoned decisions about how to share one's work with others. Future studies could focus on how opportunities for such sharing can be provided, how the disposition to share can be fostered, and whether such sharing leads to improved learning outcomes.

Limitations of the Work

While this study provides a starting point for looking at the challenges involved in the introduction of information-based problems into the mathematics classroom, there were a number of limitations that point to ways that this work could be extended in the future. In enumerating these limitations, I will address the supports provided for the teachers' work and the type of data collected.

All of the participating teachers were briefed on the idea of rational dependence and were initially able to describe the concept in their own words. However, the idea that students were to be supported in making reasoned choices about their sources was not revisited aggressively during the development of the information-based problems nor was the teachers' understanding of the concept assessed in any systematic way. In addition to the lack of assessment, the teachers were not provided with any instruction about how to best provide their students with opportunities for rational dependence. On the one hand, these limitations are a feature of the study inasmuch as it is intended as a naturalistic portrait of how mathematics teachers might take up information-based problems in an environment where such problems are encouraged. Taking this perspective, I was taking on a role similar to those researchers who were examining classroom-level work for the California Study of Elementary Mathematics (Peterson, 1990) where they examined the impact of state level mathematics curriculum policies on classroom instruction. Crucially, the question of whether or not the teachers took up the reform agenda was part of the inquiry. On the other hand, it would be useful to distinguish whether the lack of opportunities for rational dependence in the three cases are primarily due to a lack of take-up of the concept in first place or whether the competing demands of mathematics teaching are entirely the source of those limitations. In particular, the answer to this question would help dictate the form that supports for teaching with information-based problems should take.

The data collection for this work was very limited with respect to the students. I was unable to directly observe how students went about searching for information in response to the information-based problems and I was only able to collect a limited number of first- and second-hand reports, from the teaching assistants at Phi University and several of the students at Rho University. Data of that sort, whether collected through direct observations of students while they spent time seeking sources for their assignments or through the use of diaries, could help corroborate and provide more detail about the challenges the students faced as they were seeking out information, particularly with respect to the way that they were able to or not able to make use of their mathematical knowledge. This would also provide an opportunity to better explore the connection between quantitative literacy and other disciplinary literacies, as more data on students' information-seeking could be used to identify if and when students draw on their knowledge from other fields.

Questions Meriting Further Research

While this study has provided several illustrations of what it looks like when information-based problems are introduced to a mathematics class and provides examples of some of the limited opportunities for rational dependence that can arise under those conditions, I would judge that it has raised many more questions than it has resolved. For example:

A) What do students really learn about the content when they work with an information-based problem? Does evaluating the work of others force students to think more deeply about the mathematical concepts at play so that they can render an informed verdict on what they are reading or does it allow them to avoid the difficult work of unpacking a mathematical argument because they can rely on the verdict of others? The teacher's work documented throughout the three cases gave evidence of a struggle to give a mathematical value to problems that called on students to rely on the knowledge of others. This dilemma could be directly addressed by further work that looks more closely at how the information-based problems cohere with the course curriculum.

B) Is there space for engagement with information-based problems in mathematics classrooms other than those focused on the teaching of quantitative literacy? Grafstein (2002) along with Kim and Sin (2011) argue that this type of work should occur in all content classrooms but my study has not shed any light on what this would look like in, for example, an algebra or geometry course at the high school level. Are there general guidelines for how such work might be introduced or must the form and rationale always be worked out on a case-by-case basis? While the introduction of information-based problems to other mathematics courses would be responsive to the same calls for a greater focus on disciplinary literacy and information literacy that justified the present study, the dilemmas encountered by the teachers would undoubtedly be more pronounced in a classroom with more specified and demanding content goals. This does not, however, mean that there is no room for information-based problems in those contexts. In fact, as I outlined above, the findings from this study may help contribute to the development of problems that include the necessary mathematical content without sacrificing opportunities for rational dependence.

C) I have identified several features of information-based problems that may be used to better identify the opportunities for rational dependence. However, my study has shown that these opportunities may still go unrealized in the classroom if the teacher fails to capitalize on them. This gives rise to an important class of questions that I left unexplored: How can a teacher be educated to make the best use of information-based problems? Should the focus of such education be on what it means for a student to achieve rational dependence or is it better directed towards more practical considerations how to help student seek out and evaluate the expertise of others? I noted above that one of the limitations of the present study is that there was not enough evidence that the teachers fully understood the concept of rational dependence. This suggests the importance of further supports that better articulate the concept and keep it at the forefront of the teachers' work. For example, the teachers could be provided with examples of what it looks like when students provide justification for their choice of sources or, perhaps even more helpfully, they can be given examples of work in which students come to false conclusions because they do not question the provenance of a source.

D) What would it mean to implement a similar study in science, social studies, or language arts classrooms? While science is the obvious candidate as much of the discussion about relying on the knowledge of others comes out of work on scientific literacy, there is no a priori reason that arguments for the importance of rational dependence should not apply equally well to other subject areas. Crucially, a focus on other subject areas helps highlight that the examination of sources is really about access to an epistemic community rather than comparing sources on a case-by-case basis. This can best be illustrated by observing that there are many situations in which experts disagree and where there is no clear consensus -- outstanding philosophical and ethical debates provide many examples of this sort. Regardless of which subject is under consideration, the larger question is whether my cross-case observations would necessarily apply to other disciplines, or whether and how they could be further generalized in order to do so.

Final Thoughts

Mathematics problems that leverage topics ripped from the headlines are immediately compelling to many teachers and administrators: they are realistic, they are motivating, they provide a means of reaching students who are uninterested in problems that are more abstract. Nonetheless, I hope that I have successfully complicated the idea that merely providing these contextualized problems is enough if one truly wants to prepare students for the quantitative claims that they may encounter in their everyday lives. While teachers may be asked to provide opportunities for their students to learn how to draw from and live with the expertise of others, creating such opportunities is easier said than done. If students are to have the opportunity to recognize when they need to count on the knowledge of others and be able to distinguish who are the true authorities, then teachers need to provide tasks that hold students accountable for the choices that they make. My dissertation study provides many examples of how it is not a simple matter for a mathematics teacher to create tasks where students can practice rational dependence, seemingly small variations on the structure of a task can have a great influence on whether and how students draw on the expertise of others.

My analysis of the dilemmas faced by mathematics instructors who wish to create opportunities for their students' rational dependence is not intended to dissuade teachers from using information-based problems that bring students into contact with real-life quantitative claims nor to discourage the introduction of information problem-solving to mathematical tasks. Rather, it suggests that pedagogical choices must be made thoughtfully and deliberately if we are to meet our intended goals.

Appendix A: Semi-Structured Interview Format for Teaching Assistants at Phi University

1. Your general impression of that activity and how it fit into the rest of the course as you saw it? Did you have any particular thoughts about it?

2. I'm interested in how students can and can't be supported in looking for information outside of the classroom, like looking online and that sort of thing. Did you get the chance to see them doing any of that sort of activity?

3. Do you remember any particular frustrations that were voiced? Or types of problems beyond just not knowing where to look?

4. Were there any people that seemed to be doing better with that part of the assignment than others? If so, what were they doing differently?

5. Do you think it would be a good idea to do this activity next time? Why or why not?

6. What you think could be done differently or in addition to what was already done that could improve the activity?

7. What are your thoughts on the class as a whole, the good and the bad of it or what might be changed?

Appendix B: First Information-Based Problem at Rho University

Math 110: Assignment 2

Name____

Due date: Tuesday, January 28

Points: 10 points

For your second assignment, you will be finding online resources (articles, blog posts) related to claims that have been widely reported in the media. You'll look for what statistical evidence (if any) is presented in the articles or posts, and think about whether the argument is convincing. If possible, you should try to find articles representing both sides of the argument.

Choose one of the following claims:

- Vaccines cause autism.
- Listening to classical music causes people to perform better on math tests.

Find three online resources (for example, newspaper or journal articles, blog posts). For each article/post, do the following:

1. Write down the author of the piece <u>and</u> why they are credible. (The author could be an organization like the American Academy of Pediatrics.)

2. Describe whether the article found a correlation that is used to support the claim and, if so, describe the strength and nature of that correlation. (Do they say "correlation"? If so, do they provide the r value? Do they indicate whether the correlation is positive or negative?)

Type your answers to the questions above (see the example below) and turn this in on January 28. (If you miss class that day, please e-mail your typed answers to your instructor.)

We will be using the information you found for an in-class activity on January 28. You will discuss -- and possibly argue -- about the findings from your articles with your classmates. It would help if you can have the articles available (electronically or print-outs) during class.

Example (using a different topic than the options listed above)
Claim: Strong correlation between SAT writing score and length of essay

1. Article: SAT Essay Test Rewards Length and Ignores Errors by Michael Winerip, New York Times, May 4, 2005 (http://www.nytimes.com/2005/05/04/education/04education.html)
   This is a credible source because Michael Winerip was an Education reporter at the New York Times for more than ten years at the time this article was published. He is quoting an MIT professor, who collected data himself and ran correlations.

2. The author quotes a professor from MIT as saying how "complete" the correlation is (though no r value is reported) and that he has never found a quantifiable predictor in 25 years of grading that was as strong as this. It is clear from the article that it is believed that the length of essay determines (causes) the scores on the SAT writing test. The MIT professor recommends that students just write a lot – noting that it doesn't even need to be accurate writing! – in order to get a high score.

Informational Hand-out

Making a decision about which sites to use depends on evaluating how reliable or trustworthy they are. There are several things to consider in evaluating the reliability of a site. *Who is the author? How reliable is the information? How well does the site explain the information?* Below are some ideas to help you answer these questions.

Who is the author? *Can you figure out who the author is? Is the person who is providing the information someone who is knowledgeable about the topic?*

You can figure this out from several cues. One is the information provided about the author, what training the person has had, what their current occupation is. Sometimes you can tell this from the institution with which the page or author is affiliated (e.g., National Institute of Health, Fitness Centers Incorporated). Affiliation is sometimes shown in a logo or copyright statement on the page. Finally, the URL (web address) for a site lets you know whether the site is a profit making operation (.com), and educational institution (.edu), a government sponsored site (.gov) or an organization, usually non-profit (.org) or (.net).

What is their motivation?

Knowing something about the author is important because authors often have specific agendas they want to push. Frequently, web sites want to sell readers goods and services or obtain donations from them. To do so, they provide only the part of the information that supports their sales goals. Or they use the site to provide very graphic images that evoke emotional responses. Some sites may have political agendas. As you read the information on the web sites, use information about the author and site to figure out the motivations, possible biases, and purposes that the site author and host might have. You can also determine the motivation of the author by thinking about who the intended audience is.

How reliable is the information?

Is the information based on scientific/mathematical evidence?

Information that has been gathered through a scientific process can be considered more accurate than personal opinion, beliefs, or anecdotes. Is evidence provided or reported for claims? Are peer reviewed journals cited? Is this information likely to be evaluated well by informed scientists?

Is there similar information given across reliable sources?

If multiple sites or authors give the same information, it is more likely to be accurate than if the sites or authors disagree. This is especially true when the sites with converging information have affiliations that seem trustworthy. If information in a site contradicts other sites that you think are trustworthy, then it suggests the new information might not be reliable. Also consider if the account given is complete, or whether it omits information that other reliable sources mention.

How well does the site explain the information?

Does the explanation fit together with your prior knowledge or with information from other reliable sites?

Wiley, J., Goldman, S. R., Graesser, A. C., Sanchez, C. A., Ash, I. K., & Hemmerich, J. A. (2009). Source evaluation, comprehension, and learning in Internet science inquiry tasks. *American Educational Research Journal, 46*(4), 1060-1106.

Appendix C: Second Information-Based Problem at Rho University

The survey says! Exploring polling results

Find 2 examples of polling results (in editorials or articles online) on one of the following topics:

- Health Care Reform/Affordable Care Act
- Gun Control
- Legalization of Marijuana

Write a brief summary for each article that includes the following:

- The source of your article (website address and author)
- The polling company that did the survey (likely different from the author) and the date (year) of the survey
- A summary of the results that includes: the wording of the question that was asked in the poll, the number and type of people surveyed/polled (may be "general public"), the percentages reported in the polling results, and whether the article includes a confidence interval. (If any of these items are missing, please say that in the summary.)

Example (using a different topic):

Topic: Common Core (education)

Source: Edutopia, http://www.edutopia.org/blog/recent-polls-common-core-teachers-in-favor- anne-obrien

Polling Company/Date: Gallup, 2013

Group surveyed: General public

Summary: Gallup surveyed the general public about the Common Core Standards for public education and reported that a lot (49 percent) of the people polled believe that the Common Core sets standards for all subjects, which is actually not true. The author states that the general public is misinformed about these new standards. The article does not report the specific question asked, the number of people polled, or the confidence interval for the proportion.

Appendix D: Interview protocol for students at Rho University

Student Year_________
Student Major____________

1. Can you describe the process that led you to find the articles that you submitted in response to the homework assignment? [Note: Ask any necessary follow-up questions to get as many details as possible about what the student did and why as they searched for information -- in particular, I need to find about what they did in order to assess the credibility of what they found.]

    a. What sort of difficulties did you encounter searching for information? Did the hand-out help you at all? If so, how?

    b. What sort of difficulties did you encounter interpreting the information that you found?

2. What did you learn, if anything, from taking part in this assignment?

a. How did the out-of-class portion of the assignment contribute to that learning?

Appendix E: Unimplemented Information-Based Problems developed Collaboratively with College instructor in Fall 2013

First activity idea: The Polling Project

Place in the syllabus: This activity would follow chapters 14 (Censuses, Surveys, Polls, and Studies) and 15 (Graphs, Charts, and Numbers).

1. Student groups are assigned or allowed to choose one of several disputed topics to explore (e.g., health care reform, gun control, marijuana legalization) and told to prepare a brief report on the state of public opinion on the topic in question. In particular, they are asked to find evidence of the status of public opinion on these topics in the form of public opinion polls. They can look for that evidence in published editorials, research articles, or directly from polling firms. We can provide some examples of what this evidence might look like.

{**Note:** I recognize that these are controversial topics and we may be able to find topics that are less controversial (e.g., foreign aid, casinos, plastic surgery) but I think that more public topics could work better for several reasons: 1. Students tend to get more engaged when the topic is something that they care about, 2. As a more prominent issue, there will be more polling data available to students, 3. Putting the focus on public opinion would tend to keep the conversation less heated, people might make forceful statements but it would have to be focused on the merits of the polls rather than the larger ethical issues at stake -- and if strong opinion leads them to look more closely at the validity of polls then all the better!}

2. Each group shares the polling information that they found and has to present the following:

a. Their interpretation of what the polls actually establish. This would require the students to attend to the phrasing of the actual questions (as opposed to the way it is interpreted by news reports or editorials), the standard error, the existence of other polls, etc.

b. What overall conclusion they are able to draw about public opinion based on the polls that they found.

3. Depending on time, there may be an opportunity for students to critique the polls found by their peers. Perhaps, groups could trade the pertinent web addresses and see whether they agree or disagree with their peers' interpretation.

Second activity idea: Looking at Risky Investments

Place in the syllabus: This activity would follow chapter 16 (Probabilities, Odds, and Expectations)

1. Student groups are given a list of investment options (a collection of high-performing stocks, low-performing stocks, a mutual fund, a savings account) and asked to formulate a proposal for the best way to invest money for retirement. They must be able to base their argument on an analysis of the risk involved in each of the options. This will require the students to gather information from outside sources (e.g., editorials, blogs, economic textbooks) about the risks involved in each of the options. The students must document the sources that they use along with their evaluation of the credibility of the sources.

2. Each groups shares their conclusion with the rest of the class and their evidence

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