Case Study Exploring the Use of an Interdisciplinary Approach to Teach a High School Mathematics and Science Topic

A thesis presented

By

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**ABSTRACT**

This participatory case study was conducted to describe the value of an interdisciplinary teaching approach for a high school mathematics and science topic from the perspective of the students and the teacher. The topic of logarithms was selected for this lesson because it is a concept that students learn in both their high school mathematics and science courses. The teacher researcher, a high school mathematics teacher, worked with twelve student participants from a 9th and 10th grade Geometry class, along with four science and two mathematics teachers. The data collected in this study serves as a reminder of the many complexities of interdisciplinary work. This specific interdisciplinary study, signified by three overall themes, unraveled some of these complexities of the interdisciplinary approach in general. In all, the study demonstrated the utility of developing a shared language, gaining understanding of the complexities of interdisciplinary work, and sharing positive student experiences of an interdisciplinary lesson. These three themes serve as a step forward in the overall research of interdisciplinary mathematics and science work. A significant amount of additional research is needed to compare the actual student learning outcomes for interdisciplinary work versus discipline specific work. The data from this study, however, shows that as teachers work to create an interdisciplinary approach, teachers from different disciplines produce such a thoughtful and positive dialogue that only enhances student learning.
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Chapter 1: Topic Overview

Statement of the Research Problem

In most middle and high school classrooms, the science taught very often requires the application of mathematical concepts the students have previously learned, and yet many middle and high school teachers observe that students do not make cognitive connections between what they have learned in one course to the other. Educational researchers share in common the concern that students learning about related topics in separately disciplined courses often cannot grasp the full connection between the disciplines. This difficulty transferring knowledge from one subject to the next can create the disconnect students perceive between the mathematics and science topics they study, which can hinder students from fully understanding the depth and value of both fields. Xin (2009) further explains the connection between mathematics and science:

Mathematics helps achieve a deeper understanding of scientific concepts, providing ways to quantify and explain scientific concepts and relationships, whereas science provides concrete examples for abstract mathematical concepts and thoughts, creating relevancy and motivation for studying mathematical concepts and relationships. (p. 2103)

Furner and Kuman (2007) describe the gap students experience between subjects to be the result of a “layer cake” approach, or that of a “jigsaw puzzle without any picture” (p. 186), meaning that while students gain knowledge from one course, they are not making the necessary connections to similar content in another course. Authors Jones (2009) and Kamens (1991) both discuss the background of the one-discipline curriculum and claim students have “suffered” as a result.

The belief that there is value in the practice of interdisciplinary work has led to a growing trend of interdisciplinary courses. While there is an abundance of literature
describing sample interdisciplinary mathematics and science courses (Lyons & Ridley (1994), Madlung, Bremer, & Himelblau (2011), Peckham (2012), Tra & Evans (2011)), there is a need for additional research that describe the experience and value of interdisciplinary courses. As a result, educators are thinking about methods to help students’ bridge the gap between what they learn in science and mathematics courses, and many are concluding that interdisciplinary course work offers a promising solution. Youngblood (2007) provides clear and concise definitions for both multi- and inter-disciplinary work, as well as a description of what it means to “bridge disciplines”, a way of making connections between separate disciplines by studying related topics applicable to both disciplines. A review of the literature on interdisciplinary mathematics and science courses, detailed in the following chapter, reveals very little data to describe both the student and teacher experience and value of interdisciplinary mathematics and science courses.

This study was a participatory case study that showed what happens when students were involved in an interdisciplinary teaching approach and described the unique ways such a learning experience supports the authentic learning of the students. By examining such an interdisciplinary teaching approach, one can start to determine the value of interdisciplinary teaching methods in future curricula. If it is found that an interdisciplinary method does allow students to experience greater transformative learning, we can ensure students are better prepared for the future by providing more interdisciplinary approaches in our schools.

**Significance of the Problem**

A study of interdisciplinary mathematics and science teaching approaches is important for several reasons. First, such a study adds to the current literature in this field. While the concept of interdisciplinary curricula is rapidly emerging, the need for literature that provides data to support the experience and value of interdisciplinary curricula is critical.
If students can better understand the connection between the two disciplines of mathematics and science, they can be more successful in both subjects. When a student has a deeper understanding of a topic taught in mathematics that will also be applied in a science class, the student experiences transformative learning and will be better suited to identify future problems where such a process can be applied. The significance of a study on interdisciplinary mathematics and science courses is powerful, as it can provide additional support among the field of literature, improve current practice for mathematics and science educators, change the shape of school curricula, and result in better preparation of our students for their future.

Positionality Statement

Having been a high school mathematics teacher for ten years now, I have witnessed numerous situations where students are not making connections between the material I teach them in mathematics and the material they are learning in their science class. For example, when students learn about vectors in mathematics, they learn different methods and formulas to help them in solving vector-related word problems. When they are given similar word problems in their physics class, I have found that they do not properly apply the formulas and methods learned from their mathematics class. There must be some disconnect occurring in these students when they can solve a problem in one class but not solve a similar problem in another class. My colleagues have also observed the lack of knowledge transfer and agree that it is grounds for concern. We have been fortunate to teach at a private school where we are encouraged to spend time discussing such observations, and this research is an expansion of the conversations my colleagues and I began many years ago. I am hopeful that this research will position our students to be more successful in their future mathematics and science coursework.
There are some biases I bring into this study that will investigate student perceptions of the impact of an interdisciplinary mathematics and science unit at a college-preparatory high school. I have always been drawn to the concept of interdisciplinary courses, so I am eager to create a course that I can implement within the school where I teach currently. The first step I will take in this goal is to create an interdisciplinary unit that blends material from a high school mathematics course with a high school science course, but I have ideas for future units and courses should I find the first attempt does increase student understanding of both subjects. Therefore, I find myself looking at literature which does not support the idea of interdisciplinary courses, or claims that interdisciplinary courses provide no benefit to student learning, with a more critical eye.

Another item worth noting is that the school where I work, and where I conducted my research, is an independent girls’ school. Being a female mathematics teacher at a girls’ school, I am ever mindful of the reality that women are still underrepresented in Science, Technology, Engineering, and Mathematics (STEM) career fields. For this reason, I feel an even stronger passion to find teaching methods that will allow such students to experience transformative learning in the mathematics and science content they study.

The concept of an interdisciplinary curriculum is a pedagogical practice quickly emerging over the past decade. While educators have discussed interdisciplinary curricula for several decades, researchers only in the past ten to fifteen years are beginning to gather data as evidence of the experience and benefits of such a curricula. A review of the literature portrays a solid background on the practice of interdisciplinary coursework and provides many sample courses, all of which cite benefits for an interdisciplinary course.

Research Question
The aim of the study was to describe the value of the experience, both in terms of the students and the teacher, of an interdisciplinary teaching approach for a high school mathematics and science topic.

**Research question.** What is the described value of the experience of an interdisciplinary teaching approach for a common high school mathematics and science topic?

**Research sub questions.** How does an interdisciplinary teaching approach for a common high school mathematics and science topic enhance the learning experience for students? How does an interdisciplinary teaching approach for a common high school mathematics and science topic enhance the learning experience for the teacher?

**Theoretical Framework**

As the interest in interdisciplinary curricula increases, naturally so does the number of researchers investigating in this topic. Of the many researchers recently publishing work about interdisciplinary courses, the majority of them are using the transformative framework as their theoretical structure.

The theory of transformative learning, a term often credited to the work of educational researcher Mezirow, can be described as being “constructivist, an orientation which holds that the way learners interpret and reinterpret their sense experience is, central to making meaning and hence learning” (Mezirow, 1994, p. 222). Creswell further explains the reform initiated by transformative work may change “the lives of participants, the institutions in which they live and work, or even the researchers’ lives” (1998, p. 837). Research investigating the effects of interdisciplinary courses on students’ learning outcomes may be such an example of a reform initiated by transformative work, since it could lead to a major shift in the current curriculum structure of secondary schools.
A more simplified way to think about the transformative theoretical framework can be found in looking at the word transformation. To transform something is to conduct a change, so a transformative framework serves as a lens to think about research that will conduct a change within some type of organization or system. For this study, the system to be potentially transformed is the educational system that currently follows a curriculum structure for secondary schools where disciplines are isolated from one another.

Transfer of learning “is one of the seldom-specified but most important goals in education”, where students “gain knowledge and skills that they can use both in school and outside of school, immediately and in the future” (OTEC, 2007, para. 1). When students appropriately transfer learning from one topic to another, they often do so subconsciously. As the difficulty of topics learned increases, so does the difficulty for students to transfer learning to other areas. An example of a knowledge transfer that teachers hope their students will make is when a mathematics student learns about the metric system. “From the math class, students go to a science class. Frequently the science teacher reports that the students claim a complete lack of knowledge about the metric system. Essentially no transfer of learning has occurred from the math class to the science class.” (OTEC, 2007, para. 5). In a discussion about different learning theories, Perkins (2009) describes transfer of learning as a framework that researchers use to talk about such problems teachers cite regarding student knowledge transfer.

**Rationale for framework.** The transformative framework is a fitting one for this study of interdisciplinary coursework in mathematics and science since the study produces results that describe the learning experiences of students who are in an interdisciplinary unit and the ways their knowledge and beliefs shift in this experience. If it is found that the interdisciplinary teaching method leads to solid concept mastery levels, a transformation of the current curriculum structure to a more interdisciplinary approach can be justified.
**Key theorists.** The number of researchers interested in interdisciplinary course work has increased substantially in the last ten to fifteen years. Although it is considered a high-interest and rapidly growing research topic, the available background research is still limited. There are many researchers interested in the idea of interdisciplinary courses who have conducted research on sample courses, but there is a lack of data to support claims that students benefit from interdisciplinary courses. Dewey’s (1922) constructivist philosophy created a foundation for educators to think about how individuals gain knowledge within an educational setting. Interdisciplinary course work stems from this concept of constructivism, where students are learning through experiences and making connections to many different aspects of knowledge. In a review of over twenty recent education articles, the majority of the researchers were university students at the time of their research. As a result, most of them appear to have selected the topic for a one-time study, meaning that very few of the researchers have participated in multiple studies on the topic of interdisciplinary mathematics and science courses.

There are a few authors who display stronger interest in the field of interdisciplinary study and have participated in multiple studies, which is the long-term goal of this researcher, who hopes to run additional interdisciplinary studies in the future to gather more data. Berlin and White (1993) are cited in numerous studies for their work in the integration of mathematics and science, while Furner and Kumar (2007) and Matthews, Adams, and Goos (2009, 2010) are all researchers cited for their broader work in the integration of the Science, Technology, Engineering, and Mathematics (STEM) disciplines. The majority of these researchers followed a case study approach, which provides further support for the researcher’s selection of a case study for this research.

The researchers that followed a case study model for their research all created and implemented an interdisciplinary course that was later analyzed to determine whether the
interdisciplinary approach could be considered successful. A downside to this approach is that the most common location for such a study to take place is at a university. Although it can be very useful to think about interdisciplinary courses in a university setting, in order to consider the potential for a transformative change in the current curriculum structure, elementary, middle, and high school teachers must also begin to learn about interdisciplinary courses and determine whether they can bring benefits to their students with alternative approaches to teaching.
Chapter 2: Literature Review

As educators think about strategies to help students bridge the gap between what they learn in science courses and what they learn in mathematics courses, many are concluding that interdisciplinary course work offers a promising solution. By examining interdisciplinary mathematics and science courses and their value to students and teachers, one can determine the extent of their use in future curricula. In a literature review of over 300 articles Biemans, et al. (2010) showed that, “to date, scientific research into teaching and learning in interdisciplinary higher education has remained limited and explorative” (p. 365). Biemans, et al. summarize their findings and in conclusion stress the need for more interdisciplinary work. A detailed study of interdisciplinary mathematics and science courses can add to the scholarly research and lead to an improvement of overall mathematics and science instruction, potentially resulting in better learning outcomes for students. Authors Campbell and Henning (2010) made an impact in the field of interdisciplinary research with their study on interdisciplinary work in elementary schools. After completing a case study where two elementary education professors collaborated to produce an interdisciplinary course, Campbell and Henning (2010) concluded that integrated teaching could be especially helpful when thinking about student outcomes. Campbell and Henning (2010) state, “Examination of interdisciplinary units revealed that pre-service teachers receiving integrated instruction outperformed their nonintegrated coursework peers in developing, assessing, and reflecting on interdisciplinary content” (p. 179).

The common themes found when investigating interdisciplinary mathematics and science courses were the: history of interdisciplinary curricula, variety of interdisciplinary courses, advantages of interdisciplinary courses, disadvantages of interdisciplinary courses, and suggestions for successful implementation of an interdisciplinary course.

History of Interdisciplinary Curricula
Definitions. One piece of information vital to understanding interdisciplinary curricula is establishing what it means to be interdisciplinary. The literature on interdisciplinary curricula offered many definitions of not only the term interdisciplinary, but also words often used as a synonym to interdisciplinary. For example, when focusing on the term interdisciplinary, Youngblood (2007) states “the goal is to analyze what each discipline has to offer and then go beyond what each can offer separately through a process of integration” or more simply, “what happens when members of two or more disciplines cooperate” (para 5 & 3). Before providing examples of interdisciplinary courses already created by educators, Epstein (2004) first describes a clear distinction between the terms multidisciplinary, transdisciplinary, and interdisciplinary. He explains that multidisciplinary works are those that give rise to interdisciplinary studies, such as incorporating social history with a history of the arts. Transdisciplinary, as Epstein (2004) explains, refers to topics that transcend the scope of our traditional disciplines, such as phenomenology and social biology. The author then limits the use of the word interdisciplinary “to use the description of fields of study that are fully integrated; that cannot be broken into component disciplines without distortion. [An example] of such interdiscipline are Urban Planning (integration of history, architecture, art, geography, demographics, design, engineering)” (p. 2). Huntley (1999) provides a slightly different definition for interdisciplinary curricula as one with “the focus of instruction on one discipline, and other discipline(s) support or facilitate content in the first domain. The teacher(s) makes connections between the disciplines only implicitly”, setting the stage for the students to make such connections on their own (p. 58).

When thinking about such full integration in terms of high school mathematics and science, it would mean that when students learn about vectors, for example, as they learn how to use them to model real-life scenarios, the students would not be able to differentiate the “math” part of the problem from when they are doing the “science” part. Huntley’s (1999)
definition of interdisciplinary is a more fitting guideline when creating an interdisciplinary mathematics and science course since both disciplines support one another, and Epstein’s (2004) definition is more fitting for a course using both disciplines together for a different purpose, such as a high school level engineering course.

**Curricula background.** Another important aspect in the history of interdisciplinary curricula includes knowing the background of today’s common curriculum. In the majority of United States middle and high schools today, students attend separate mathematics and science classes. Each year the mathematics courses build on one another (Geometry, Algebra 1, Algebra 2, Trigonometry/Precalculus, Calculus, etc.), and the science courses often focus on one specific area each school year (Biology, Chemistry, Physics, etc.). Kamens (1991) provides background information on the subjects of mathematics and science and their introduction into the elementary and secondary school curricula in the 19th century. At both elementary and secondary levels, science was added to the curricula decades after mathematics. Kamens (1991) illustrates the slow progression of change within our common curriculum and provides a better sense of why schools divided the disciplines in the first place. The school curricula that we know today was put in place to “redefine the lives of young people as potential contributors to the national development project” (Kamens, 1991, p.140). More specifically, the article explains that the adoption of mathematics and science in the official curricula, “undoubtedly strengthened the view that these subjects were important preconditions for a productive and prosperous industrializing society” (Kamens, 1991, p.146). In other words, as schools historically prepared students for future work in the ever-industrializing society, schools necessarily began to focus on the mathematics and science skill sets, enabling students to better understand the new technological developments in the work force.
Miller and Burroughs (2010) provide additional insight into the background of our curriculum. In discussing what constitutes curriculum, they dissect it into three parts—planned, enacted, and perceived. Miller and Burroughs, along with Kamens’ thorough background of today’s curriculum structure, provide their opinions on such a curriculum in comparison to an interdisciplinary one. Jones (2009) supports Kamens’ explanation of the background of the one-discipline curriculum, and claims students have “suffered” as a result. He further explains “[i]nterdisciplinary techniques are not only important for a student to learn any one single discipline or solve problems in a synthesized manner, but it also enriches a student’s lifelong learning habits, academic skills, and personal growth” (p. 78). Although each author supports the idea of interdisciplinary course work, their research was limited overall.

The Biemans, et al. (2009) literature review of over 300 articles, mentioned earlier, showed that “to date, scientific research into teaching and learning in interdisciplinary higher education has remained limited and explorative” (p. 365). Although 300 articles may seem like enough research to support the need for interdisciplinary work, the majority of the articles only contain insight from professors or researchers stating they think there would be a positive effect, but much of the research, thus far, is lacking in large-scale studies to back up the beliefs of many. The literature as a whole, however, provides additional insight into how a curriculum can change over the years and further indicates the best direction for the future is towards an interdisciplinary curriculum.

**Variety of Interdisciplinary Courses**

Interdisciplinary course literature commonly includes details about sample interdisciplinary courses. A look at many different sample interdisciplinary courses showed connections in the following areas: mathematics and science integration, mathematics or
science and humanities, problem solving, and global citizenry. Each of these four themes within the topic of sample interdisciplinary courses will be discussed further.

**Mathematics and science.** Of the articles showing sample interdisciplinary courses reviewed, only a small group contained courses that solely blended mathematics and science. The lack of interdisciplinary courses focusing purely on mathematics and science is interesting, especially since these two subjects are often thought of as being linked with one another. In one example displaying the transfer of knowledge between disciplines so many researchers refer to, Madlung, Bremer, and Himelblau (2011) present a summary of an interdisciplinary mathematics and biology course. The authors developed and assessed a learning module for both first-year undergraduate and more advanced students. They summarized the interdisciplinary mathematics and biology course, provided a thorough description of the program, study, and results. They looked in-depth at the assessment of the learning module, which was conducted at the end of the course, and after doing so stated that there “is increasing enthusiasm for teaching approaches that combine mathematics and biology” (Madlung, Bremer, & Himelblau, 2011, p 43). Tra and Evans (2010) also created a similar course for undergraduate students. They incorporated student feedback into their evaluation of the course before claiming it to be a success. Although all of these examples allow researchers to get a sense of the types of interdisciplinary courses implemented, what is lacking in each example is research about the effectiveness of the courses.

Another example of a course blending science and mathematics, described by Peckham (2012), comes from a Georgia school that received science, technology, engineering, and mathematics (STEM) funding and used it to create an elective course for high school students. The course was created by three teachers (one math, one science, one engineering) working together on all aspects of course planning. After completing one semester of the course, the teachers state that the course model they created has improved
student outcomes, and one teacher explained that the collaboration “helped us get a lot further than we would have gotten on our own” (Peckham, 2012, p.8). Lyons and Ridley (1994) provide a comprehensive, interdisciplinary unit for a sixth-grade class that is thorough enough for any teacher to pick up and use. Their unit was viewed as such a seminal piece of interdisciplinary work that the Smithsonian Institute turned it into a book.

Although the sample size of fewer than thirty articles is small, the fact that less than twenty percent of them being solely integrated mathematics and science courses indicates a potential lack in this area of interdisciplinary studies. Also, while a few of the articles cited some results regarding the courses’ effectiveness, the majority of them were lacking any substantial data to back up claims made regarding the effectiveness of each course.

**Mathematics or science with humanities.** Interdisciplinary courses that blend either mathematics or science with a humanities aspect were the most common in the thirty articles reviewed. Wilburne and Napoli (2007) provide a sample lesson that first have seventh grade students read a chapter from a young adult mystery novel to introduce a mathematical mystery, which they then have the students solve. Other examples include science topics mixed with the humanities in a similar fashion. After stating that scientific writing has often been ignored within many high school English departments, Comeau (2011) writes about a course that embeds scientific writing within an English class. The similar work by Richter and Paretti (2009) is much more thorough than that of Comeau because they not only investigate sample interdisciplinary courses merging engineering and humanities, but they also complete a case study on the topic.

While the above sample lessons are created for mostly middle and high school students, Clayton (2011) provides a sample course for doctoral students. Clayton’s course is an experiment between Ph.D. English students and Vanderbilt Medical School faculty. The goal was to blend more ethical thinking into science and medical research. Although the
majority of the sample courses reviewed were created for secondary school students, Clayton’s example indicates that interdisciplinary courses are also an option for higher education.

**Problem solving.** In France, while mathematics and science are taught as separate courses, the national curriculum of both disciplines is taught in complete conjunction with problem solving. Mathematics and science instruction includes “situations requiring research, which lead [pupils] to explore the steps involved in solving problems and to take a research-oriented approach to concepts and new tools” (France Ministry of National Education, 1995, p. 48). The main purpose of the country’s instruction is to teach students to problem solve and think critically: “to look for answers, think abstractly, reason and prove one's answers to be correct” (France Ministry of National Education, 1995, p. 62). Although the example of the French curriculum is not truly an interdisciplinary course, the strong integration of problem solving in both the mathematics and science curriculum indicates the country’s desire to ensure students see the connection between the two disciplines.

Singapore is another country that incorporates strong problem solving activities into the mathematics and science curriculum. Although Singapore’s curriculum includes mathematics and science courses as two separate disciplines, some schools have attempted to blend both subject areas while still taking care to meet each of the requirements for the individual disciplines. One such example is of a school that used a computer game called *Quest Atlantis* to integrate different course topics (Lim, 2008). Lim (2008) noted “[t]he major challenge then in this study was to plan and design activities that would support the teachers and students to take up the learning opportunities of the game-like environment”, and this appears to be a common challenge among educators creating interdisciplinary courses in general (p. 1076). Overall, when it comes to developing problem solving skills as a means of
connecting mathematics and science, the literature has shown that countries like France and Singapore appear to be making strides.

**Global citizenry.** Another common method for integrating mathematics and science topics is to use an overarching goal of leading students to become global citizens. Many examples of interdisciplinary courses found both in the U.S. and among other countries were built around situations where the students had to work to find solutions to a global issue. In a discussion of such a course in Singapore, Lim (2008) concluded that a global citizenship education not only motivates students but also “secures the buy-in of the teachers, and at the same time, provides students and teachers with opportunities to critically examine local and global issues and act upon them” (p.1089).

An example of such a global citizenry course is one created by a U.S. university that is focused on global water issues (Kosal, Lawrence & Austin, 2010). For this course, “students designed a semester-long research project, collected and analyzed data, and ultimately presented their results and conclusions to the larger community” (Kosal, Lawrence & Austin, 2010, p.1). The global citizenry course blended mathematics, biology, and chemistry topics while pushing students to work towards one united goal. The course instructors noted an improvement in students’ science literacy as well as increased curiosity and confidence in the science field (Kosal, Lawrence & Austin, 2010).

Phillips (2007) explained the benefits of using a global citizenry approach as a means of connecting mathematics and science topics but reminded educators of a certain required level of competency in the subjects before gaining the ability to solve world issues. Since “issues such as global warming, deforestation, use of fossil fuels, population growth, ozone depletion, rising obesity rates and pandemic virus infections can only be addressed when enough people in the general population understand the science underlying these problems”,
the practice of integrating the study of global issues into the mathematics and science classrooms may possibly create future global problem solvers (Phillips, 2007, p.4).

**Advantages of Interdisciplinary Courses**

A review of the literature also indicated many advantages of interdisciplinary courses. The positive outcomes described in the literature were formed from a combination of student, faculty, and external feedback. Specifically, all of the articles discussing the use of interdisciplinary courses for pre-service teachers cite many advantages. After completing a case study where two elementary education professors collaborated to produce a fully interdisciplinary course, Campbell and Henning (2010) conclude that integrated teaching could be especially helpful when thinking about student outcomes. Campbell and Henning state, “[e]xamination of interdisciplinary units revealed that pre-service teachers receiving integrated instruction outperformed their nonintegrated coursework peers in developing, assessing, and reflecting on interdisciplinary content” (p. 179). Similarly, after a year-long qualitative study of pre-service teachers in a rural area, Laughlin and Nganga (2008) found that “[w]hile planning and implementing this study, interdisciplinary themes emerged that provided rich opportunities to examine the curriculum and our own understandings of culturally responsive instruction” (p. 118). Andersson, et al. (2010) agrees with the claims of Campbell and Henning and Laughlin and Nganga in saying expected results of an interdisciplinary course “are the abilities of transferring what the students have learned to new situations and perceive situations in their entirety” (p.12). Thus, the ability to transfer learning was found to be a common advantage.

While many of the other articles provided feedback from their sample interdisciplinary courses, indicating the presence of advantages, much of the literature was lacking support to back up these claims. Two articles, however, did manage to provide solid justification for their assertions. They not only listed advantages of an interdisciplinary
course, but also provided reasoning and justification for doing so. Madlung, Bremer, and Himelblau (2011), who summarized the interdisciplinary mathematics and biology course, provided a thorough description of the program, study, and results. They looked in-depth at the assessment of the learning module, which was conducted at the end of the course, and after doing so stated that there “is increasing enthusiasm for teaching approaches that combine mathematics and biology” (p 43). Tra and Evans (2010), authors who also summarized an interdisciplinary course on biology and mathematics (this one was considered a research heavy course), incorporated student feedback into their evaluation of the course before claiming it to be a success.

Overall, the literature portrays positive results from the many sample interdisciplinary courses described, but only a few of the articles contain support to back up these results. One thought among educators regarding interdisciplinary curricula is that such course work can allow students to yield a deeper sense of understanding of the course material. The lack of clear and verified advantages for interdisciplinary courses leads to a possible conclusion that the literature is greatly deficient in additional studies providing substantial support for the claims.

Disadvantages of Interdisciplinary Courses

Although the literature on interdisciplinary curricula indicates several advantages to an interdisciplinary course rather than the more common one-discipline courses, some authors also state disadvantages. The disadvantages cited fall under two areas: interpersonal issues and lack of research. In their discussion of the “homelessness and hunger” course, Rooks and Winkler (2012) write, “[t]he course planning process clearly demonstrated that instructional team members may not share tacit values and assumptions, theories and methodologies, epistemologies, and notions of adequate proof” (p. 18). Peckham’s (2012) article of the Georgia STEM course created by three teachers contains a similar discussion of
the struggles these teachers experience in creating a joint course due to personality conflicts; Tra and Evans (2010) suggest similar challenges in their interdisciplinary course creation.

After creating an interdisciplinary mathematics and science unit for two different teachers to follow within their middle school classrooms, Huntley (1999) noted challenges with the concept of an interdisciplinary implementation. The author discussed the struggles faced by the teachers and explains how “directive or modeling approaches dominated their classroom teaching, and they provided students few opportunities to engage in tasks stimulating high cognitive demand” (p. 66). Huntley’s observations indicate that a prerequisite for teachers of interdisciplinary courses is a solid understanding of the content in each of the individual disciplines, or else the students may not gain any additional understanding in either discipline as a result of the interdisciplinary course.

Several authors mention the need for further research on the creation and implementation of interdisciplinary courses, but many of these suggestions are made in a general sense, without providing support to back up their reasoning for the suggestions. Richter and Paretti’s (2009) paper, which contains both a review of the literature and also a case study on interdisciplinary work in engineering classrooms poses several thorough questions for further research, claims “educators still lack rigorous research about learning barriers, outcomes, and concrete interventions to support this interdisciplinary development” (p. 29). Overall, the disadvantages cited by authors of interdisciplinary courses are rather limited. Such a limitation can lead to two possible conclusions: interdisciplinary courses have more advantages than disadvantages, or there is a lack of studies to compare data regarding any disadvantages of interdisciplinary courses.

**Successful Implementation of an Interdisciplinary Course**

In the literature review focused around interdisciplinary courses, a “lessons learned” theme also emerged, containing suggestions for creating one’s own interdisciplinary course.
Many articles listed lessons learned from educators or students who have been involved in an interdisciplinary course. The suggestions can be summarized into the following five overall tips: organization, clear and constant communication, assessment, sustained professional development, and reflection. Almost all of the articles provide one or more of these suggestions.

**Organization.** Epstein’s (2004) article provides clear guidelines for creating an interdisciplinary course, stating the strong need for thorough organization. In the sample course on acoustic ecology, the author provides a course outline, assignments, projects, and assessments for the course. The detailed layout provides educators with a useful model to follow when creating their own interdisciplinary course. Malik and Malik’s (2011) first nine of twelve tips for designing an integrated curriculum are all methods for organization and planning. They stress the need for identification of themes, learning outcomes, course timetables, scope and levels of integration, and responsibilities of group members. Thorough organization is a necessity for running any successful course, but both Epstein (2004) and Malik and Malik (2011) emphasize the critical importance when specifically designing an interdisciplinary course.

**Clear and constant communication.** A second suggestion found among the literature involves clear communication. Many authors state incidences where constant communication with coordinating teachers or other parties involved was critical in the success of the course. McLaughlin and Talbert (2006) discuss how important it is when implementing a change to spread the word among learning communities. They remind readers how changes in curriculum “depend on outside players knowing about teachers’ learning goals and needs, and their capacity and inclination to support teachers’ efforts and learning communities in material and moral terms” (p.79). Similarly, Malik and Malik (2011) recommend the need for clear communication and state, “[w]ell-informed staff members and
students ensure the successful implementation of the curriculum” while reminding readers that, “[r]egular communications between faculty and students are useful to allay fears and to stop inaccurate rumours circulating” (p.103).

Assessment. One of the most common suggestions for creating an interdisciplinary course found among the literature is to include a course assessment. Most significantly, Duin, Jorn, and Whiteside (2009) stress the need for educators to “PAIR” up. PAIR (Partner, Assess, Integrate, Revisit) is an acronym related to partnering up with educators and collaborating among disciplines. The authors provide an extremely detailed discussion of the “Assessment” portion of PAIR, in order to stress the need for educators to find appropriate ways to assess whether such work is valuable. Duin, Jorn, and Whiteside (2009) remind educators to assess “how learning is influenced in new learning spaces” (p. 13). The article, which provides feedback from students or teachers regarding several aspects of the course, creates a clear picture of the interdisciplinary course and its added value for all parties involved.

Sustained professional development. A suggestion that appears to be lacking in the majority of the literature, is that of professional development. Whenever educators face a change in curriculum, some type of professional development should be provided, especially when creating a brand new course like an interdisciplinary one. McLaughlin and Talbert (2006) introduce the idea of “sustained professional development” (p. 67). They recommend the opportunity for such development because it can lead to “conceptual shifts in their understanding of subject instruction”, which might lead to further interdisciplinary work (2006, p.67). As an example, the McLaughlin and Talbert (2006) state, “[i]nteraction with math colleagues outside the school in regional professional associations and informal local networks ensures that the community stays up to date on research-based knowledge” (p.66). Similarly, Stinson et al. (2009) reminds readers of the fact that “professional development for
teachers where science and mathematics integration is a desired outcome must begin by providing teachers with a sense of how teachers will know integration when they see it” (p. 159). The discussions that occur within such learning communities seem critical when beginning to implement a new interdisciplinary course.

**Reflection.** The fifth major suggestion for creating an interdisciplinary course is often a general suggestion given to all teachers, a reminder to reflect upon a course frequently to ensure all goals are being met. A case study of the San Lucio Mathematics Department provided by McLaughlin and Talbert (2006) suggests collaborative practice should always include much reflection. One recommendation is for “ongoing discussion among teachers about the successes and failures they experience in teacher particular lessons” in order to improve future instruction (McLaughlin & Talbert, 2006, p.23). Malik and Malik’s (2011) “twelve tips for developing an integrated curriculum” guide readers through the entire process of course development, including training, collaboration, planning a timeline, planning learning outcomes, and assessing. Malik and Malik (2011) remind educators that a “willingness to accept the shortcomings in the curriculum or its implementation and to make the appropriate changes should be an ongoing process” (p. 101). Although their suggestion of reflection is not a new concept, it is an important one for educators to keep in mind as they begin their work in interdisciplinary courses.

**Assessing conceptual understanding**

Several studies have been conducted in the field of education that investigate different levels of student understanding after learning new skills or concepts. One study in particular provides insight into several different areas of problem-solving transfer and various levels of understanding. Winkles (1986) led a study with 46 eighth grade students in Australia who were introduced to the topic of trigonometry and then requested to demonstrate their newly learned skills. Winkles (1986) found that there was no discernable advantage for students
who were explicitly taught a skill, compared to those who had a relational style of instruction, when it came to their performance on the post-study test. When Winkles (1986) assessed whether students demonstrated lateral transfer of their newly learned skills to other mathematical problems, however, the relational style of instruction showed advantages over the explicit instruction. This study indicates that some methods of instruction can lead to a better transfer of knowledge among disciplines than other teaching methods.

Niemi’s study (1996) also investigated levels of conceptual understanding in students, but viewed them through the lens of various assessment models. In a study involving 540 fifth grade students, Niemi (1996) found that in order to accurately assess the full depth of a student’s knowledge on any given topic or skill, teachers must assess “representational knowledge across a broad array of representations, because master of principles that enable the generation and use of an indefinite number of correct representations cannot be inferred from the ability to identify or use only one type of representation” (p. 360). These results imply that the instruction should focus on developing a conceptual understanding rather than aiming for rote memorization, or explicit instruction, as Winkles (1986) also confirmed in his findings. In a similar study, Alibali, Rittle-Johnson, and Siegler (2001) worked with fifth grade students as they learned about decimal fractions. When determining whether students were competent in the topic (by their pre-set standards and guidelines), they found that true competence requires not just procedural knowledge, but also conceptual knowledge. The researchers state that “conceptual and procedural knowledge appear to develop in a hand-over-hand process” (Alibali, Rittle-Johnson, & Siegler, 2001, p. 360). This agrees with the findings of both Niemi (1996) and Winkles (1986) to show that true conceptual understanding comes when students not only recite steps or knowledge back to a teacher but when they can also transfer that knowledge in various methods of assessment.

**Literature Summary**
A review of the literature was conducted to determine the insight we can gain from the literature on the topic of interdisciplinary mathematics and science courses. Five overall themes emerged from the literature: history of interdisciplinary curricula, variety of interdisciplinary courses, advantages of interdisciplinary courses, disadvantages of interdisciplinary courses, and suggestions for successful implementation of an interdisciplinary course. Among the different sample interdisciplinary courses reviewed, interdisciplinary courses were created with the following combinations: mathematics and science integrated, mathematics or science and humanities, problem solving, and global citizenry.

Many articles listed “lessons learned” from either educators or students who have been involved in an interdisciplinary course. The suggestions fit into the following five overall tips for interdisciplinary course creation: organization, clear and constant communication, assessment, sustained professional development, and reflection. Interestingly, almost all of the articles hinted at one or more of these suggestions, but very few provided additional support to further explain their suggestions.

While there is an abundance of literature describing sample interdisciplinary mathematics and science courses, there is a need for additional research that examines the fundamental question of whether interdisciplinary courses can effectively bridge the two disciplines. Much like the suggestions for implementation, the literature clearly portrayed positive results from the many sample interdisciplinary courses described, but only a few of the articles contained support to back up these results. There appears to be a significant lack of clear and verified advantages for interdisciplinary courses, which leads to a possible conclusion that the literature is greatly deficient in additional studies. A considerable lack of disadvantages cited by authors of interdisciplinary courses also suggests a deficiency in substantive data.
The concept of interdisciplinary mathematics and science courses could possibly be a method for educators to strengthen the students’ connection to the two disciplines, and also improve student performance overall. When it comes to the advantages, disadvantages, and lessons learned cited among the literature, there appear to be several benefits to an interdisciplinary course, but there is a significant need for additional research on this topic to validate the findings. Applebee, Adler, and Flahán (2007) mention the literature available on interdisciplinary teaching but warn it is “largely an advocacy literature, arguing pro or con based on the experiences of individual teachers or schools” (p. 1003). Researchers Epstein (2004), Furner and Kuman (2007), Jones (2009), Kamens (1991) and Youngblood (2007) all indicate the need for educators to consider interdisciplinary course to assist students in building strong connections between disciplines. Educational researchers are only skimming the surface when it comes to thorough investigation of interdisciplinary courses.
Chapter 3: Methodology

Qualitative Research Paradigm

The purpose of this research was to describe the value of the experience, both in terms of the students and the teacher, of an interdisciplinary teaching approach for a high school mathematics and science topic. The researcher selected the radical structuralist paradigm because the study is investigating the “structural relationships” that are naturally built between science and mathematics (Burrell & Morgan, 1979, p. 34). The current structure of the traditional high school curriculum incorporates many different classes, each comprised of one discipline per class. With an interest in the potential influence an interdisciplinary teaching approach can provide, the radical structuralist paradigm guides the research towards investigating a possible alternative method to the current high school curriculum structure.

Role of Researcher

The participatory researcher had a very large role within this research, since she conducted all of the focus groups and will also teach a lesson using the interdisciplinary approach. The small, private school setting and researcher as a participant afforded a rich and deep immersion in the study, and as a result, the study provided many layers of insights of the experiences of this work. The participatory researcher’s prior knowledge of the school and the students was an added benefit for the study, since this sense of familiarity can be useful when looking at a final analysis and description of the case studied.

Research Design

Qualitative research is more fitting for the research methods, rather than quantitative, since the study contains three of the four common characteristics Creswell (2013) provides for qualitative research: natural setting, researcher as key instrument, and complex reasoning through logic. Creswell’s (2013) use of phrases such as “an approach for exploring and
understanding” and “research involves emerging questions and procedures” in his description of qualitative research also serve as confirmation that this research, which revolves around exploring and describing differences observed between the three teaching methods, is more qualitative than quantitative (p. 4). Further, the research site is the site of the question being studied (and not a lab or alternate setting); the researcher will be the main data collector and the study’s teacher researcher.

**Research Tradition**

**Rationale.** The research tradition followed was that of a participatory case study, as described by Creswell (2012) and Bergold and Thomas (2012). The case being studied in this research explored the incorporation of an interdisciplinary teaching approach. Creswell (2012) states that a “case” must be bounded by parameters and should be current, meaning that the phenomenon is ongoing during the study. This case was bounded by the one topic that is taught (logarithms) in the single school research location, and the researcher sought an in-depth understanding of the influences of an interdisciplinary teaching approach. The use of a case study was appropriate for this research in that it allowed for different perspectives to emerge and provided an in-depth understanding of multiple participants (Creswell, 2013).

According to Bergold and Thomas (2012), “participatory research methods are geared towards planning and conducting the research process with those people whose life-world and meaningful actions are under study” (para 1). The researcher not only planned and conducted the research, but also interacted with the students and the colleague focus groups as part of the study, therefore following the structure of a participatory case study. The perspectives of the researcher and the other participants were blended together to answer the research questions.

Since an aim for a case study is to provide an in-depth understanding of the case, multiple forms of data were collected (Creswell, 2013). In this study, the researcher gathered
a variety of data, mainly through teacher researcher logs. Secondary data, student work artifacts, came from the students after they completed the interdisciplinary lesson. A comparison of these documents together created a comprehensive and descriptive analysis. The data have the potential to become powerful evidence for reflecting on how we teach high school students mathematics and science, by answering the overall research question, “What is the described value of the experience of an interdisciplinary teaching approach for a common high school mathematics and science topic?”

**Participants**

There were three different groups of participants in the study: the teacher researcher, the students, and the teacher colleagues. The teacher researcher has been teaching at the research school for eight years and knows the students and faculty well. The students are students from the teacher researcher’s mathematics class that will volunteer to participate in the study. The students are 9th and 10th graders who have not yet been exposed to the topic of logarithms. The teacher colleagues are members of the mathematics or science department at the research school that will serve as co-designers of the unit and will then serve as a focus group after the lesson.

The students within this sample were from a variety of racial backgrounds due to the diversity of the school, however all students were female because the research school is an all-girls’ school. Students all had a similar level of mathematics and science ability, as a result of the ongoing tracking that occurs at the research school. The sampling strategies described as both convenience sampling and purposeful sampling by Creswell (2012) were followed for the study. Although the school was generous enough to serve as a location for this research, the researcher was confined by the small size of the school. The students mentioned above are not only the students available for such research, but also the only ones
taking the courses aligning with the research needs. Convenience sampling, therefore, was made a necessary selection. Since the researcher works at the research site, location and participant selection were both key factors in the decision to use purposeful sampling. The study involved twelve students and six teacher colleagues. The number of participants allowed for adequate data to identify common themes (Creswell, 2012).

**Recruitment and Access**

Since the researcher works at the research location, she already had access to all participants via the school directory and also the school email system. With assistance via the school’s computer-based scheduling program, the researcher identified potential students, based on the pre-requisite that they have not yet been exposed to logarithms in their mathematics or science classes. Parents/guardians of all eligible students were sent a letter explaining the study and requesting volunteers to participate in the study. Those interested in participating were required to sign an informed consent agreement, and since the student participants are all under the age of 18, the parents/guardians of the students also needed to sign the agreement. Participation for the students included sitting through a thirty minute lesson on logarithms from the teacher researcher and then participating in a student feedback session after the lesson. Participation for teacher colleagues included being a part of a colleague working group to plan the lesson and then a colleague focus group to debrief the lesson. As a small incentive, participants were treated to a pizza and ice cream party at the conclusion of the study. Eligible participants were also reminded that there were no consequences if they choose not to participate in the study and that their involvement in the study will help provide a needed supplement to the currently limited collection of research data on interdisciplinary units and courses.

**Data Collection**
Following the guidelines of a case study, more than one form of data was collected in the study. Data gathered during the research included several different formats: teacher researcher logs, transcriptions from audio tape recordings, student work artifacts, and student feedback. The teacher researcher logs were the notes taken, including analytic memos, by the teacher researcher after the colleague working group and in the teacher researcher’s preparation and teaching of the lesson. The researcher transcribed the audio recordings from the colleague working group and the colleague focus group. The student work artifacts were completed at the end of the students’ interdisciplinary lesson, and student feedback was provided at that time also. The researcher was only able to analyze the students’ responses to the logarithm problem on the work artifacts, withholding names to provide anonymity.

Data Storage

The teacher researcher logs, the audio recordings and transcripts, and the completed logarithm problem sheets (student work artifacts) were kept in a locked file cabinet in the home of the researcher. A master list of the types of information gathered in the study was also kept in the home of the researcher (Creswell, 2012). Only the researcher had access to the data. All materials will be destroyed three years after the conclusion of the study.

Data Analysis

The inductive analysis process for this qualitative research project followed the Descriptive Coding, or Topic Coding, methods described by Saldaña (2009). This method of coding “summarizes in a word or short phrase- most often a noun- the basic topic of a passage of qualitative data” (Saldaña, 2009, p. 88). The researcher applied descriptive, first-round codes throughout both transcriptions and also the student work artifacts. After the first-round coding process was complete, the researcher then looked for similarities among the many first-round codes. The first-round codes were grouped into categories that each fit under the main research question and that also portray application of the transformative
learning framework. The entire coding process was done using manual coding, where the researcher used “paper and pencil on hard copies of the data entered and formatted with basic word processing software only” (Saldaña, 2009, p. 25). The manual coding process was selected over the use of Computer-Assisted Qualitative Data Analysis Software (CAQDAS) due to the small sample size.

**Trustworthiness**

Creswell (1998) presents several validation strategies, and this study included a combination of several strategies in order to maintain the validity of the study. Since the teacher researcher, students, and members of the teacher working group are from the same school, the familiarity with one another helped to establish trust during the study. Researchers at the school’s connected research site, the Center for Research on Girls (CRG), assisted in a peer review of the study’s methods and interpretations. The positionality statement included as part of the final study report included a discussion of the researcher’s background and biases, and served the role of clarifying researcher bias. Finally, the process of member checking took place before the final report was completed. For this, the other teacher participants (those from the colleague working group) were given the opportunity to review the draft report in order to confirm appropriate interpretation occurred. According to Lincoln and Guba (1985), this member checking strategy is considered to be “the most critical technique for establishing credibility” (as cited in Creswell, 2013, p. 252).

Although it is impossible to completely remove all potential threats to internal validity, there were minimal threats associated with this study. The sample size was small and the location is at a school that is already attached to a research organization (Laurel School’s CRG), so all of the participants were already very familiar with the protocol for running similar studies. The majority of the student participants had already been a part of at least one other study at this school. Should any issues arise among participants that could
pose a threat to the internal validity of the study, the data from those participants could easily have been eliminated from the study if necessary.

While the sampling strategies of convenience sampling and purposeful sampling are appropriate methods for this case study, they also created a concern to the validity of the study. First, the researcher personally knew all of the students participating in the study. Second, the students themselves are not from as diverse of a background as would be ideal for this study. All students were of the female sex and have a similar ability level due to the tracking that occurs at the research school.

**Protection of Human Subjects**

This study will be conducted at one location, an independent girls’ school. Since human subjects were involved in this study, approval from Northeastern University’s Institutional Review Board’s (IRB) was obtained prior to the start of the study. In order to gain IRB approval, the researcher submitted a completed IRB application form that included details on the consent process, study procedures, associated risks, and confidentiality for all participants. In order to avoid any dilemmas when working with human subjects, the researcher demonstrated respect and ensured protection for each individual involved. Additionally, the researcher completed the web-based “Protecting Human Research Participants” training video and included the certificate of course completion in Northeastern University’s IRB application (*Appendix B*).

An informed consent agreement was signed by the other teachers involved and the parents/guardians of all students since they were under the age of 18. All procedures and processes for obtaining consent adhered to the guidelines of the IRB. A copy of the researcher’s IRB approval application and all consent forms are provided in *Appendices A and B*. The student participants were high school students between the ages of 14 and 16, a vulnerable population. Prior to being asked to sign the consent forms, all participants were
told of the purpose of the research, the research plan, and the risks and benefits of the study.

The Director of the Center for Research on Girls at Laurel School also signed a consent form (Appendix C) to acknowledge the study and grant permission for the researcher to use teachers and students from the school in the study. The school is affiliated with a national research organization, the CRG, and as a result members of the school community were familiar with the protocol for gathering research participants.

All data gathered from the study was reported in an anonymous manner. The confidentiality of each participant was preserved throughout the entire study and any identifying elements were eliminated. The other teachers in the study, those from the teacher working group, were also given the opportunity to review the draft report for accuracy and to confirm confidentiality.
Chapter 4: Report of Research Findings

This participatory case study was conducted to describe the value of the experience, both in terms of the students and the teacher, of an interdisciplinary teaching approach for a high school mathematics and science topic. The topic selected for this lesson was that of logarithms, a concept that students learn about in both their high school mathematics and science courses. The researcher invited thirty-five current 9th and 10th grade students from Laurel School who had not yet been exposed to the topic of logarithms. A total of twelve students volunteered to participate. All twelve students were currently in the researcher’s Geometry class in the 2014-2015 school year. The researcher also invited thirteen colleagues at Laurel School from both the high school mathematics and science department to serve as members of a working group and focus group. A total of six colleagues volunteered to participate: four from the science department and two from the mathematics department.

The following research questions guided this study:

1. What is the described value of the experience of an interdisciplinary teaching approach for a common high school mathematics and science topic?
2. How does an interdisciplinary teaching approach for a common high school mathematics and science topic enhance the learning experience for students?
3. How does an interdisciplinary teaching approach for a common high school mathematics and science topic enhance the learning experience for the teacher?

Following the guidelines of a participatory case study, more than one form of data was collected in the study. Data gathered during the research included several different formats: transcriptions from audio tape recordings, student work artifacts, student feedback, and teacher researcher logs. A summary of each form of data collected will follow, organized
into three overall categories: teacher researcher collaboration, student experience, teacher researcher experience.

After the researcher collected all forms of data, the inductive analysis process for this qualitative research project followed Descriptive Coding. The researcher applied descriptive, first-round codes throughout both transcriptions and also the student feedback. After the first-round coding process was complete, the researcher then looked for similarities among the many first-round codes. The first-round codes were grouped into categories, and from there a total of three themes surfaced. Details of the coding process can be viewed in Appendix J. The three themes that the majority of the first-round coding descriptors folded into are provided in Table 1.

Table 1: Three themes from descriptive coding

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<td>1.</td>
<td>Developing a shared language</td>
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<tr>
<td>2.</td>
<td>Gaining understanding of the complexities of interdisciplinary work</td>
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<tr>
<td>3.</td>
<td>Positive student experiences of interdisciplinary lesson</td>
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These three themes guided the analysis of the data. The data analysis is broken down first by the categories of data collection (teacher researcher collaboration, student experience, teacher researcher experience), followed by an explanation and discussion of the themes present.

**Teacher Researcher Collaboration**

The researcher’s collaboration with the six colleague participants provided a significant source of data. During the data analysis and written documentation of the study, pseudonyms were used for the six colleagues: Alex, Betty, Carl, David, Eliza, and Frank. The group of seven teachers first gathered together on February 17, 2015 as a colleague working group. The purpose of the working group was to discuss ideas for an interdisciplinary, introductory lesson on logarithms that the researcher would later present to
the twelve student participants. The working group met for forty-five minutes and began with an introduction from the researcher containing details of the goals of the study and the dates for both the student lesson and the follow up colleague focus group. The audio recording of the session was later transcribed by the researcher and the entire transcription can be found in Appendix D.

This same colleague working group gathered for a second time on March 10, 2015, which was five days after the researcher had presented the lesson to the student participants. The group again met for forty-five minutes and the audio of the session was recorded. The purpose of the second colleague group was to serve as a focus group for the researcher. The researcher selected the topic of earthquakes as the focus for the interdisciplinary lesson that was to serve as an introduction to logarithms. The researcher began the colleague focus group session by sharing details of the lesson she taught to the students, the worksheets the students completed (Appendices G and H), and a summary sheet containing all of the student feedback (Appendix I). The researcher then asked the colleague group for their feedback on the lesson, and suggestions for improvement if the lesson were to be taught again in the future. The audio recording of the session was later transcribed by the researcher and the entire transcription can be found in Appendix E.

Colleague working group. The researcher reminded the colleague participants that the purpose of the working group was to discuss ideas for an interdisciplinary, introductory lesson on logarithms that the researcher would later present to the twelve student participants. When the researcher asked the working group for lesson suggestions, participants mentioned that the lesson needs to provide a context for the topic of logarithms to help students understand the relationships; the use of modeling was an approach that the group agreed would help provide context. Another suggestion was that the lesson should pose an interesting question to the students in order to engage them. The colleagues also suggested
the lesson should contain terminology that will be the same in their future mathematics and science courses.

When the working group discussed the topic of logarithms and what specifically the students should learn about, three key concepts came up. First, that logarithms are often used as a convenience, to better represent either very small or very large quantities in a more simplified manner. Second, that they are directly related to exponents and making that connection for students was very important. The third concept that the working group felt was important to teach in a logarithm lesson was estimating with logarithms. The working group agreed that if students could properly ballpark estimates of different logarithms, then that would prove they have a real understanding of what logarithms are and how they work.

The researcher used the input from this colleague working group to then create a lesson for the twelve student participants. The researcher had two weeks to prepare and rehearse the lesson before it was actually taught. The lesson was then shared with the colleague group after it was taught in the colleague focus group.

**Colleague focus group.** The purpose of the second colleague group was to serve as a focus group for the researcher after the lesson was taught to the student participants. The focus group was held five days after the researcher taught the lesson. The session began with the researcher sharing details of the lesson. Based on the suggestions provided in the colleague working group, the researcher decided to use the topic of earthquakes as the center of the lesson. By selecting a topic that students will discuss in both mathematics and science classes (earthquakes), the researcher hoped this could help to provide the context students need to make connections about logarithms. After providing rationale and an overview of the lesson, the researcher shared the student work artifacts and the student feedback with the other teachers in the focus group, and then opened up the discussion.
Some details of the lesson that the focus group thought to be positive was the topic of earthquakes, the connection made between logarithms and exponents, and the estimating that students were asked to do on their own at the end of the lesson. The group thought that these ideas followed the key suggestions from the original working group. Helpful suggestions for future improvement of the lesson were also provided, such as having the students spend more time practicing estimating, and also inviting the students to think of other examples where logarithms may be useful.

A large portion of the focus group was spent discussing what interdisciplinary really means and when it can be used as an approach to best serve mathematics and science students. The group discussion waivered between waiting until students have gained mastery of two disciplines before introducing them to an interdisciplinary approach, which means in a level two high school course or at the collegiate level, or using an interdisciplinary approach as a way of planting a seed for students that they will use in future courses. The former idea that was discussed would serve a group of students on a more general track (students who may not take advanced mathematics and science courses in high school) and would be viewed as an introductory course to spark interest and make a connection for them in their future required mathematics and science courses.

**Student Experience**

In order to help investigate the research question about an enhanced learning experience for the students of an interdisciplinary teaching approach, the researcher collected two forms of data from the twelve student participants. At the end of the lesson, the teacher researcher asked students to complete a short worksheet (*Appendix G*) containing summary questions about the earthquake lesson on logarithms. After they completed the worksheet, students were also asked to respond to three reflection questions. A summary of the student work artifacts and student feedback follows. Analysis of the student feedback was done using
a descriptive coding method, the same method that was applied to the colleague group transcripts.

**Student work artifacts.** Students completed the worksheet independently at the end of the lesson, and the worksheets were collected (Appendix H). Students were instructed to not include their name anywhere on the worksheets. They used their calculators for the first three questions and were asked to put their calculator away when completing the four questions about estimating logarithms.

The questions on the worksheet were put together by the teacher researcher following the suggestions provided during the colleague working group. During that working group, two of the three key concepts that were suggested included directly relating exponents to logarithms and also focusing on estimating with logarithms. The first two questions on the worksheet were aimed at making the connection between logarithms and exponents and the last question on the worksheet was written to get a sense of how well the students understood logarithms at the end of the lesson based on their estimation skills.

All twelve students answered both the first and second questions correctly on the worksheet. Nine of the twelve students were able to correctly answer the third question, which asked students to compare the intensity of the two earthquakes given. The last question was the most difficult question since it required students to do their own estimating of different log values. All of the values asked were not ones that were discussed during the lesson. Nine of the students correctly answered parts a and b of question four, but of those nine students, only four students also answered part c correctly. There was one student who didn’t get part a or b correct but did answer part c correctly. The rest of the students were off in their estimating on all three parts of the question.
Student feedback. In the last few minutes of the lesson, after the students completed the worksheet, the teacher researcher asked students to provide feedback to any of the following three questions they were comfortable answering:

1. What did you think of today’s lesson? Please try to provide specific examples about what you liked or didn’t like.
2. How would you best describe today’s lesson to someone who didn’t attend?
3. What did you learn in today’s lesson?

Students were allowed to answer any of the questions verbally and they were also given paper if they preferred to write their answers down. All responses were collected and put into a summary chart (Appendix I).

The colleague working group helped the researcher create these three student reflection questions. The purpose of asking the questions was to gather input from students in an open-ended way. In the first question, students had the opportunity to mention something they liked or didn’t like about the lesson. This could help the researcher understand whether the interdisciplinary approach attempted was something the students enjoyed or not. The purpose of the second student feedback question posed, asking students to describe the lesson to someone who didn’t attend the class, was to see whether the lesson was described as either a mathematics or a science lesson, or if it was viewed differently. The third feedback question for students was also very open ended, asking students what they learned in the lesson. The purpose of this question was to see if students mentioned any of the key concept connections the teachers discussed in the colleague working group, such as logarithms being a form of exponents, or why logarithms can be helpful.

Teacher Researcher Experience

The third category of data collected for this study came directly from the teacher researcher in order to help provide input to the research question related to the learning
experience for the teacher. The teacher researcher kept a personal log (Appendix F) and used it to record thoughts after two different steps in the study process.

**Teacher researcher logs.** The first time the teacher researcher made notes in their personal log was after the colleague working group session on February 17, 2015. Although the session was recorded and a full transcription would later be available, the researcher spent approximately thirty minutes immediately following the working group to write down a summary of the session and key points that came up. The list created in this log ended up serving as a foundation for the researcher when later creating the lesson.

The second time the teacher researcher made notes in the log was after the student lesson held on March 5, 2015. The researcher spent again approximately thirty minutes immediately following the lesson to write down a summary of the lesson and any thoughts that she had about the student participation and responses on the worksheet. This was an important time for reflection on the lesson since the lesson itself was not recorded and therefore no transcription would be available for review later.

The teacher researcher logs were the last of the three categories of data collected during this study: teacher researcher collaboration, student experience, and teacher researcher experience. The collection of data from these three categories was guided by the study’s research questions. Three themes emerged from the descriptive coding analysis of the data: developing a shared language, gaining understanding of the complexities of interdisciplinary work, and positive student experiences of interdisciplinary lesson. Each of these themes will be described next.

**Thematic Analysis**

The data collected in this study serves as a reminder of the many complexities of interdisciplinary work. Looking at feedback from three different sources (colleagues, students, and teacher researcher) after creating and implementing an interdisciplinary lesson
allowed for the researcher to gain a broad sense of the overall experience for each group involved. This also allowed complexities to surface that were not necessary on the researcher’s radar prior to running the study. An unraveling of these complexities displayed three overall themes of this specific interdisciplinary approach.

**Developing a shared language.** A large portion of both the colleague working group and the colleague focus group was spent discussing specific language and terminology used in the mathematics and science classrooms. After nearly forty minutes of substantive discussion in the colleague working group, Betty pointed out, “I think terminology has more to do with this conversation than anything else”. These colleague discussions were full of rich exchanges and served as an exceptional listening activity for the teachers involved to get a better sense of how concepts are explained in one discipline compared to another. Throughout the discussions, the importance of having a shared language between the two disciplines became an obvious need for the interdisciplinary lesson that was created. The colleagues worked to grow a language that they all could agree on. To do this, the working group began by discussing the overall purpose of the lesson. Teachers noted that the lesson should “plant a seed” about the topic and provide students “with a better context” for why logarithms can be useful. Then, with the goal in mind, the conversation shifted to terminology—how are questions asked, and what is the context that logarithms are used in the two disciplines. The process of talking very specifically about topic context and application in each classroom ended up being an extremely valuable piece of information in moving forward with the lesson planning. In fact, it may be that the process of talking together and creating a curriculum for the new lesson that contains a shared language—one that is present and familiar in both the mathematics and science classroom—is a key component of a meaningful interdisciplinary approach. If students can attend both their mathematics and science classes hearing consistent vocabulary being used in both, then the
working group goals of planting a seed and having better context for the topic taught with the interdisciplinary approach could be considered met.

The importance of creating a shared language in interdisciplinary work implies that the teacher collaboration is a critical piece in developing interdisciplinary curriculum. In order for the colleague working group to put together a lesson, they had to prioritize and decide what the learning outcomes should be for the students attending the interdisciplinary lesson.

Gaining understanding of the complexities of interdisciplinary work. A second complexity in the puzzle of interdisciplinary work is getting to the root of what interdisciplinary really means. During the colleague focus group, Alex helped to summarize the challenge of the group’s work: “I think the goal question is an important one to answer. What is the goal of an interdisciplinary course? And in answering that you’re asking also, who is it serving?” In both of the colleague groups, the question of what is really meant by an interdisciplinary lesson was constantly asked. When it came to looking at the goal for the sample lesson, the group investigated the larger question of what is the goal of an interdisciplinary approach. Common responses included key phrases such as conceptual, context, connections, relationships, and being able to answer why.

What does interdisciplinary mean? In order to achieve the goals created by the group of a general interdisciplinary approach, the working group agreed on the incorporation of several strategies, including providing an introduction, using real world samples, modeling, and investigating phenomena. In discussing such ideas, however, there seemed to be a fine line between what some teachers were comfortable calling interdisciplinary work and what others were not. Alex explained that the use of real world examples, even actual activities or field trips, doesn’t necessarily make something interdisciplinary. For example, if a teacher takes students to clean up a river in order to study pollution, which can be done through both a mathematical and scientific lens (along with other disciplines), the result may not create
what this teacher feels is true interdisciplinary work, since, “If they [the students] don’t actually take the time to understand pollution aspect, then they’ll come up with nonsensical answers.” Betty connected that idea to the use of story problems in a mathematics classroom. Story problems in mathematics textbooks often discuss a scientific topic (such as earthquakes) and have students follow the calculation they are studying in mathematics to answer the problem associated with that science topic. In many textbooks, the term “science” is even written next to such problems, so that students can clearly see that the problem is connected to their science class. Betty explained though that this is a false sense of interdisciplinary, “Story problems are not interdisciplinary…[t]hey are just an example of a problem where you are applying the math to a science aspect.”

The discussion continued to waver between goals of the sample lesson, goals of a more general interdisciplinary approach, and strategies for implementing an interdisciplinary approach in future mathematics and science courses. The working group discussion shows what a valuable experience it can be for mathematics and science teachers to spend time together discussing ideas for interdisciplinary approaches. The group not only narrowed down some of the same descriptors the students themselves used to describe their experience, but they also went beyond the topic at hand (logarithms) and began to create strategies for future interdisciplinary approaches.

In addition to the necessity for developing a shared language necessary for working together between two disciplines, the teachers requested a specific definition for that was really meant when the researcher said they were planning an interdisciplinary lesson on logarithms. Since each teacher involved already had their own ideas around how they define interdisciplinary work, the task of trying to blend those backgrounds and understandings was a challenging one. Even after the group discussed their ideas during the working group to help create plans for the lesson, the discussion during the focus group showed that there was
still a disconnect between each teacher’s idea of true interdisciplinary work. In evaluation of the teacher researcher’s lesson on earthquakes, one teacher participant (Alex) stated:

To me, this isn’t interdisciplinary work. This is using an interdisciplinary topic to provide context to a concept in math. Where when I think of interdisciplinary work, this is a true blending of both of those things. The same way I might use a physics topic to get them to learn some math topic.

A few of the other teachers, however, felt that the lesson did provide an interdisciplinary approach to the topic of logarithms. Carl commented, “I think it is an awesome approach. I think that using something real world, something that is interesting to them is absolutely a good approach.” In response to that, Betty mentioned how simply teaching a topic that is used in more than one discipline does not make for interdisciplinary work. Betty explained:

I always feel funny about problems that included other things and calling that interdisciplinary. That to me is not interdisciplinary either. To me interdisciplinary is…like an engineering case study that you’ve got to build a chair or a bridge and so you have to bring in the science and the math, the technology, and you have to understand them or else.

It is interesting that after one thorough, forty-five minute brainstorming session for what an interdisciplinary lesson on logarithms might look like, when the same group reviewed and reflected on the lesson after it was taught, different ideas about what interdisciplinary work really looks like were still emerging. Teacher collaboration is so important in interdisciplinary work in order to establish a shared language, but those involved must be prepared for the challenge of truly understanding each participant’s background and views of interdisciplinary work in order to truly find a common plan that all participants feel satisfied with.
**Deciding student readiness.** A second difficulty for the colleague group in understanding interdisciplinary work was deciding on student readiness for interdisciplinary lessons and courses. In trying to sort out what interdisciplinary truly looks like, figuring out the ideal student skills necessary for that work also became an important part of the discussion in both the working group and the focus group. Teacher participants indicated that if the proper level of mathematical maturity isn’t present yet in a student, then it could present a problem for truly understanding what is going on with a scientific concept. Alex explained, “For me, I need your math maturity at a certain level, so you are not simultaneously learning the math and the science I’m trying to teach you. You have this level of maturity in math, so you can focus on the science.” Betty supported this thought and reminded the group that this is the reason many science courses often have a prerequisite of a specific mathematics course. The discussion was then centered on the sharing of examples of interdisciplinary courses that the teachers had read about or heard of at other schools, and what made some of them successful. The common item in the successful examples was a proper match between the course curriculum and the readiness and background of the students enrolled in the course. Betty described such a course that had actually been run at the research location more than fifteen years ago and explained why it was a success:

> [The course was] tailored to college prep kids, so in an ideal world, if you can have two faculty members working together on a course, I mean of course, that … is ideal because you had the best of both worlds, coming together with a really strong curriculum, and those girls, because then I ended up having them later in chemistry, they were as solid as could be because they had it all together in ninth grade.

The course mentioned above ran at the school for only one year since it became too difficult to sustain one course that two teachers jointly taught. There is no actual data to support the success of the course aside from statements such as the one from Betty above mentioning
how well prepared those students appeared to be in their future science courses. It was agreed on by the focus group that the perceived success was not only having two teachers working together, but also because the student ability was perfectly matched for the course curriculum. When the teacher researcher asked the group if they thought there were any other good matches for mathematics and science ability, they suggested Algebra 2 and Chemistry, and also Physics and an honors level Pre-Calculus or Calculus class. Alex was hesitant to say that such pairings could lead to success and added:

> I tend to feel, and I have no evidence to back it up, but I tend to feel that the best interdisciplinary efforts happen after the students have demonstrated mastery in the individual areas. That I actually find it very difficult to do meaningful interdisciplinary work if they are trying to simultaneously learn two different modes of thinking. When I think about a problem mathematically, I am not thinking about it in the same way I am thinking about it scientifically.

The work with the teacher colleagues in both of the group sessions in trying to understand what interdisciplinary really means showed that the concept involves so many complexities, making it difficult to find common opinions. The colleagues were all very supportive of one another, but due to the different backgrounds and experiences they each brought into the group, the goals they had in mind of interdisciplinary work varied. The other factor in the complexity of gaining a common understanding of interdisciplinary work is centered on the students and their own level of readiness for an interdisciplinary experience. Some teachers felt that this work can only happen at the advanced high school or college levels, after students have a thorough understanding of each discipline. Other teachers felt that with a true match of their mathematical and scientific ability, interdisciplinary work can begin at a younger age. All teachers agreed that having more than one teacher involved in the planning process was extremely beneficial. Overall, the colleague working group and focus group
provided the opportunity for valuable and engaging discussion about interdisciplinary mathematics and science work, but showed that the many complexities of interdisciplinary work can make it difficult to reach a common understanding about what it should look like.

Positive student experiences of interdisciplinary lesson. When asked for feedback on the lesson, student responses were positive and contained explanations such as, “A quick, easy, and fun way to learn all about logarithms.” A third piece of the interdisciplinary puzzle shown from the data comes from the student aspect and how they felt about the lesson. This interdisciplinary study showed the importance of developing a shared language and also the complexity in understanding what interdisciplinary work really is. Analysis of the student data to get a sense of their experience can also help to better understand the first two themes.

Student experience of shared language. One way to examine the student data is to determine whether students were able to experience the shared language the teacher colleague group worked to develop within the lesson. In a descriptive coding analysis of the student feedback, descriptors of the student experience were pulled from the data. There were sixteen different descriptors used by students to summarize their experience, the majority of which were the very same descriptors mentioned in the colleague working group. These descriptors that came up in the colleague working group did so when the focus of the discussion was on the goals of the interdisciplinary lesson they were helping the researcher create. Some of the common descriptors mentioned by the students in their feedback and by the colleagues in the working group were: connection, context, relatable, real-world, and understand (why). Each of these concepts mentioned by the students were listed as main goals of the sample lesson in the colleague working group. Since the students used many of the same key words that the teachers discussed in their own working group, this alignment shows that the students were able to experience much of the shared language the colleagues spent so much time talking through and developing.
**Student feedback.** Another way to analyze how students received the lesson is to look at what stood out to the students. A better sense of how the students perceived the lesson can provide understanding of whether or not there was a benefit to teaching the lesson with an interdisciplinary approach. When the students were asked, “What did you think of today’s lesson?”, their responses were all very positive. Part of this is very likely due to the fact that the teacher researcher had been all of the students’ mathematics teacher for that school year, so they had a positive working relationship with the teacher and would not want to be too negative in their responses as a result of this relationship. This at first made it seem to the researcher that the responses to this question would not be helpful in the data analysis, however a deeper look at the students’ explanations of why they thought it was a great lesson can be useful in the analysis.

One of the common descriptions students provided when asked for their thoughts on the lesson was that it was fun and easy. Positive responses such as these show that the students enjoyed their interdisciplinary experience, but their explanations as to why this was the case provided more substance to this conclusion. Some of these explanations are listed in Table 2.

**Table 2: Student explanations why they enjoyed the lesson**

| I liked how [teacher] related logarithms to real life occurrences. |
| I liked how it was broken down piece by piece so it makes sense. |
| [The teacher] did a really good job at making logarithms less scary and made them a lot easier to understand. |
| I think it was very well explained and I understood the lesson. |
| I liked relating the lesson to earthquakes, it made the lesson even more understandable. |
| It was effective, I understood the material within a short period of time. |
| I liked how we used a real life example that everyone knew about, to learn about and solve logarithms. |
| It was nice and explained well. |

These explanations from the students help us understand why they liked the lesson.

The fact that is was explained well, was broken into parts that were effective, and was related
to something that the students already understood (at least in a general way) are the main reasons the students cited. All of these components are ones that many teachers would argue should be present in any good lesson, whether it is interdisciplinary or not. However, the thorough discussions that occurred among the study’s colleague working group as they tried to better understand what interdisciplinary work really is included some components that mirrored the components present in the student explanations. In the colleague working group, as the teachers were discussing what the interdisciplinary lesson should look like, Betty mentioned that the lesson should include a modeling to real-life and an explanation of “What is the relationship, and then, oh by the way, math can help us with this”. Eliza agreed with this and further explained that the goal for the lesson is for the students to “be able to manipulate those relationships, whatever those relationships are, and to spend time trying to discuss those relationships”. The colleagues agreed that overall the lesson should give students a sense of what a logarithm is and in what circumstances it can be a useful tool for them to understand, and the student responses seem to indicate that this goal was achieved. This conclusion can be supported in the results of the student work artifacts, which was gathered from the worksheet that the students completed during the lesson. The worksheet contained four questions about logarithms and their application. All twelve students answered both the first and second questions correctly on the worksheet, and nine of the twelve students were able to correctly answer the third question, which asked students to compare the intensity of the two earthquakes given. As an introduction to logarithms, the fact that students performed well in applying what they learned on three of the four questions asked of them supports the student responses explaining why they liked the lesson.

Although the teachers may not have been able to come to the same understanding of what was meant by the term interdisciplinary, the student experience was a positive one, and many of the reasons they provided as to why indicates that the lesson was explained well,
was broken into parts that were effective, and was related to something that the students already understood (earthquakes). Some of the larger goals set up in the colleague working group when creating the lesson matched with these explanations the students had about why the enjoyed the lesson, but more questions can be raised from this analysis that link back to understanding what an interdisciplinary approach really looks like. Since the students were pleased with aspects of the lesson that could be components of a strong single discipline lesson, and the fact that the group of mathematics and science teachers had a difficult time settling in on a common understanding of interdisciplinary work, the student data in this study really ends up adding more complexities into the puzzle of interdisciplinary work rather than helping to clearly unfold the benefits of this approach. The data collected in this study serves as a reminder of the many complexities of interdisciplinary work. An unraveling of these complexities displayed that developing a shared language, gaining understanding of the complexities of interdisciplinary work, and positive student experiences of interdisciplinary lesson were the three overall themes present in this specific interdisciplinary approach.
Chapter 5: Discussion of Research Findings

The concept of an interdisciplinary curriculum is a pedagogical practice quickly gaining interest over the past decade. While educators have discussed interdisciplinary curricula for several decades, researchers only in the past ten to fifteen years are beginning to gather data as evidence of the experience and benefits of such a curricula. The aim of this study was to describe the value of the experience, both in terms of the students and the teacher, of an interdisciplinary teaching approach for a high school mathematics and science topic. This study was a participatory case study that showed what happens when students and a group of mathematics and science teachers were involved in an interdisciplinary teaching approach. The research question that guided this study was, “What is the described value of the experience of an interdisciplinary teaching approach for a common high school mathematics and science topic?” and the research sub-questions were:

How does an interdisciplinary teaching approach for a common high school mathematics and science topic enhance the learning experience for students?

How does an interdisciplinary teaching approach for a common high school mathematics and science topic enhance the learning experience for the teacher?”

A discussion of the findings from this study, both in relation to the theoretical framework and the literature review, as well as a discussion of the study’s implications, is included in this chapter.

Discussion of Findings in Relation to Theoretical Framework

This study applied the transformative framework since the research centered on creating a description of the learning experiences of students and teachers of an interdisciplinary approach, which holds the potential to transfer concepts between the two disciplines. Analysis of the research findings identified three themes, and all three of these themes have a connection to some sort of knowledge or beliefs transfer during this
experience. Looking back to Mezirow’s (1994) description of transformative learning, which considers the learners interpreting and reinterpreting of their experience as being central to their learning, both the student and teacher participants experienced some sort of transformative learning. As the teacher colleagues worked in their two sessions together to develop a shared language, they were constantly reinterpreting their own thoughts about how to discuss logarithms with students. In the end, the group agreed to certain aspects of logarithms that are important to both disciplines, and therefore transformed the language from separate disciplines into one with common context. The teacher colleagues experienced another sort of central interpretation transfer in relation to their own understanding of the term interdisciplinary. As the teacher colleagues worked to decide on the goals and purpose of the interdisciplinary lesson, they had to grapple with bigger thoughts around student readiness for interdisciplinary work and a true definition of interdisciplinary.

The students in this study also experienced a form of transformative learning. Overall the students described their experience as a positive one and mentioned how the lesson made a difficult topic seem easy to understand and relatable to something they already knew about. In this sense, students reinterpreted what they previously understood about the concept of logarithms and will hopefully approach logarithms in the future with a more open mind.

Another justification for the transformative framework in this study was in terms of the larger potential for a change of the current curriculum structure. Although the findings in this study provide educators with new insight into the experience of creating and teaching an interdisciplinary lesson, the findings do not show enough evidence to support whether or not interdisciplinary work leads to better concept mastery levels for students. There is certainly some positive indication that the process of planning and teaching an interdisciplinary lesson is a good experience for both teachers and students, but more research is needed to study whether or not such a process truly improves student learning.
Lastly, a significant transformation occurred in the teacher researcher. The experience of this study has allowed for a shift in how the teacher researcher thinks about teaching mathematics. These experiences have shown the importance of approaching lesson planning from a different perspective to make sure colleagues in the science department would agree with the approach and would feel like the mathematics students are being set up for success in their science classes as well. It is also important to note the importance of application in this approach. Since science is often the application of mathematics, having more application problems in mathematics courses can help students to bridge the gap between the two disciplines. For this teacher researcher, the transformative learning occurred in better understanding all of this and in realizing the value of taking things that are already known in terms of good teaching methods and blending them together to help students see and understand the application of the mathematics.

**Discussion of Findings in Relation to Literature**

A review of the literature on interdisciplinary approaches found that while there is an abundance of literature describing sample interdisciplinary mathematics and science courses, there is a need for additional research that examines the fundamental question of whether interdisciplinary courses can effectively bridge the two disciplines. Much like the suggestions for implementation, the literature clearly portrayed positive results from the many sample interdisciplinary courses described, but only a few of the articles contained support to back up these results. There appears to be a significant lack of clear and verified advantages for interdisciplinary courses, which leads to a possible conclusion that the literature is greatly deficient in additional studies. A considerable lack of disadvantages cited by authors of interdisciplinary courses also suggests a deficiency in substantive data. This study served to add additional insight on the experience for both the students and teachers involved in an interdisciplinary mathematics and science approach, but this study did not attempt to measure
the actual effectiveness of such an approach. A full understanding of both the experience and
the effectiveness of an interdisciplinary teaching approach is critical before educators make
any long-term decisions about curriculum changes that may include interdisciplinary work.
The effectiveness aspect of an interdisciplinary approach would require a much larger study
than was possible in this research of the student and teacher experience, but it is a study that
is greatly needed.

The concept of interdisciplinary mathematics and science courses could possibly be a
method for educators to strengthen the students’ connection to the two disciplines, and also
improve student performance overall. When it comes to the advantages, disadvantages, and
lessons learned cited among the literature, there appear to be several benefits to an
interdisciplinary course, but there is a significant need for additional research on this topic to
validate the findings by measuring the effectiveness of this approach. The findings from this
study lean towards many of the positive aspects cited in other literature about
interdisciplinary work, since the student experience was perceived as positive and the
conversations in the colleague working group and colleague focus group were extremely
helpful to the teacher researcher in planning the lesson. However, educational researchers are
only skimming the surface when it comes to thorough investigation of interdisciplinary
courses. Further examination of interdisciplinary teaching approaches can help educators
determine the value of interdisciplinary teaching methods in future curricula. If it is found
that an interdisciplinary method does allow students to experience greater transformative
learning, we can ensure students are better prepared for the future by providing more
interdisciplinary approaches in our schools.

Lastly, one final item that must be addressed in terms of the literature is the fact that
this study was conducted at a girls’ school, and the two disciplines investigated were
mathematics and science. It is well known that there is a deficit when it comes to women in
Science, Technology, Engineering, and Mathematics (STEM) career fields, so a study that incorporates an interdisciplinary teaching approach for a topic common to both the high school mathematics and science classrooms was important not only to gain a better sense of the experience of the students and teachers involved, but such a study also provides further insight into the experience of high school females in STEM classes. Researchers investigating the high school experience for females in STEM courses in order to learn more about the background for the deficit of women in STEM career fields may be able to find the data from this study beneficial in their own research. One of the features of this study that could be useful for other research is the fact that study was about a female teacher looking at ways to teach a STEM topic to a group of high school girls. Other research, centered on girls and STEM, explained that girls become more engaged when they see real life application and also when they have positive female role models; both of those pieces were present in this study. The students mentioned in their feedback that they had a positive experience, and some explained that was due to that fact that logarithms no longer seem so “scary”. Getting these students to see that a mathematics and science topic can be interesting and not as intimidating as they thought, may have an impact on how they approach their future mathematics and science courses. The key for these students was building enthusiasm around the application of the topic, showing support for one another, and making things more comfortable for them as they learned a new concept.

Implications

The problem of practice that served as the foundation for this study stemmed from the observations made by middle and high school teachers about how their students have difficulty making cognitive connections between what they have learned in one course to the other. This described difficulty transferring knowledge from one subject to the next can create the disconnect students perceive between the mathematics and science topics they
study, which can hinder students from fully understanding the depth and value of both fields. The three themes discovered in the analysis of this study provide insight into this problem of practice and can serve as a step forward in the overall research of interdisciplinary mathematics and science work.

**Implications of developing a shared language.** As the colleague working group spent time talking through what the interdisciplinary lesson should look like, they realized the importance of a shared language between the two disciplines. The process of talking together and creating a curriculum for the new lesson that contains a shared language—one that is present and familiar in both the mathematics and science classroom—turned out to be a key component to this interdisciplinary approach. Not only did the students seem to benefit from the creation of the shared language, so did the teachers. Developing a shared language allowed for engaging and deep discussions among the working group and helped all of the teachers involved to appreciate the time and opportunity they had to collaborate. In describing the experience of the interdisciplinary approach for the teachers involved (both the teacher researcher and the colleague participants), it is easy to conclude that the collaboration that occurred among the colleagues during the working group and focus group was a rewarding activity in itself.

**Implications of gaining understanding of the complexities of interdisciplinary work.** The working group discussion showed what a valuable experience it can be for mathematics and science teachers to spend time together discussing ideas for interdisciplinary approaches. These colleague conversations provided the opportunity for valuable and engaging discussion about interdisciplinary mathematics and science work, but showed that the many complexities of interdisciplinary work can make it difficult to reach a common understanding about what it should look like. Another discovered difficulty in this process was deciding on the appropriate level of student readiness for the planned interdisciplinary
work. Although the size of the group (seven teachers in total) worked well for this study and provided a wide enough variety of background with interdisciplinary approaches, the size could also be seen as an added challenge. With so many different experiences and understandings of interdisciplinary approaches being brought to the discussion, it was more difficult to find consensus on overall goals for the sample lesson than it likely would be with a smaller group. There is a tough balance when thinking about colleague groups to help plan for interdisciplinary work—more people help increase the suggestions and recommendations for the work at hand, but having too many people can also mean that the complexities of understanding the interdisciplinary approach becomes counterproductive.

**Implications of positive student experiences of interdisciplinary lesson.** In the analysis of the student data, it was observed that the students used many of the same key words that the teachers discussed in their own working group, which showed that the students were able to experience much of the shared language the colleagues spent so much time talking through and developing. The feedback from the students was positive and could indicate a successful lesson, although a lot of the student feedback could also raise more questions than conclusions. Hearing that the students thought the lesson seemed “fun” and “easy” does sound positive, but in order to better evaluate the student feedback, it would be helpful to have more details in the student explanations of why it seemed easy. This could be a difficult task since students may only be able to provide general descriptions of why they liked the lesson; they don’t have the background knowledge about interdisciplinary work and transformative learning to understand why it may or may not be beneficial for them. Reading about the positive experiences of the lesson that students described enhances the complexities of the puzzle of interdisciplinary work rather than helping to clearly unfold the benefits of this approach from the student perspective.
**Practitioner and scholarly significance.** This study of interdisciplinary mathematics and science teaching approaches was important for several reasons. First, such a study added to the current literature in this field. While the concept of interdisciplinary curricula is rapidly emerging, the need for literature that provides data to support the experience and value of interdisciplinary curricula is critical. If students can better understand the connection between the two disciplines of mathematics and science, they can be more successful in both subjects. When a student has a deeper understanding of a topic taught in mathematics that will also be applied in a science class, the student experiences transformative learning and will be better suited to identify future problems where such a process can be applied. The significance of a study such as this one on interdisciplinary mathematics and science work is that it increases the potential, in connection with other similar literature, to improve current practice for mathematics and science educators, change the shape of school curricula, and eventually result in better preparation of our students for their future. These findings can be helpful on a small scale to mathematics or science teachers looking to work together to create interdisciplinary lessons or courses, or on a larger scale for scholars choosing to add to the growing research on interdisciplinary coursework and the benefits it can provide for both students and teachers.

**Conclusion**

This participatory case study was conducted to describe the value of the experience, both in terms of the students and the teachers, of an interdisciplinary teaching approach for a the common high school mathematics and science topic of logarithms. The data collected was organized into the categories of teacher researcher collaboration, student experience, teacher researcher experience. An analysis of the data identified the three themes of developing a shared language, gaining understanding of the complexities of interdisciplinary work, and positive student experiences of interdisciplinary lesson. All three of these themes have a
connection to some sort of knowledge or beliefs transfer during this experience, which can be applied through the theoretical lens of the transformative framework.

There are several recommendations that can be made from the results of this study for educators thinking about beginning interdisciplinary work. Two or more teachers, each with a background in a different discipline, can help to develop a shared language that is needed for an interdisciplinary approach, and it is important that those teachers have a significant amount of time together for discussion and planning. Understanding the goals of the interdisciplinary work at hand and setting clear guidelines in terms of student readiness can be a daunting task that may take up more time than allotted. It is also recommended that those teachers begin by creating one interdisciplinary lesson and work to refine the lesson to better understand what their interdisciplinary approach should look like for the age and ability they are working with. Such an experience can be useful for teachers involved before diving into large-scale work such as creating a full interdisciplinary course. More specifically, Table 3 includes recommendations for Laurel School to continue the work around interdisciplinary mathematics and science approaches that this study began to investigate.

**Table 3: Recommendations for Laurel School**

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<tr>
<td>1.</td>
<td>Teacher researcher should continue to adjust mathematics lessons to include more application problems and refine lesson strategies discussed in colleague group.</td>
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<tr>
<td>2.</td>
<td>Teacher researcher should develop a brief summary of key insights from this research to share with curricular leaders at Laurel School.</td>
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<tr>
<td>3.</td>
<td>Colleague group from this study should schedule additional lunch meetings in the 2015-2016 school year to continue discussions around an interdisciplinary approach and shared language, with each meeting centered on a different shared topic.</td>
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<td>4.</td>
<td>Expand the colleague group from this study to include all Middle and Upper School mathematics and science teachers.</td>
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<td>5.</td>
<td>Document what occurs in the continued colleague discussions to gain more insight into what the group wishes to achieve, how they know whether they achieve it, and what barriers are in the way.</td>
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<tr>
<td>6.</td>
<td>Consider new ways, in addition to the already established MayTerm, to increase the Upper School teacher experience of working towards a shared language among more disciplines.</td>
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7. Ensure that with every new interdisciplinary component that is added to the curriculum there is an appropriate match of student readiness suitable for the approach.

This study served to add additional insight on the experience for both the students and teachers involved in an interdisciplinary mathematics and science approach, but this study did not attempt to measure the actual effectiveness of such an approach. A full understanding of both the experience and the effectiveness of an interdisciplinary teaching approach is critical before educators make any long-term decisions about curriculum changes that may include interdisciplinary work. Research on the effectiveness aspect of an interdisciplinary approach, especially larger studies that include analysis of the student learning outcomes of such an approach, is relevant and vital for educators thinking about the future structure of curricular systems.

As a personal reflection in this experience, this research has made a significant impact on my work as a mathematics educator. My roles of scholar practitioner and also teacher researcher in this study are now completely interwoven, and I hope to continue to move forward in understanding more about the experience of creating interdisciplinary approaches to teaching high school mathematics and science. I find myself constantly thinking about what interdisciplinary really means, what the students need to understand from concept, and how to best approach it. I am hopeful for more opportunities to work with my colleagues from the science department to continue our discussion about interdisciplinary lessons and how we can work together to further develop a shared language among our classrooms. I am now overly critical of my own lessons, especially when I begin a unit on logarithms, and am looking for ways to better incorporate the shared language and goals discussed with the science teachers at my school. The two sessions I spent talking with my colleagues about creating an interdisciplinary lesson were some of the most rewarding and thought-provoking
professional development experiences I have ever encountered, and I strongly feel that schools should make time for opportunities for such conversations to occur. Not only can the teachers benefit from these rich discussions, but students who are in the classroom of a teacher that put so much thought into just one lesson can only be better off than they would be if their teacher was not a part of such a discussion. Even if more research needs to be done comparing the student learning outcomes for interdisciplinary work versus discipline specific work, it is clear to me that anything involving such a thoughtful and positive dialogue between teachers is one that can only enhance student learning. Such experiences may be thought of as small—to have a group of teachers collaborate on one lesson with a more interdisciplinary approach—but if the number of lessons such as this one begins to grow within a school, the teachers can eventually find themselves on a path where they are incorporating multiple lessons into a more interdisciplinary course, and maybe even one day restructuring the mathematics and science curriculum to better suit their students.
References


National Academy of Sciences - National Research Council, Washington, DC Mathematical Sciences, Education Board. (1996). *Mathematics and science education around the world: What can we learn from the survey of mathematics and science opportunities (SMSO) and the third international mathematics and science study (TIMSS)?*


Appendix A: Participant Consent Forms

PARENT FORM

Northeastern University, College of Professional Studies

Name of Investigator(s): Dr. Karen Reiss Medwed (principal investigator) and Kelly Winkelhake (doctoral student)
Title: Case Study Exploring the Use of an Interdisciplinary Approach to Teach a High School Mathematics and Science Topic

Informed Consent to Participate in a Research Study
We are inviting a group of Laurel students to take part in a research study. Students do not have to participate if they do not want to; there is no consequence if they choose not to participate. If a student decides to participate, the researcher will ask the parent/guardian of the student to indicate this on the last page of this consent form, and the parent will be given a copy of the signed form to keep.

Why is this research study being done?
This study will be a case study that shows what happens when students are involved in an interdisciplinary teaching approach. The study will help to describe ways this different teaching approach could support student learning. The topic taught will be one that is often taught to students in both a math and a science class. By examining such teaching approaches, educators may be able to determine whether to consider adding more interdisciplinary lessons into the school curriculum.

What will participants be asked to do?
We are looking for two types of participants for this study:
   a) Your daughter, who is a student this year in the teacher researcher’s Geometry class. These students are 9th and 10th graders who have not yet been exposed to the topic of logarithms. Participation for your daughter will include sitting through a lesson (approximately 30 minutes) on logarithms from the teacher researcher and then participating in a student focus group discussing the lesson. Both the lesson and focus group will take place during your daughter’s regularly scheduled mathematics class.
   b) The teacher colleagues, who are members of the mathematics or science department at the research school that will serve as co-designers of the unit and will then serve as member of a focus group after the lesson.

Where will this take place and how much of my time will it take?
The study will take place at Laurel School’s Lyman campus, during the students’ regularly scheduled mathematics class. The study will take one class period (48 minutes total) and will occur on a day during the month of February.

Will I benefit by being in this research?
There are no direct benefits for the participants. As a small thank you for their time, participants will be treated to a pizza and ice cream party at the conclusion of the study.

Who will see the information about me?
The teacher researcher will take notes during the student focus group, but it will not be recorded in any way. The students will be asked to complete the lesson examples on a handout, which will be turned in to the teacher researcher at the end of the lesson. The researcher will only be able to see the students’ responses to the logarithm problems on the handout, withholding names to provide confidentiality. Your daughter’s identity as a participant in this study will not be known in the summary report that will be written about the study. Only the researcher will have access to the data. All materials will be permanently deleted three years after the conclusion of the study.

Who can I contact regarding this study?  
If you have any questions about the study or any problems to do with the study you can contact Kelly Winkelhake at 216-245-9871 or winkelhake.k@husky.neu.edu. You may also contact the Dr. Karen Reiss Medwed, the Northeastern University advisor for this study, at 617-390-4072 or k.reissmedwed@neu.edu.

Who can I contact about my rights (or my child’s rights) as a participant?  
If you have any questions about your rights in this research, you may contact Nan C. Regina, Director, Human Subject Research Protection, 960 Renaissance Park, Northeastern University, Boston, MA 02115. Tel: 617.373.4588, Email: n.regina@neu.edu. You may call anonymously if you wish.

TO THE PARENT/GUARDIAN OF A STUDENT PARTICIPANT

Please check the appropriate box below:

☐ I have read the attached information. If I have asked questions, I have received answers to these questions. I allow my daughter to participate in this research.

☐ I have read the attached information. I do not allow my daughter to participate in this research.

Printed Name of Participant: _________________________

Signature of Participant Parent/Guardian: ________________________

Date: ______________
TEACHER FORM

Northeastern University, College of Professional Studies

Name of Investigator(s): Dr. Karen Reiss Medwed (principal investigator) and Kelly Winkelhake (doctoral student)

Title: Case Study Exploring the Use of an Interdisciplinary Approach to Teach a High School Mathematics and Science Topic

Informed Consent to Participate in a Research Study

We are inviting a group of Laurel mathematics and science teachers to take part in a research study. Teachers do not have to participate if they do not want to; there is no consequence if they choose not to participate. If a teacher decides to participate, the researcher will ask them to indicate this on the last page of this consent form, and the teacher will be given a copy of the signed form to keep.

Why is this research study being done?
This study will be a case study that shows what happens when students are involved in an interdisciplinary teaching approach. The study will help to describe ways this different teaching approach could support student learning. The topic taught will be one that is often taught to students in both a math and a science class. By examining such teaching approaches, educators may be able to determine whether to consider adding more interdisciplinary lessons into the school curriculum.

What will participants be asked to do?
We are looking for two types of participants for this study:

a) Laurel students who are in the teacher researcher’s Geometry class this year. These students are 9th and 10th graders who have not yet been exposed to the topic of logarithms. Participation for the students will include sitting through a lesson (approximately 30 minutes) on logarithms from the teacher researcher and then participating in a student focus group discussing the lesson. Both the lesson and focus group will take place during the students’ regularly scheduled mathematics class.

b) Laurel teacher colleagues who are members of the mathematics or science department at the research school that will serve as co-designers of the interdisciplinary unit and will then serve as member of a focus group after the lesson.

Where will this take place and how much of my time will it take?
The study will take place at Laurel School’s Lyman campus and will include two separate sessions. One will be a working group where teachers participate in a brainstorming session (approximately 45 minutes) to help plan the interdisciplinary "intro to logarithms" lesson. The purpose of the second session, the focus group, is for the researcher to share notes on the lesson and also the student feedback, then the group can provide their thoughts on the experience. Both sessions will occur on two separate days in the month of February.

Will I benefit by being in this research?
There are no direct benefits for the participants. As a small thank you for their time, participants will be treated to a party at the conclusion of the study.

Who will see the information about me?
Both of the teacher sessions will be audio recorded. The researcher will also take notes during the sessions. Your identity as a participant in this study will not be known in the summary report that will be written about the study. Only the researcher will have access to the notes, audio recordings, and transcriptions of the audio recordings. All materials will be permanently deleted three years after the conclusion of the study.

**Who can I contact regarding this study?**
If you have any questions about the study or any problems to do with the study you can contact Kelly Winkelhake at 216-245-9871 or winkelhake.k@husky.neu.edu. You may also contact the Dr. Karen Reiss Medwed, the Northeastern University advisor for this study, at 617-390-4072 or k.reissmedwed@neu.edu.

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**TO THE PARTICIPANT:**

**Please check the appropriate box below:**

☐ I have read the attached information. I am at least 18 years of age. If I have asked questions, I have received answers to these questions. I agree to participate in this research.

☐ I have read the attached information. I do not wish to participate in this research.

**Printed Name of Participant:** __________________________

**Signature of Participant:** __________________________

**Date:** ____________
Appendix B: NIH Certificate

Certificate of Completion
The National Institutes of Health (NIH) Office of Extramural Research certifies that Kelly Winkelhake successfully completed the NIH Web-based training course “Protecting Human Research Participants”.

Date of completion: 03/09/2013
Certification Number: 1139643
Appendix C: Consent from Research Location

April 3, 2014

To Whom It May Concern:

Laurel School gives permission for Kelly Winkelhake to carry out her doctoral research study on an interdisciplinary mathematics and science unit with a group of Laurel School's Upper School girls and faculty.

Lisa Dainour, Ph.D.
Director
Center for Research on Girls at Laurel School
Appendix D: Transcription of Colleague Working Group

17 FEBRUARY 2105

RESEARCHER: WINKELHAKE

PARTICIPANTS, six total (P1-P6) [Identity removed from interview transcription]

RESEARCHER (R)

R: Thank you all for coming. I am recording now. I'm just going to give an overview—I really want this to be a working group where together we are talking about logarithms and what it would look like to introduce students to them for the first time. So I really only have the math perspective on this, right? We teach logarithms in Algebra 2 and in Honors Algebra 2, and then we study them more in depth in our precalculus courses. So what I was looking for was just other ideas, an interdisciplinary approach, if there is one, I want to know what that means for us and what it would look like—if we were going to teach our girls logarithms—an introduction to logarithms—for the very first time. What I did, to kind of start the conversation, websites have tons of resources on intro to logarithm lessons, you'll find tons of lessons, so I found kind of a typical intro to logarithm lesson and I looked at what I do in my classes as well, and they all have a similar approach. It is really just here they are, here is exponential form, here is logarithmic form, and let's go back and forth to make sure you are comfortable with that so that you understand the difference, and then in mathematics the goal in the earlier stages (I think, and P5 and P6 you can jump in), the goal is to get to a point where we have an exponential function and we use logs to help us solve something we need in that function. In advanced math courses we do other things—we look at the graphs, we look at the transformations, we try to get them to picture what the graph of natural log of x looks like, and other things. But, I want to try to focus on intro to logs, what our girls see in science, what they see in math, and how we can go from there. So, I don't know—I'll just turn it over-- I know you all have a lot of ideas, and again I want to keep our focus on introduction to logs, if you saw a lesson like this scientists, what are the things you don't think should be in it, what can we add to make it more science friendly that would help your students in your classes to have a better understanding of logs, or do you think that these types of things are already working?

P3: So this is the first question I'm ready to ask—when you come at students with logarithms for the first time, in a lesson like this, what is the rational that you provide to them, from a mathematical perspective of why this is important? Why they need to learn them.

R: To solve exponential equations. We do this right after we cover exponential equations and we use logs to solve them.

P1: So all you are doing is shifting. Why do I care about exponential equations?

R: In math, one of the main functions that we study in Algebra 2 is an exponential functions. Going back to the math approach of things, we introduce new functions and we look at inputs and outputs of those functions and we try to find when certain inputs create certain outputs. So when we do linear equations, it is lots of solving—they solve for x or y. Then we go to quadratic equations, we do a good quarter of that in Algebra 2, and we look at solving them. When x is this, what is y; when y is this, what is x. So we take the same approach and we go to exponential functions, and we talk about solving for those, when we have a word problem that leads to an exponential function and now we want to know what is the x value when our y needs to be this, that is the place where introduce logs.
P6: The reason we study exponential functions is because they are another kind of function that we can study. They are interesting.

P2: It is interesting (R) what you said initially at the very beginning, when you said is that the goals of math and science are different. Because for us as science people, we have to put our math in context. Our math has to always be in context and we have to always solve in context.

P3: We are looking at relationships among variables in the universe.

P5: And what we will talk to the kids about, there are times we are just doing equations, what we will bring into the classroom is, hey, there is phenomena in the world that you will study in your science classes, and being able to model that is good thing to predict future behavior when we don't have data for us. And there are some things that can be modeled with linear equations, and there are some phenomena that can be modeled with quadratic equations, and there are some that are exponential. When we are introducing exponential and logarithms the kids don't have a lot of exposure to that. As they get into their later classes, like (R) said, yeah, we get away from linear equations, and start talking about exponential and higher power functions and that sort of thing, so we try to present to the kids that yeah, you are going to see these things out in the real world.

P3: So these are young teenagers, and they probably in their lives, don't have a grasp of what most functional relationships are in the universe anyway. For example, they don't know intuitively, that if you invest money in the market and your making some interest on that money that that is an exponential relationship. They don't really have the context for that. So how do you context them into why it is important other than to study equations.

P1: So I'm actually going to, I take my science colleagues point, and I think very much the same way, at the same time, I think we can still pose an interesting question that is inherently mathematical, that it doesn't have to be external to the world, that I mean, I guess I'm curious, historically, why did humanity come up with logarithms. What was the driving question?

P6: How do I solve \( y = 10 \) to the \( x \)?

P1: Yeah, it might be that.

P4: Did it come from there first-- did it come from the algebraic first or did it come, and again this is as a scientist, for me a logarithm is a way to demonstrate an immense amount of information in very compact space?

P1: Yeah, I think it came from the algebraic one. If you look at the history of mathematics, I think someone sat down and said well look, what about...

P6: That's why we have rational numbers, that's why we have irrational numbers. That's why we have pretty much everything that we get.

P5: How do you solve the square root of negative 4, what does that mean?

P1: To be fair it was what's the solution to \( x \) squared plus 4 equals 0. Someone said, well I can write this down, but does it have some meaning to it. Because in the current context of what I understand about algebra and numbers, I can't come up with a meaning, and I know historically people looked at them and labeled them as nonsensical equations until that leap was made. Sorry I took a history of math and science class.
R: Do you think that is a way to start though? Is that, in a course, as we are introducing students?

P1: I think that'd be a great way to start in a mathematics course. If you are looking for an interdisciplinary course, I think what (P5) was talking about in modeling. Here is an interesting phenomena. Let's try to model it linearly. That failed. Let's try quadratically. That failed. There must be some new way to talk about this relationship. How could we get at it?

P6: How many, and I'm thinking about problems from our math books, where we have some amount of data, almost all of the examples that are exponential functions, could also be modeled well by a polynomial function.

P1: That is why you pick data sets that can't be. You completely stack the deck.

P6: But how many data points do you need to convince somebody that an exponential function is what you need compared to any other function?

P1: So my experience of this is that it is not necessarily, while the amount of data certainly plays a role, I would not want to do it with four or five data points, you also start talking about the extremes, right? What would we expect from this phenomena when x equals 0? What would we expect when time equals infinity?

P5: We call that end behavior.

P1: So that, I use that, in week 1 when we do the pendulum. It's like OK, you could fit it linearly, but then you have a y-intercept, but then you have some time when you have a pendulum with no length. Does that make sense? And their like well no, that doesn't make sense at all, I guess we have to use something else.

P2: So in physics it is the modeling, where there is that connection. In chemistry, it tends to be viewed, for example, when we talk about pH--pH is the negative log of the hydrogen ion concentration. Why we even introduce logs in that case is because the hydrogen ion concentrations are so tiny, we are talking with really tiny numbers, and anytime you have very tiny numbers or very big numbers then logarithms seem to help with the conversation because now you can talk about this thing called pH which is a very easy number in the sense that it is just, you know, nothing you have to put in scientific notation or anything like that. But the concept is always when you have a pH of 1 and you go to a pH of 2, what did that do to the hydrogen ion concentration? You've got that negative to the ten. So it is the concept that's oh so important. Before you even discuss logs, the students have to understand conceptually what's occurring in terms of pH and hydrogen ion concentrations.

P5: And exponential...then that goes back to exponential functions, which is the precursor to logarithms. Yeah, going from 10 to the first to 10 squared, what does that mean? Its not double, right. And so we expose the kids to that but does it grasp, do they grasp it conceptually.

P2: We always start with the science concept first. Math is just a way to help us.

P4: I start talking about that--sophomores have it.

P2: So when is logarithms covered again?

P5: Algebra 2.

P2: Which is when?
R: 9th, 10th, or 11th grade.

P2: But there is a band of when it is covered.

R: So the first time they see it in science is in 10th grade.

P4: Does [teacher] introduce it in biology? She does pH

P2: I don't know if she goes into logs.

P3: She does exponents, yes, but. Well in teaching regular sophomore chemistry, probably 50-75% of the kids in that class, the first time they see logarithms from a mathematics perspective is in that class. They haven't had it in their mathematics class yet. But in honors chemistry I expect that the vast majority of the kids have already seen logarithms by the time they need them. So there's this disconnect is who's really introducing them.

P4: Last year I took a day and just taught logs.

R: And what does that mean that you taught logs.

P4: Ok, how can you, and I always couch it in the science, and I view math as a tool for explaining the natural order, so it's like ok, you have this much of our hydrogen ion and it's an incredibly small number because it's a concentration. What does it mean if I make it double? What does it mean if I make it ten times? How is this affecting it? OK this is a huge range of concentration from a pH of 1 to a pH of 14, or 13.8 or whatever. So if we were to actually spread this out, there is a vast range of numbers, we need a way to deal with this so that it's more approachable. So let's figure something out and then I go into well mathematicians came up with this really cool way of shrinking down numbers so we can deal with magnitude in an easier way. And that's how I couch it.

R: And then once you show them logs, do you do, like in science, will anyone every practice logs, like let's try...

P4: We try them in terms of pH and poh, so it's in our construct.

P3: And it is base 10 logs only. Now when you get to AP chem you deal with natural logs.

P4: As well as inverse log, which in my age was anti-log.

P1: By the time you get to AP physics I just assume they can do whatever they need to with logs.

P6: Do you at any point linearize data using a log scale?

P1: In AP physics.

P3: I do it in college prep physics too. We do the pendulum. You know, there is a linearization.

P1: Yeah but you don't use a log scale.

P3: No, not like using log, log, right
P1: In honors physics everything is linear, quadratic, inverse, root, relationship, those types of things, so they are all powers.

P3: In chemistry--I mean pH is a log scale.

P4: In physics we get into it with sound decibels.

P1: Sound and drag force.

P3: Yeah, and in AP chem there are some really great relationships that can best be explained with linearizing using logarithms. It is really the first time that they really put sense to how they can extract information by linearizing data using a logarithm scale.

P2: So the key I guess in science is never really throwing an equation up on the board and saying practice. It seems like, at least with this group, we don't do that. It is always conceptually begin thinking about these variables with modeling of course, and what is the relationship, and then oh by the way math can help us with this.

P4: Yeah, it is math can make life easier, it's not let's practice.

P3: The other thing I would say is that for our scientific perspective, doing base 4 or base 7 or base 13 logarithms would be absolutely senseless unless there were some sort of relationship that can best be described by behavior in groups of 4 or 7 or 13.

P2: Because I know we can certainly get our students to do it, but the purpose for us is why have them do it.

P1: Base 2 maybe.

P4: I can see, especially if you really go down the computer science route, I can see base 6 or base 8 as well.

P5: 6?

P4: Uh hexadecimal coding is used for a lot of places.

P5: 16?

P4: Oh sorry, uh six would just be hexal coding. Is used when you have serious amounts of variables so within like programs you use on your computers to keep track of millions of variables, you use those addresses.

R: So if I have one class with the students, and they've never seen logs, we want to maybe start with modeling, have them naturally come up with logs, we would want to introduce pH, maybe talk about the chemistry application. Mathematically, what would we want them to understand? Is there anything else you would add?

P5: Well looking at this lesson, it is very much how you take logarithm. And I always start with, the way I teach logarithms, I go, I gotta write on the board.

P1: This is what you told me last year. I was [age] last year, had a masters in physics, and I never put together what I think you are about to write down.
P2: You have an engineering background.

P5: First of all I say what is the logarithm in this equation, and people tell me it is b or x, then I'll go here and say what is the square root in this equation and everybody says 7. I go OK, well now we understand what is the logarithm here, the logarithm is y. So we get through that, and then what is this equation in exponential form? B to the log equals x. What I really reinforce with the kids is a logarithm is an exponent. A logarithm is an exponent. And I think that helps then tie it into, which I guess I don't do, is that you can deal with very large numbers if you are dealing with logarithms. Because we talk about the significance of 8.25 times ten to the 6th, what is the most important number here, it is 6, and so oh yeah, it is the exponent that is really important.

P2: So what was the wow for you on this?

P1: That logs are exponents. Like literally, I can do all the manipulation, I can do log a plus log b, what is really connecting conceptually, saying to kids when you are plotting log vs log, you are plotting exponents vs exponents.

P2: And you know what is helpful, is that when they get this conceptually, do not pull out a calculator. When they can do a ballpark on the log, then you know they know what they're talking about.

P1: Now I can look at that and go oh, yeah's that's gonna be...

P2: Yeah, and that's the thing. When they can start doing that conceptually without a calculator, cause as soon as they start using calculators, I know you're going to hate me for this, the concept goes out the window.

P6: So is it important for, one of the big picture goals of learning logarithms for our students should be, this is a question, that if I have something, if I have two sets of data, and as one increases the other one increases very slowly, that a log function would be a good choice to plot. Is that something that we need to get out of it? That the log function would model it better than the square root function?

P5: But if it grows very slowly, why wouldn't a linear or quadratic function work?

P4: I think more than trying to gate where these things apply, it would be better for our students, they would be better served in walking through the logic processes of how do you determine which things apply instead of giving them a rule that if it does this, it is this.

P6: But do we want them to get to that conclusion about log functions? That they model.

P3: I think that is a very good conclusion for them to get to, but I also think that it is good for them to struggle with representing the relationships conventionally first. So you have something that changes very very slowly, right, you know slowly with x.

P6: Which is what happens when we are talking about hydrogen concentration in something or we are talking about pH.

P2: pH is minus the log of the hydrogen concentration. The hydrogen concentrations are really tiny numbers, and the pH numbers can go from 0 to 14, so in other words, those numbers, have that variance, but the concentrations are really small.
P3: I guess the way I can add it, is that you're blood is acidic. Believe it or not, if the amount of acid in your blood doubled overnight, you would never even know. It would have absolutely no effect on you. But doubling is so small that it can have absolutely no effect.

P2: Now if your pH changes, you'll die. You know like within a tenth of the range.

P3: Well you can actually handle a couple of tenths.

P2: Yeah, but anything more is over. So you can double your.

P6: So it's really about magnitude.

P5: But that discussion you just had is, I don't see how you can have that in a math classroom. Because if I double something else in me, it is gonna kill me. And so, to say that oh doubling the amount of acid is not gonna kill you, but then doubling the amount of bile, I don't know, is gonna kill me.

P3: Bullets tend to be on off. If you have none, you are OK.

P1: But this has gone so far away from what occurs at that point.

P4: And I think that becomes, especially at honors and AP, but when start to introduce and we have to talk about logs for pH, it's not something that is really easy for them to grasp conceptually like oh, it is a small amount of hydrogen ions. I honestly think, as I'm sitting here, the one that would be the easiest to grasp, and I'm willing to bet there is a phone app out there that'll let you do it, if not, we have at least one in the science wing, but is sound. Taking measurements of different levels of sound and realizing oh when I, if this sound is 30 decibels, and this sound that's too my ears is significantly louder, only registers as 38 decibels, and then all of a sudden a jackhammer is another 40 on top of that, then you start to see the scale of which your dealing with. I'm almost starting to think perhaps that can be a way to get at it just as a way for students to wrap their brains around what is physically going on. Because the pH, it is difficult to conceptualize what is going on.

P5: I'm thinking light intensity. Light intensity isn't modeled with a logarithmic scale. Isn't it just inverse square?

P1: Well the intensity is the distance squared.

P5: And so why don't we...then why do we have that scale for sound? Why don't we just do a quadratic? Or and inverse quadratic?

P1: But there is a difference here that you are talking about, both of those the intensity of them falls off as the distance squared. When you are talking about the decibel scale, you are talking about the log of the ratio of the intensity of your sound to a standard, where I don't know, there might be an astronomical discussions of light intensity, but I don't know if there is a standard.

P5: I guess what I'm thinking about all of this, as a math teacher, the kids are presented this stuff, by you guys, I want them to be able to manipulate those relationships, whatever those relationships are, and to spend time trying to discuss those relationships. You see something that can be modeled by a logarithm, here is how to do it.
P2: It is interesting because sometimes they get hit with something in our class and they've never seen it so we have to go through it and teach it our way, and then there are times when they are introduced to it the first time with you guys and they view it a different way, but that is OK. So it is a matter of where, I guess the idea here is that we know they'll be introduced in one area or another, and that we work together so that your way of teaching doesn't have to be like ours, and we don't have to teach your way, and it can't be the same. As we said initially, our goals are different. But we just have to make sure that when it comes to terminology and words that when we say what is the log of blah blah blah, they know cause they've seen it before. So I think terminology has more to do with this conversation than anything because we may put it more in context and you not, but it is more of, when the girls see it in your context, and then the come to take science course, and they say oh yeah, we absolutely know that that's the inverse because you know we've been talking about it.

P1: I think that's really important about any lesson that comes out of this. I see a lot with systems of equations, where we'll do a force problem, and we have one equation and we have another equation, and they are like, we can't solve it. They don't even recognize that that is a system of equations because

P6: It is not set up like a system.

P1: I say well you have two equations, so solve them.

P5: When you say that, is that enough for them?

P1: For about a third to a half of them. Then they are like, oh, ok. The other half..

P6: Are these two linear equations, because if they are not, well!

P1: Yes, they are linear. On the same token, when I write, even for my AP physics class, b times log a equals logs a to the b, I want them to understand why other than that's the rule for logarithms. I want them to know well oh those are just exponents.

R: Do you teach them that in science or do you just teach them how to manipulate. Is it the math piece that you want us to teach them why all of these properties are properties?

P1: That would be my personal expectation of what comes out of a math class. Numerous times I will have a quadratic equation and I'll say OK, how do you solve this and they rattle off the quadratic formula, and every once in a while I'll go, why is that the solution. Uh, because it is. I do the exact same thing with a physics question, and I know they would look dumbfounded.

P5: But I would say for our non honors kids, even if they've seen derivation, it is still very tough for them to interpret.

P3: I'll be honest, I present logarithms, pretty much as convenience. I say to them the reason we do this is because it is convenient to do so. It is a heck of a lot easier to use addition and subtraction than to use multiplication and division.

R: So do you just give them a quick run through of the properties? You just give here are the properties, here is how to use them?

P3: Sure, well we actually go through it. Like if this property in chemistry is called kw, it is the auto ionization concept for water, basically what it is is the degree to which water molecules dissociate into acid mix, and that is
a very well known value, it is 1.0 times ten to the minus 14, right, and that is always true for [ ] solution, that means as acid goes down, the base must go down, to maintain that same constant value. So logarithms make that easy. The minute you turn that into a logarithmic equation, it is like oh wow, pH plus poh equals 14. All done.

P2: So there are things we can work together on. For example, ball park figures, I'm sure you guys do this, and to go back to the problem and think, this just doesn't make sense. We got to work on that.

P5: I think it their history with these calculators. I tell them, you guys don't have the number sense that we may have, because we didn't have that. But they can explore a whole bunch of different things I never would have done.

P4: I had a discussion with a physics student this morning, because on her test she did five times 70.5 and she said 42 hundred. Ok, 5 times 7, what is it going to be? Is it where you think it is now. She said oh I must have hit a button wrong.

P2: And so like, a lesson on logarithms can be the ballpark of logs. But it is that sense, once they get that sense of what on earth is a log, what is it and what can it do for you.

R: And that will help in the math classroom when they then explore the function, and that'll help in the science classroom when they use logs. Ok-- so my task is to create this lesson, and I hope to do this in the next few weeks, and I hope to run it whenever I can make it work with my class. I am not video taping that lesson, but the girls will have a session after where they can give feedback and they'll have a worksheet as well. And then after I teach the lesson I'll go to a quiet room and just write down everything I remember from the lesson, and then I can share all of that with you after I have the lesson, but if in the next few weeks, as I'm planning my lesson, I hope it is alright to go to come to any one of you for feedback and same thing, if you think of something or you see an example or you see something in one of the books and you think it would be great to talk about, please share it with me and if it is in the next few weeks and I'll try to incorporate it in the lesson. And then I know it's gonna have a lot of flaws but I'm going to do my best, I'll put something together and the idea is to try it, to get feedback from me, on what it was like for me, to get feedback from the girls, and then to go back to all of you, we'll meet again after I do it, and I'll just give you what I have and we'll see what else we would adjust if we wanted to make it better, if we were doing this again. So thank you all, very much! I'm going to stop the recording now.
Appendix E: Transcription of Colleague Focus Group

10 MARCH 2015

RESEARCHER: WINKELHAKE

PARTICIPANTS, six total (P1-P6) [Identity removed from interview transcription]

RESEARCHER (R)

R: So we are now recording and I thank you again for coming and spending this time with me. I'm going to walk you through how I came up with the lesson, which I would love your feedback on when we get to that point, and what my overall thinking was. I went through the notes we had from our time together and I made myself a little summary of what, you know, there was a lot of information, and I left feeling like I didn't even know what to do. But then I kept trying to think about if students are going to see logs for the first time, I didn't want to bombard them the math way, which is we just show them properties and do them, do them, do them. I thought about putting them in context so that they could understand where they came about, and then I thought well let me just pick a topic that uses logs and just start from that background approach. So I picked earthquakes to be the thing I was going to use so sort of shove in there. I thought we sort of talk about them in math class a lot, we use them as example problems, and I'm sure you talk about things related to earthquakes in science classes, so I used earthquakes as my way in. So I created my lesson about earthquakes. What is the Richter scale, how do they measure earthquakes, what does it mean to have a magnitude 5, but then we looked at, when we started going down, so if you look on the lesson I just did intro on the logarithmic scale and I'm going to teach you what a log scale is and why we need it, but on the Richter scale I explained what a magnitude 3 to a magnitude 4 means, that it is 10 times greater. So then we talked about how they all have that common 10, times 10, times 10. So I used that to get into logarithms, and you must humor me, on the second page the slide that has the little guy in it, right, so I said logarithms are, and it has that little picture there and when you move the little face, it says exponents. So that was my way of trying to get them to connect exponents and logarithms, and then we did do some, this is where I felt like it was really mathy, we did some examples. What do you know about exponents, 3 squared, oh its 9. Well what if I want to write it in a different way, so we wrote it in logarithmic form. So that felt mathy to me. Then we started going back to the Richter scale--remember that times 10, times 10..., well let's look at the scale and how it has all exponents with base 10. So I used that, then we got into more details about seismographs and how they actually measured them. It is covered up because I have a little boxes on the smartboard lessons that you can slide away. But we talked about microns and what that really means, what kind of numbers we'll be getting. So I made this sample scale on the board and said well what if we have 30 microns and how do you even scale that with all of these numbers. How do we count by that and what if I had 360 microns, what does that mean on my scale, and we talked about how that came into the idea of a logarithmic scale, and then we converted it to the Richter scale. Oh, it is much easier! When you have numbers and they all count by 1, and you either have a magnitude of 4 or a magnitude of 6, it is easier to see. So I used that as my way to get in. Then we just did some problems related to earthquakes. And I was hoping they would apply what they learned about earthquakes and magnitudes and taking 10 to what power equals what number and comparing them. And then in my lesson, you'll see at the end of the worksheet, this was my way to sort of say, these are going to happen in other places, will you ever see logs again and I just put some examples and we
talked about it. I said have you ever been in science class and there are numbers that you use that are really small or really big and they said well yeah, and I said when you have that happen, that is where logarithms may come in. So that is what I did, and then I hope that these girls go to their science classes and when they see logs being used again, they'll think, oh yeah, I remember that earthquake lesson. And the math girls, I didn't do anything about the graphs of them, or what it means to create shifts of them, but hopefully they'll have a better understanding of what it is so that when they are taught it in a math class it'll be much easier. So then this is where I felt like this is what I wanted to get out of it. I had them give feedback, and I was trying to keep everything in a 30 minute timeframe, so by the time we got to the worksheet they had only about 10 minutes, not even 10 minutes left, so I asked them, we just talked about all of these earthquakes, I asked them to do questions 1 and 2, which is I thought was pretty basic. Here are earthquake magnitudes, I tried to pick interesting ones from greatest recorded magnitude and then one in Ohio and I had them write it in exponential form. So that again for me felt really mathy, but I just had such a hard time not trying to get that connection between exponents and logarithms. Then I wanted them to apply it, I had them compare and think about the Richter scale, how many more times intense was one earthquake than the other. Then the last question, this went back to (P2), in my notes from before, you said well part of it was getting them to ballpark something. We know they have it if they can really ballpark it. So this was rushed when I was creating this but I thought let me just put three things on there just to see if they know what they equal. And some of them I put where it would be a whole number but some of them I require ballparking like they really have to make an estimate. So I have the results of that I'll pass those around. After we did that, we talked again about logarithms, where will they come up, and then at the end I asked them to give feedback to three questions I had. So the results you have on this summary sheet is all 12 girls that attended and all of their feedback. This is OK, but it doesn't really tell me that much. Of course, they are my students, they are not going to say anything bad. There were some things, I liked question 3, what did you learn, because I thought what did they get, or what did they get most out of it, what was the one thing they remember. Lots of kids said Richter scale, lots said logarithms, but I was hoping more would, see someone said logarithms are exponents and I thought yes, good! So that is one of them. So some of this information is helpful just to see what they are getting out of this. The old calculator comment I told them to bring their calculators, but they all didn't so I had this bin of old scientific calculators, so if they didn't have their calculator they had to use this one, and they didn't even know how to use them. So I thought that information was good, and I still have yet to summarize (I just did the lesson on Thursday), I have them all in here and maybe you can just pass them around and look through them so that you can see, and I want you to look at the bottom where they ballparked it, what they got and then what they did on the other ones. They did the totally on their own, I didn't let them work with neighbors, and they didn't have their calculator on the last questions. They didn't work together, I told them not to put their name on it, this is so I know what you are thinking about this. Is that a good enough overview of what I did? Ok, so now I want, well, I should tell you my feedback first. I have a little summary that I wrote to myself after the lesson so I didn't forget. Some things I said, it went as rehearsed, I practiced it a few times before, I had typical participation level as I usually do with those girls in the class. One thing was that I told them not to take notes, I said oh you don't need your notebooks, this isn't a class, but then I felt like they should have because they were just sitting there watching and being engaged in the lesson but it felt like some of them may have wanted to write some things down along the way. When we did the samples on the board with the converting, they got it really fast. But then when I looked at that sheet I was surprised. When we did spot estimating on the board too, I just put up some
examples, like 10 to the 2.5, but that went well in class, but it was like two girls, and then we know which girls those are because on the worksheet they got it, but I should have done more with that because clearly not all of them understood it.

P5: I actually give my honors algebra 2 girls a question where 10 to the 2.5 is buried in a word problem and less than half see that they can actually calculate that, which always kind of surprises me. They see 2.5 and they don't think 5 halves.

R: My other thoughts are overall I had a good feeling at the end of the lesson, I felt really rushed because I was trying to fit it in the class period, I'm sure I was talking really fast, and the other thing was that I felt it took me so long to create this lesson. I researched for so long and thought about so many different ways and finally I got the earthquake and I stuck with it, but then I can't believe how long it took to get something that I was somewhat satisfied with. And I couldn't change it then because then I was teaching it two days later. So that was very eye-opening. All of that said, I want to open it up to discussion. What do you think-- was it an interdisciplinary approach? Do you think--what would you do differently? If we were doing this three more times, what would you want to change? And remember that those worksheets are being passed around so you can see what students did.

P3: I think it is an awesome approach. I think that using something real world, something that is interesting to them is absolutely a good approach. If you were to go further with this in the future you might, as you are developing your teaching of logarithms and as you are developing the unit, you might start to include some other examples, or ask the class to start bringing examples of where a logarithmic scale might be useful, right. They might come up with some interesting things. I would say that I love that you had the estimation on there because that's a skill that I think they really need to practice. I love the fact that you asked them to compare the two earthquakes and it is interesting that nobody wrote how many times more intense was the earthquake. Nobody wrote ten to the 4.1. I guess, but you really haven't taught them the exponential operations yet with this, so. The one thing that I would say in the future, and this is the math science alignment, um is we don't use microns anymore. It is now micrometers, because it is a systematic way of addressing the micrometer means times 10 to the minus 6 meters, just like millimeter means times 10 to the minus 3rd meters, so just a future tweak.

R: So that would help because the girls will see micrometers in the future?

P3: They will see micrometers in science, absolutely.

R: And if they had heard that, they may think back and remember, oh like earthquakes.

P3: Microns and angstrom are the two archaic units that used to be used and aren't as much anymore.

R: Thank you. Any other thoughts? You could be mean, it is OK.

P1: I would say, looking at the results, they were good at the more algorithmic, like oh this number goes in this location, I can move these around, and then as you noted, they had more trouble with the estimation. I wouldn't beat yourself up about that. You did this one day for 30 minutes. I wouldn't expect them to all be estimating very well after one lesson on this.
P5: For students who may not really understand powers of ten to begin with.

P4: I mean I've been working on estimation skills with some of my sophomores now for 7, 8, months and still I get estimations that are off by multiple factors of 10 because they are not looking at, oh, ok well if I'm going to divide by a thing in the thousands by a thing that is in the hundreds, it is probably going to be a single digit. They still really struggle.

P1: That being said, I do think that is a higher order skill than the first two questions. Where it is more about manipulating the location of numbers and then using a calculator to get there.

R: So what could have been different in the lesson? Should there have been a different focus, should I have spent more time working on estimating? What could have been different so that that skill would be stronger? Or do you really think it is years, it is not the best lesson in the world, it is years and years of practice?

P4: Honestly, I think it a familiarity with math and understanding at a deeper level than simply being able to chug through an equation, you have to know why does the math work this way and only then can you start to look at this and start making those jumps.

P2: Yeah, I think this is an excellent introductory. I mean this is one period and look what you've done with them, so I think this is certainly a positive thing. And your next lesson would then include more in terms of exponents in decimal form, because I think that is where some of the hiccup is because they don't realize 3.5 is between 3 and 4 and that's going to tell you a whole lot about what that number looks like.

P1: I think it is just a weird idea to consider, wait I can take 10 and raise it to some number and get 9.5? What is that number?

P2: And it is interesting that you said that this took a lot of work, which I am absolutely certain it did, where as in science, we too have to find the application, but for us it is like we have the application but we now have to start applying the math. So I think it is harder for you than it is for us.

R: Right, I can put together a "mathy" lesson in two minutes.

P2: So the fact that it is hard, you got to continue to do it, because this is going to stick with them, when they make those connections in other arenas, and some thing for us science teachers, when they make more of those connections, the chances are it is going to stick with them.

P5: I want to go back to your comment about exponents that I can take 10 and raise 10 to some number and get 9.5, but then I go back, do these kids understand exponents, I can't take ten and raise it to some number and get negative 10, and that's also a weird thought.

P6: It is also weird to think about taking 10 to the 9.5.

P5: And wow, that doesn't sound like much, but wow, that's a big number.
P6: But when we are exponentiating it, doesn't fit in with all of this really either. I mean, it does, but

P5: Putting it all together-- I mean when I am trying to have them understand logarithms, without them potentially really understanding exponents, is really a tough task because of those questions.

P3: Another application is if you took one penny and doubled it every day for a month, how much money would you have.

P1: This is always the questions, right, do you want a thousand dollars now, or [ ] every day for x number of days.

P6: I also thought it was interesting to me, R, I taught logs in trig/precalc and what we did in a week in algebra 2 I did in a day in trig/precalc. The kids are more mature mathematically, and this understanding of the exponents and understanding of numbers even, that, in geometry the girls just don't have.

P5: I'm getting off topic, to me that says that when we present stuff, whether it is math or science, especially a new topic, we are presenting a seed. They are not going to get it the first time. And there are things about exponents that have been stewing in there for a year and then you can go faster. So these kids that have had this, and I am really curious, when they start to see logarithms, are they going to be like, oh, I remember that and will they be more successful with it. But that is way down the program.

R: So on what P6 said, what about girls in earlier levels of math, if we were trying to do something really interdisciplinary, if there math maturity isn't there yet, what does that mean for what we can do in terms of their science.

P1: I thought about that a lot, because frankly for me it's I need your math maturity at a certain level, so you are not simultaneously learning the math and the science I'm trying to teach you. You have this level of maturity in math, so you can focus on the science.

P2: And that is why in our science courses we've got prerequisites for a math in many of our courses.

P4: It is something I fight with daily with chemistry students because since chemistry is a required class I'm essentially teaching algebra once or twice a week, and even today when we are doing heat transfer problems, I said OK we have an addition function inside this multiplication function, how can we isolate that variable, and it was, I had multiple students who had no clue on where to go with that. I had to go back and say let's work on isolation. Those were sophomores.

R: So when schools are trying to create interdisciplinary math and science classes, there are some schools where you don't take chemistry and you don't take algebra 2, you take interdisciplinary math and science level 2--what do you think about that? Do you wait until they get to those higher levels? Do you not put those things together until they are in physics and precalc, or can you do that with chemistry and algebra 2?
P4: I've talked to [name] quite a bit, he teaches at [location] and he teaches AP calc and AP physics C together, and I always wonder how do you get that much information in to a class. And frankly there are many pieces of calc that don't require physics or there isn't a great application, or there are many pieces of physics where it is like you don't really need calc for this, at this point. So I found that really interesting that he is able to be successful in that and I've found that he has days where they are more calc days and days that are more physics days. It just kind of shifts where your priorities are.

P2: Yeah, it is interesting, when I first came here I actually was a sub, and I subbed for [name] who was actually co-teaching with [name], and it actually was, and I was a long-term sub for it, and it was an amazing course. It tailored to college prep kids, so in an ideal world, if you can have two faculty members working together on a course, I mean of course, that to me is ideal because you had the best of both worlds, coming together with a really strong curriculum, and those girls, because then I ended up having them later on chemistry, they were as solid as could be because they had it all together in ninth grade. We called it physchem.

R: So you think as long as you making a good match with the students math ability and what they know in science, then you feel like at any level you really could put them together?

P2: Right, it is the match of that course. Honors chem would be matched with honors algebra 2. I mean that would be the ideal match there. Goodness it couldn't be any better that way, because what we do now, which is kind of, I'll go to a math teacher or they'll come to me, and say when do you do whatever, when do you do logs, and then you'll come back and say logs are anytime 9 though 12, depending on the course.

P1: So clearly this was a successful example. I tend to feel, and I have no evidence to back it up, but I tend to feel that the best interdisciplinary efforts happen after the students have demonstrated mastery in the individual areas. That I actually find it very difficult to do meaningful interdisciplinary work if they are trying to simultaneously learn two different modes of thinking. When I think about a problem mathematically, I am not thinking about it in the same way I am thinking about it scientifically.

P5: I have a questions for you- are you thinking about the specific curriculum, a physics class or a chemistry class. And what I mean by that, like a lesson like this, earthquakes. Are there topics that can be interdisciplinary that don't necessarily fit into the chemistry, and aren't a good match for the chemistry curriculum, or the physics curriculum. Or if they are, you are doing it, in a baby sense, in the combined course, and then when they see it again, because yeah, I am really curious of these 12 kids, whenever they see logarithms, is there going to be that seed that's been planted, or when they start to talk about pH, has that seed been planted, magnitude times 10, oh...but I agree, I don't think you can get deep into stuff, if they don't have that individual foundation. So that's, is there some kind of, it was a college prep course that I've always heard very positive things about that, I think part of that is because it went away, and it was like why don't we have that, but it was supposed to be a really strong course, and for college prep kids it makes sense, it didn't have to get deep into any one thing maybe in particular but it really helps them make those connections.

P1: I do think that interdisciplinary approaches do benefit kids in terms of context. I do think many kids come to my physics class and say, oh, that math makes sense to me now because I
provide a context for it. That being said, for instance, this lesson, I would be willing to bet a lot of money, that the kids in this lesson would understand less about earthquakes and logarithms than kids who just did a lesson on earthquakes or just did a lesson on logarithms. That’s my concern.

P5: I would agree with that, I don’t know if that’s necessarily a bad thing.

P1: Right, so this is the decision point, right? To me, this isn’t interdisciplinary work. This is using an interdisciplinary topic to provide context to a concept in math. Where when I think of interdisciplinary work, this is a true blending of both of those things. The same way I might use a physics topic to get them to learn some math topic.

P2: Yeah, I always feel funny about problems that included other things and calling that interdisciplinary. That to me is not interdisciplinary either. To me interdisciplinary is you know, like an engineering case study that you’ve got to build a chair or a bridge and so you have to bring in the science and the math, the technology, and you have to understand them or else

P1: Right, it is like a problem where, oh, let’s have kids clean up the river. Well, if they don’t actually take the time to understand pollution aspect, then they’ll come up with nonsensical answers.

P2: Problems are not really, well story problems are not interdisciplinary is what I’m saying. They are just an example of a problem where you are applying the math to a science aspect.

P1: It can be context rich.

P2: Yes, context rich. I like that.

P1: There is some work around context rich problems and how kids can latch on to them and have an easier time understanding the material.

P2: So I guess if we were to define interdisciplinary, it sounds like, you are saying the same thing.

P1: Yeah, that is my personal view of it. I think biophysics as interdisciplinary, right? You have to actually understand both biology and physics to be able to make a dent in that.

P2: I think engineering. You have to understand your math, your science, and your technology.

P5: But, I’m thinking about building a chair out of cardboard. I don’t know if a kid can learn the physics, or if you will, the math behind it. Oh, what makes the best structure, strengths of material, I mean, just that thought. If a kid really wanted to optimize that, by other than trial and error.
P2: Well you talk about tension, compression, center of gravity. You talk about all of the math involved. You are talking math when you are doing these projects. You are not just saying here are some sticks, put them together. But, you are right. Often that is not the case, they are doing just trial and error, especially I think in the lower grades. Not only here, but everywhere. I think it is a lot of trial and error. I’m saying, though you’ve got to know the math and that means you have to have instructors who are trained in that. They don’t have to be engineers, but they have to be trained.

R: So, P1, going on your definition of interdisciplinary, do you then think that you really can’t have an interdisciplinary lesson or a class until you are in advanced math and science?

P1: For me personally, I think at the collegiate level. Now clearly there are schools that claim to do it, and do it well, I haven’t had a chance to look at what they do, so I’m certainly open to seeing that.

P6: Or even, it seems like, a level 2 course.

P1: Ok, yeah, perhaps an AP level course that is a second year. You have to have a foundation to stand on.

P6: I think our honors precalc class is a good place to look for more opportunities to do this, because they’ve seen a lot of the mathematics that we do before. They have experience with exponents.

P5: The book we used is called functions modeling change. It’s modeling. Well I think, in college, oftentimes what is the last course you take, it is some type of a capstone. I mean, why is it the last course that you take.

P2: But there are also, in engineering programs, freshman level courses to hook you. Almost every school has them now, to hook you, where you don’t necessarily have all of the math and science. So it is really the goal. In an engineering course, it’s more, it’s not all about the math and the science, it is about optimization. It is about safety. It’s about all of these other criteria, and of course cost. These are things that you want kids to get a sense of. So therefore the goal is different. It is not do you know all the math in the world that applies to this problem, or do you know all of the science in the world. It is other things when it comes to engineering that you are trying to develop. It is developmental, it is not mastery. I don’t expect the kids to build a bridge on their own once they’ve taken this course. It is developing, not mastery.

P1: I think the goal question is an important one to answer. What is the goal of an interdisciplinary course? And in answering that you’re asking also, who is it serving? Are you trying to serve the college prep style kids and provide them a very rich context in terms of here is how these things are actually used, or are you shooting for some version of mastery with higher level kids and say well what can you do with this number?
R: Or is it just to help the teacher, because even if the kids didn’t get anything out of this lesson, it was a really good experience for me.

P2: Yeah, how do you feel about this? Would you do more application do you feel?

R: Honestly I feel scared. For algebra 2, I feel like I have to re-think the whole approach, but I don’t feel I have the time to really do that.

P2: It’s overwhelming, isn’t it, cause you know that this is really kind of a good thing.

R: And now I really see, of course our algebra 2 girls have trouble with logs. I can’t even figure out how to teach it right, so how are they supposed to get it?

P2: Excellent. Yeah, that’s true.

P5: You taught out of the discovering geometry book, right?

R: Yes.

P5: In theory it is a great book. They discover everything (each theorem)

P2: Are they problems?

P5: They give you a bunch of examples and they walk you through and you’re like, oh, so the sum of the angles of…and they leap. That’s a huge amount of work and it slows down the course.

P1: Teach them less material.

P5: Yes, it is breadth versus depth.

P2: I’m curious in math do you ever have them do an activity like how much paint is it going to take for this room? So they have to think about how it’s going to lay, what does a gallon cover. How much real world application do they actually get?

R: For me, the more advanced the course, the less we do. In geometry, I have free reign in that class. They don’t need that much for their future classes, so I can do really cool things like that in geometry. But then they get to algebra 2 and they need a lot of stuff before they take precalc next year, so we cram it, and do things like logs in a week, well I guess we did that in a few weeks, and it is hard, and they don’t get it all.

P6: Some of them do, and the rest of them we say, well, they’ll see it again in a future course.

P1: And honestly, speaking for myself, some of them get it without understanding it. There is that whole swath of your great math kids who are nailing it on the exams and stuff and really don’t understand what a log is.

P5: Oh, I don’t think until honors algebra 2 do they understand the quadratic formula. And I like to think that I help them understand it now.
P6: What does a unit for this look like, or did you not even think that far ahead?

R: I didn’t even think that far ahead. One lesson. 30 minutes. I’ve got that time to introduce them to logarithms, how do I introduce them, what do I want to do.

P6: So a lot of our introductions could be done in contexts like this, but then it is time to do more

P2: That’s a good point. An introduction to kind of hook them, and then go through more of the mathematics if you have to go in that direction.

P6: And we did do this when we taught exponents.

R: We did, we did. We started our exponential/log section, we did an activity with them. We had them roll the die, they were on this island, to see how many catch this disease and we were trying to keep track of how many survivors we had, and then we created an exponential function

P6: And I got the worst data ever. Two people died every time. It was a line.

P2: And I do the same with demos. You do a demo in science, you kind of hook em.

P4: I talked about momentum today and they were cornering me about a test they just took, so I took out a trap and said, what can you do to make that part hurt me more. And they loved it.

R: Thank you all very much. The Tuesday we return from break remember we’ll have our thank you party. Thank you again.
Appendix F: Teacher Researcher Logs

Notes after Colleague Working Group (17 February 2015)

Summary of notes to include in lesson:

- Needs to be in context; they should understand the relationships
- Pose an interesting question
- Sometimes we have an immense amount of numbers…logs can help us work with them
- Use modeling?? Given data, try linear fit, try exponential, try log…
- Logs are a convenience—they are used in: chemistry (pH), to express magnitudes, concentrations, sound,
- Logs ARE exponents!!—they need to make that connection
- Need to give them log properties—how?
- Want the TERMINOLOGY to be the same in math and science—that helps both aspects
- To know if they really get it—when they do a ballpark (no calculator) as a log!! (check this at the end of the lesson); terminology, number sense

My thoughts—use earthquakes as a way of introducing a reason for logs. Show properties, but connect them to exponential properties (logs are exponents). Stick with common log for now (base 10)? Logs are practical in a lot of other places (so they know when and why they may see them again). The graphs of logs have some cool connections to graphs of exponents. Do some quick ball-parking at the end to see if they can manipulate and understand what a log means.

Notes after Interdisciplinary Lesson and Student Focus Group (5 March 2015)

Lesson went as I had rehearsed

Usual participation level as with my normal class with them

I didn’t have them take notes—just asked them to follow along with the lesson—maybe they should have taken notes?

They seemed to quickly be able to convert from exponential form to log form

Asked them to do a spot estimate for log (base 10) of 130 and they came up with 2.1 (10^2.1 is about 126)—pretty good estimate!

They didn’t all have their calculators so I had them use the extra set, which they didn’t know as well, so some of them had trouble raising something to a power on their calculator—took a bit longer for me to show them all this
After the notes, we did the first question on the worksheet together, then I had them do questions 2, 3, and 4 on their own. Will look at results later and compile summary.

Asked them three questions (see my notes)—seem to get lots of helpful responses. Will look at notes later and compile summary.

Overall, good feeling after lesson. I put a lot of work into it and it seemed to go by so fast (about 30 minutes on the lesson)!
Appendix G: Student Worksheet

Earthquake Lesson Worksheet

1. The greatest recorded Richter Scale value for an earthquake is 9.5. It occurred in Chile in 1960.
   a. Write this Richter Scale value as a basic exponential equation. \(10^? = ?\)
   b. Using the logarithmic definition of a Richter Scale value, write the basic logarithmic equation for this Richter Scale reading. \(\log_? ? = ?\)

2. The greatest Richter Scale value for an earthquake in the Ohio area is 5.4. It occurred in western Ohio in 1937.
   a. Write this Richter Scale value as a basic exponential equation. \(10^? = ?\)
   b. Using the logarithmic definition of a Richter Scale value, write the basic logarithmic equation for this Richter Scale reading. \(\log_? ? = ?\)

3. Write a statement that identifies how many times more intense the Chile earthquake was than the Ohio earthquake.

4. Without a calculator, estimate the value of the following logarithms:
   a. \(\log_{10}100 = \)
   b. \(\log_{10}120 = \)
   c. \(\log_418 = \)
Appendix H: Student Work Artifacts

*Earthquake Lesson Worksheet*

1. The greatest recorded Richter Scale value for an earthquake is **9.5**.
   
   It occurred in Chile in 1960.
   
   a. Write this Richter Scale value as a basic exponential equation. \((10^7 = ?)\)
   
   \[ 10^9.5 = 3,162,277,665 \]
   
   b. Using the logarithmic definition of a Richter Scale value, write the basic logarithmic equation for this Richter Scale reading. \((\log_{10} ? = ?)\)
   
   \[ \log_{10} 3,162,277,665 = 9.5 \]

2. The greatest Richter Scale value for an earthquake in the Ohio area is **5.4**.
   
   It occurred in western Ohio in 1937.
   
   a. Write this Richter Scale value as a basic exponential equation. \((10^7 = ?)\)
   
   \[ 10^{5.4} = 251,189 \]
   
   b. Using the logarithmic definition of a Richter Scale value, write the basic logarithmic equation for this Richter Scale reading. \((\log_{10} ? = ?)\)
   
   \[ \log_{10} 251,189 = 5.4 \]

3. Write a statement that identifies how many times more intense the Chile earthquake was than the Ohio earthquake.

   \[ 10^{4.1} \text{ or } 12,589.3 \text{ times} \]

4. Without a calculator, estimate the value of the following logarithms;
   
   a. \( \log_{10} 100 = 2 \) (This is exact)
   
   b. \( \log_{10} 120 \approx 1.07 \)
   
   c. \( \log_{10} 18 = 2.02 \)
Earthquake Lesson Worksheet

1. The greatest recorded Richter Scale value for an earthquake is **9.5**.
   
   It occurred in Chile in 1960.
   
   a. Write this Richter Scale value as a basic exponential equation. \((10^9 = ?)\)
   
   \[ 10^{9.5} = 3,162,277,676 \text{ microns} \]
   
   b. Using the logarithmic definition of a Richter Scale value, write the basic logarithmic equation for this Richter Scale reading. \((\log_{10} ? = ?)\)
   
   \[ \log_{10} 3,162,277,676 = 9.5 \]

2. The greatest Richter Scale value for an earthquake in the Ohio area is **5.4**.

   It occurred in western Ohio in 1937.
   
   a. Write this Richter Scale value as a basic exponential equation. \((10^9 = ?)\)
   
   \[ 10^{5.4} = 251183 \text{ m} \]
   
   b. Using the logarithmic definition of a Richter Scale value, write the basic logarithmic equation for this Richter Scale reading. \((\log_{10} ? = ?)\)
   
   \[ \log_{10} 251183 = 5.4 \]

3. Write a statement that identifies how many times more intense the Chile earthquake was than the Ohio earthquake.
   
   \[ \frac{10^{9.5}}{10^{5.4}} \]

4. Without a calculator, estimate the value of the following logarithms:
   
   a. \( \log_{10} 100 = 2 \)
   
   b. \( \log_{10} 120 = 1.1 \)
   
   c. \( \log_{10} 18 = 1.2 \)
Earthquake Lesson Worksheet

1. The greatest recorded Richter Scale value for an earthquake is **9.5**.
   
   It occurred in Chile in 1960.
   
   a. Write this Richter Scale value as a basic exponential equation. \(10^9.5 = ?\)
   \[
   10^{9.5} = 3162277.660
   \]
   
   b. Using the logarithmic definition of a Richter Scale value, write the basic logarithmic equation for this Richter Scale reading. \(\log_{10} ? = ?\)
   \[
   \log_{10} 3162277.660 = 9.5
   \]

2. The greatest Richter Scale value for an earthquake in the Ohio area is **5.4**.
   
   It occurred in western Ohio in 1937.
   
   a. Write this Richter Scale value as a basic exponential equation. \(10^5.4 = ?\)
   \[
   10^{5.4} = 251189.9
   \]
   
   b. Using the logarithmic definition of a Richter Scale value, write the basic logarithmic equation for this Richter Scale reading. \(\log_{10} ? = ?\)
   \[
   \log_{10} 251189.9 = 5.4
   \]

3. Write a statement that identifies how many times more intense the Chile earthquake was than the Ohio earthquake.
   \[
   (4.1) \times 10^{4.1} = 12589.3
   \]

4. Without a calculator, estimate the value of the following logarithms:
   
   a. \(\log_{10} 100 = ?\)
   \[
   2
   \]
   
   b. \(\log_{10} 120 = ?\)
   \[
   2.1
   \]
   
   c. \(\log_4 18 = ?\)
   \[
   2
   \]
Earthquake Lesson Worksheet

1. The greatest recorded Richter Scale value for an earthquake is $9.5$.
   
   It occurred in Chile in 1960.
   
   a. Write this Richter Scale value as a basic exponential equation. \(10^9 = ?\)
   \[10^{9.5} = 3.162277660\]
   
   b. Using the logarithmic definition of a Richter Scale value, write the basic logarithmic equation for this Richter Scale reading. \(\log_{10} ? = ?\)
   \[\log_{10} 3.162277660 = 9.5\]

2. The greatest Richter Scale value for an earthquake in the Ohio area is $5.4$.
   
   It occurred in western Ohio in 1937.
   
   a. Write this Richter Scale value as a basic exponential equation. \(10^5 = ?\)
   \[10^{5.4} = 251188.6432\]
   
   b. Using the logarithmic definition of a Richter Scale value, write the basic logarithmic equation for this Richter Scale reading. \(\log_{10} ? = ?\)
   \[\log_{10} 251188.6432 = 5.4\]

3. Write a statement that identifies how many times more intense the Chile earthquake was than the Ohio earthquake.
   The Chile earthquake was $12,589,26412$ more intense than the Ohio earthquake.

4. Without a calculator, estimate the value of the following logarithms:
   a. \[\log_{10} 100 = ?\]
   \[\log_{10} 100 = 2\]
   
   b. \[\log_{10} 120 = ?\]
   \[\log_{10} 120 = 2.1\]
   
   c. \[\log_{4} 18 = ?\]
   \[\log_{4} 18 = 4.2\]
Earthquake Lesson Worksheet

1. The greatest recorded Richter Scale value for an earthquake is **9.5**.

   It occurred in Chile in 1960.
   
   a. Write this Richter Scale value as a basic exponential equation. \((10^? = ?)\)
   \[
   10^{9.5} = 3,162,277,660
   \]
   
   b. Using the logarithmic definition of a Richter Scale value, write the basic logarithmic equation for this Richter Scale reading. \((\log_{10} ? = ?)\)
   \[
   \log_{10} 3,162,277,660 = 9.5
   \]

2. The greatest Richter Scale value for an earthquake in the Ohio area is **5.4**.

   It occurred in western Ohio in 1937.
   
   a. Write this Richter Scale value as a basic exponential equation. \((10^? = ?)\)
   \[
   10^{5.4} = 251,189
   \]
   
   b. Using the logarithmic definition of a Richter Scale value, write the basic logarithmic equation for this Richter Scale reading. \((\log_{10} ? = ?)\)
   \[
   \log_{10} 251,189 = 5.4
   \]

3. Write a statement that identifies how many times more intense the Chile earthquake was than the Ohio earthquake.
   \[
   9.5 - 5.4 = 4.1
   \]
   \[
   10^{4.1} = 2,589,3
   \]

4. Without a calculator, estimate the value of the following logarithms:
   
   a. \(\log_{10} 100 = 2\)

   b. \(\log_{10} 120 = 2.1\)

   c. \(\log_{10} 18 = 2\)
**Earthquake Lesson Worksheet**

1. The greatest recorded Richter Scale value for an earthquake is **9.5**.
   
   It occurred in Chile in 1960.
   
   a. Write this Richter Scale value as a basic exponential equation. \((10^9 = ?)\)
   
   \[
   10^{9.5} = 3.162 \times 10^{9.6}
   \]
   
   b. Using the logarithmic definition of a Richter Scale value, write the basic logarithmic equation for this Richter Scale reading. \((\log_{10} ? = ?)\)
   
   \[
   \log_{10} 3.162 \times 10^{9.6} = 9.5
   \]

2. The greatest Richter Scale value for an earthquake in the Ohio area is **5.4**.
   
   It occurred in western Ohio in 1937.
   
   a. Write this Richter Scale value as a basic exponential equation. \((10^5 = ?)\)
   
   \[
   10^{5.4} = 251,188.4432
   \]
   
   b. Using the logarithmic definition of a Richter Scale value, write the basic logarithmic equation for this Richter Scale reading. \((\log_{10} ? = ?)\)
   
   \[
   \log_{10} 251,188.4432 = 5.4
   \]

3. Write a statement that identifies how many times more intense the Chile earthquake was than the Ohio earthquake.
   
   It is **4.1 times greater** than the Ohio earthquake.

4. Without a calculator, estimate the value of the following logarithms:
   
   a. \(\log_{10} 100 = 2\)
   
   b. \(\log_{10} 120 = 2.13\)
   
   c. \(\log_{10} 18 = 2.02\)
Earthquake Lesson Worksheet

1. The greatest recorded Richter Scale value for an earthquake is 9.5.
   It occurred in Chile in 1960.
   a. Write this Richter Scale value as a basic exponential equation. \(10^7 = ?\)
      \[10^{9.5} = 3.162, 277, 646\, mm\]
   b. Using the logarithmic definition of a Richter Scale value, write the basic logarithmic equation for this Richter Scale reading. \(\log_2 ? = ?\)
      \[\log_{10} 3.162, 277, 646 = 9.5\]

2. The greatest Richter Scale value for an earthquake in the Ohio area is 5.4.
   It occurred in western Ohio in 1937.
   a. Write this Richter Scale value as a basic exponential equation. \(10^7 = ?\)
      \[10^{5.4} = 251, 186, 643\, \text{?}\]
   b. Using the logarithmic definition of a Richter Scale value, write the basic logarithmic equation for this Richter Scale reading. \(\log_2 ? = ?\)
      \[\log_{10} 251, 186, 643 = 5.4\]

3. Write a statement that identifies how many times more intense the Chile earthquake was than the Ohio earthquake.
   \[10^{5.4} \text{ times}\]

4. Without a calculator, estimate the value of the following logarithms:
   a. \(\log_{10} 1000\) =
      \[1,000,000,000,000,000\]
   b. \(\log_{10} 120\) =
      \[1,200,000,000,000,000\]
   c. \(\log_4 18\) =
      \[4,000,000,000,000,000\]
Earthquake Lesson Worksheet

1. The greatest recorded Richter Scale value for an earthquake is **9.5**.
   It occurred in Chile in 1960.
   a. Write this Richter Scale value as a basic exponential equation. \(10^9 = ?\)
      \[
      10^{4.5} = 3,622,777,660
      \]
   b. Using the logarithmic definition of a Richter Scale value, write the basic logarithmic equation for this Richter Scale reading. \(\log_{10} ? = ?\)
      \[
      \log_{10} 3,622,777,660 = 9.5
      \]

2. The greatest Richter Scale value for an earthquake in the Ohio area is **5.4**.
   It occurred in western Ohio in 1937.
   a. Write this Richter Scale value as a basic exponential equation. \(10^9 = ?\)
      \[
      10^{5.4} = 251,88,641
      \]
   b. Using the logarithmic definition of a Richter Scale value, write the basic logarithmic equation for this Richter Scale reading. \(\log_{10} ? = ?\)
      \[
      \log_{10} 251,88,641 = 5.4
      \]

3. Write a statement that identifies **how many times more intense** the Chile earthquake was than the Ohio earthquake.
   The earthquake in Chile was **10 x** more intense than the one in Ohio.

4. Without a calculator, estimate the value of the following logarithms:
   a. \(\log_{10} 100 = 2\)
   b. \(\log_{10} 120 = 2.1\)
   c. \(\log_{10} 18 = 1.3\)
Earthquake Lesson Worksheet

1. The greatest recorded Richter Scale value for an earthquake is **9.5**.

   It occurred in Chile in 1960.

   a. Write this Richter Scale value as a basic exponential equation. \(10^2 = ?\)

   \[
   10^{9.5} = 3.1 \times 10^{21.7}, \text{ or } 3.1 \times 10^{24}
   \]

   b. Using the logarithmic definition of a Richter Scale value, write the basic logarithmic equation for this Richter Scale reading. \((\log_{10} ? = ?)\)

   \[
   \log_{10} 3.1 \times 10^{21.7}, \text{ or } 3.1 \times 10^{24} = 4.5
   \]

2. The greatest Richter Scale value for an earthquake in the Ohio area is **5.4**.

   It occurred in western Ohio in 1937.

   a. Write this Richter Scale value as a basic exponential equation. \(10^2 = ?\)

   \[
   10^{5.4} = 251,189
   \]

   b. Using the logarithmic definition of a Richter Scale value, write the basic logarithmic equation for this Richter Scale reading. \((\log_{10} ? = ?)\)

   \[
   \log_{10} 251,189 = 5.4
   \]

3. Write a statement that identifies how many times more intense the Chile earthquake was than the Ohio earthquake.

   The earthquake in Chile was \(10^{4.4}\) times more intense than the Ohio earthquake, which is 12.5 times.

4. Without a calculator, estimate the value of the following logarithms:

   a. \(\log_{10} 100 = 2\)

   b. \(\log_{10} 120 \approx 2.1\)

   c. \(\log_{10} 18 \approx 2.1\)
Earthquake Lesson Worksheet

1. The greatest recorded Richter Scale value for an earthquake is 9.5.
   It occurred in Chile in 1960.
   a. Write this Richter Scale value as a basic exponential equation. \(10^9 = ?\)
      \(10^{9.5} = 316227760\)
   b. Using the logarithmic definition of a Richter Scale value, write the basic logarithmic equation for this Richter Scale reading. \(\log_{10} ? = 9.5\)
      \(\log_{10} 316227760 = 9.5\)

2. The greatest Richter Scale value for an earthquake in the Ohio area is 5.4.
   It occurred in western Ohio in 1937.
   a. Write this Richter Scale value as a basic exponential equation. \(10^5 = ?\)
      \(10^{5.4} = 251188\)
   b. Using the logarithmic definition of a Richter Scale value, write the basic logarithmic equation for this Richter Scale reading. \(\log_{10} ? = 5.4\)
      \(\log_{10} 251188 = 5.4\)

3. Write a statement that identifies how many times more intense the Chile earthquake was than the Ohio earthquake.
   \(10^{1.41} = 2589\)

4. Without a calculator, estimate the value of the following logarithms:
   a. \(\log_{10} 100 = \) 2
   b. \(\log_{10} 120 = \) 2.1
   c. \(\log_{10} 18 = \) 1.4
Earthquake Lesson Worksheet

1. The greatest recorded Richter Scale value for an earthquake is 9.5.
   It occurred in Chile in 1960.
   a. Write this Richter Scale value as a basic exponential equation. \(10^9.5 = \text{?}\)

   \[
   10^{9.5} = 316,227,7660
   \]

   b. Using the logarithmic definition of a Richter Scale value, write the basic logarithmic equation for this Richter Scale reading. \((\log_{\text{?}} \text{?} = \text{?})\)

   \[
   \log_{10} 316,227,7660 = 9.5
   \]

2. The greatest Richter Scale value for an earthquake in the Ohio area is 5.4.
   It occurred in western Ohio in 1937.
   a. Write this Richter Scale value as a basic exponential equation. \(10^5.4 = \text{?}\)

   \[
   10^{5.4} = 254,888
   \]

   b. Using the logarithmic definition of a Richter Scale value, write the basic logarithmic equation for this Richter Scale reading. \((\log_{\text{?}} \text{?} = \text{?})\)

   \[
   \log_{10} 254,888 = 5.4
   \]

3. Write a statement that identifies how many times more intense the Chile earthquake was than the Ohio earthquake.

   \[
   10,000 \text{ times more intense}
   \]

4. Without a calculator, estimate the value of the following logarithms:
   a. \(\log_{10} 100 = \text{?}\)

   b. \(\log_{10} 120 = \text{?}\)

   c. \(\log_{10} 18 = \text{?}\)

   a. \(\log_{10} 100 = 2\)

   b. \(\log_{10} 120 = 2.1\)

   c. \(\log_{10} 18 = 2.05\)
**Earthquake Lesson Worksheet**

1. The greatest recorded Richter Scale value for an earthquake is **9.5**.
   
   It occurred in Chile in 1960.
   
   a. Write this Richter Scale value as a basic exponential equation. \(10^9.5 = ?\)
      
      \[
      10^{9.5} = 3.162, 277, 000
      \]
   
   b. Using the logarithmic definition of a Richter Scale value, write the basic logarithmic equation for this Richter Scale reading. \(\log_{10} ? = ?\)
      
      \[
      \log_{10} 3.162 \times 10^{77} = 9.5
      \]

2. The greatest Richter Scale value for an earthquake in the Ohio area is **5.4**.
   
   It occurred in western Ohio in 1937.
   
   a. Write this Richter Scale value as a basic exponential equation. \(10^5.4 = ?\)
      
      \[
      10^{5.4} = 251, 189
      \]
   
   b. Using the logarithmic definition of a Richter Scale value, write the basic logarithmic equation for this Richter Scale reading. \(\log_{10} ? = ?\)
      
      \[
      \log_{10} 251, 189 = 5.4
      \]

3. Write a statement that identifies **how many times more intense** the Chile earthquake was than the Ohio earthquake.
   
   \(10^{5.4} \rightarrow \text{Chile is} ~ 1, 251, 189 \times 3 \text{ more intense.}\)

4. Without a calculator, estimate the value of the following logarithms:
   
   a. \(\log_{10} 100 = 2\)
      
   b. \(\log_{10} 120 = 2.1\)
      
   c. \(\log_{10} 18 = \text{About} 2.1\)
Appendix I: Student Feedback

Question 1: What did you think of today’s lesson? Please try to provide specific examples about what you liked or didn’t like.

- It was nice and explained well. Now I know how earthquakes are measured and the reason.
- I liked how [teacher] related logarithms to real life occurrences.
- I really enjoyed this lesson, it was fun.
- Today’s lesson was very helpful and very engaging. I liked how we used a real life example that everyone knew about, to learn about and solve logarithms.
- I liked that it taught me more about the Richter scale, and I also learned an important math skill.
- I liked relating the lesson to earthquakes, it made the lesson even more understandable.
- It was great; it was explained very nicely. The only thing I didn’t like about it was that it involved exponents (haha)!
- I liked it. The beginning as especially easy to understand, but I could have used more practice with the estimating. Overall, I really enjoyed it.
- I think it was very well explained and I understood the lesson. I liked how it was broken down piece by piece so it makes sense.
- It was effective, I understood the material within a short period of time, the format was good.
- I thought today’s lesson was really helpful, I understand logs now but I just am not sure how it went right with math because the learning math part wasn’t as explicit I felt like…does that make sense?
- I thought it was a lot of fun. [Teacher] did a really good job at making logarithms less scary and made them a lot easier to understand.

Question 2: How would you best describe today’s lesson to someone who didn’t attend?

- Logarithms are an easier way to describe big number scales.
- It explained how to learn logarithms in a simple and relatable way.
- It was fun.
- I learned something new that I did not know before and could easily explain what I learned to them.
- We learned about logarithms and earthquakes and how they apply to each other.
- I would describe the Richter scale as the scale used to determine intensity of an earthquake, the scale used logarithms.
- Easily taught, fun, interesting, engaging.
- It was clear and easy to understand. The earthquake made it easier to understand logs.
- I would say that we learned about logarithms and basically worked with exponents.
- It was short and sweet and it explained in detail the basics of logs and how they are used.
- We learned about logs and how they worked with earthquakes and how logs are huge and small numbers.
- A quick, easy, and fun way to learn all about logarithms.

Question 3: What did you learn in today’s lesson?

- Logarithms and how they connect to earthquakes.
- It taught me something new and important in an easy way to understand.
- Logarithms and the Richter scale.
- I learned about the Richter scale and logarithms.
- I learned about logarithms, which I knew nothing about before and learned about how you use them in the Richter scale.
- Logarithms.
- More about exponents and how they are used in math and science in real-life examples.
- Logarithms are exponents written differently and logarithms are actually pretty easy.
- I learned basically everything new about earthquakes and logarithms because I didn’t know much of anything before.
- I learned about how logs are used and how to do them. I know have a background for next time.
- Logs, what the Richter scale meant, how to use an old calculator.
- I learned the basics of logarithms and how they are easily applicable to the real world.
Appendix J: Coding Method

**FIRST ROUND CODING**

Manual approach (pencil and paper) in the margins of the two transcripts (Appendices D and E) and also the student feedback (Appendix I)

<table>
<thead>
<tr>
<th>Student feedback</th>
<th>Colleague feedback</th>
</tr>
</thead>
<tbody>
<tr>
<td>apply logs</td>
<td>advanced math/science</td>
</tr>
<tr>
<td>big and small numbers</td>
<td>after students have mastery</td>
</tr>
<tr>
<td>broken down</td>
<td>algebraic</td>
</tr>
<tr>
<td>clear</td>
<td>algorithmic</td>
</tr>
<tr>
<td>connection</td>
<td>application</td>
</tr>
<tr>
<td>earthquakes</td>
<td>background on logs</td>
</tr>
<tr>
<td>easy</td>
<td>ballpark</td>
</tr>
<tr>
<td>effective</td>
<td>base 10</td>
</tr>
<tr>
<td>engaging</td>
<td>benefit is context</td>
</tr>
<tr>
<td>estimating</td>
<td>biophysics</td>
</tr>
<tr>
<td>exponents</td>
<td>capstone</td>
</tr>
<tr>
<td>fun</td>
<td>coding</td>
</tr>
<tr>
<td>great</td>
<td>collegiate</td>
</tr>
<tr>
<td>helpful</td>
<td>compact space</td>
</tr>
<tr>
<td>how to use logs</td>
<td>conceptual</td>
</tr>
<tr>
<td>interesting</td>
<td>connection</td>
</tr>
<tr>
<td>less scary</td>
<td>connections make it stick</td>
</tr>
<tr>
<td>log intro</td>
<td>context for science</td>
</tr>
<tr>
<td>made sense</td>
<td>context rich</td>
</tr>
<tr>
<td>math skill</td>
<td>convenience</td>
</tr>
<tr>
<td>nice</td>
<td>demo</td>
</tr>
<tr>
<td>not explicit math</td>
<td>depth vs breadth</td>
</tr>
<tr>
<td>quick</td>
<td>developing vs mastery</td>
</tr>
<tr>
<td>-------</td>
<td>-----------------------</td>
</tr>
<tr>
<td>real life/real world</td>
<td>different view and goals</td>
</tr>
<tr>
<td>relatable</td>
<td>discover</td>
</tr>
<tr>
<td>Richter</td>
<td>engineering</td>
</tr>
<tr>
<td></td>
<td>estimation</td>
</tr>
<tr>
<td></td>
<td>example: investments</td>
</tr>
<tr>
<td></td>
<td>example: pendulum</td>
</tr>
<tr>
<td></td>
<td>excellent intro</td>
</tr>
<tr>
<td></td>
<td>exponents</td>
</tr>
<tr>
<td></td>
<td>exponents and logs</td>
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<tr>
<td></td>
<td>familiarity</td>
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<tr>
<td></td>
<td>fight in chemistry</td>
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<td></td>
<td>goals</td>
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<td>grasp</td>
</tr>
<tr>
<td></td>
<td>hard work</td>
</tr>
<tr>
<td></td>
<td>hiccup--number sense</td>
</tr>
<tr>
<td></td>
<td>history of logs</td>
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<tr>
<td></td>
<td>honors precalculus</td>
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<tr>
<td></td>
<td>ideal two teachers</td>
</tr>
<tr>
<td></td>
<td>interdisciplinary</td>
</tr>
<tr>
<td></td>
<td>intro to hook students</td>
</tr>
<tr>
<td></td>
<td>introduce</td>
</tr>
<tr>
<td></td>
<td>isolate variable</td>
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<tr>
<td></td>
<td>level 2 course</td>
</tr>
<tr>
<td></td>
<td>light intensity</td>
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<td></td>
<td>log scale</td>
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<td>magnitude</td>
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<td></td>
<td>manipulate properties</td>
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<tr>
<td></td>
<td>match ability</td>
</tr>
<tr>
<td></td>
<td>math helps science concepts</td>
</tr>
<tr>
<td></td>
<td>math maturity</td>
</tr>
<tr>
<td></td>
<td>modeling</td>
</tr>
<tr>
<td></td>
<td>more examples</td>
</tr>
<tr>
<td></td>
<td>need foundation</td>
</tr>
<tr>
<td></td>
<td>no calculator</td>
</tr>
<tr>
<td></td>
<td>no exposure</td>
</tr>
</tbody>
</table>
no microns/alignment
no specific curriculum; concept instead
not interdisciplinary
other bases? overwhelming
pH phenomena
physics, biology, chemistry
practice
present a seed
provide context
purpose
put together
rational
real world
real world application
really small
relationships
same terminology
see it again
serving who?
shift priorities
simultaneously
slow process
solid
solve exponential equations
sound decibels
stack deck of data
starting activity
story problems
strong curriculum
struggle
study functions
tiny numbers
to model
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<tr>
<th><strong>tool</strong></th>
<th><strong>trial and error</strong></th>
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</thead>
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<tr>
<td><strong>trouble estimating</strong></td>
<td><strong>understand why</strong></td>
</tr>
<tr>
<td><strong>vast range</strong></td>
<td><strong>why?</strong></td>
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**SECOND ROUND CODING--Categories**

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<thead>
<tr>
<th><strong>Categories</strong></th>
<th><strong>Student experience (descriptors)</strong></th>
<th><strong>Sample lesson goals</strong></th>
<th><strong>Goal/Purpose of interdisciplinary</strong></th>
<th><strong>Strategies for interdisciplinary lesson</strong></th>
<th><strong>Other possible examples to use</strong></th>
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<td><strong>free</strong></td>
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<td>apply logs</td>
<td>benefit is context</td>
<td>advanced math/science</td>
<td>coding</td>
</tr>
<tr>
<td></td>
<td>clear</td>
<td>big and small numbers</td>
<td>capstone</td>
<td>after students have mastery</td>
<td>engineering</td>
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<tr>
<td></td>
<td>easy</td>
<td>earthquakes</td>
<td>conceptual</td>
<td>application</td>
<td>example: investments</td>
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<td>connection</td>
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<td>connections make it stick</td>
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<td>chemistry/algebra 2</td>
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<td>how to use logs</td>
<td>context for science</td>
<td>demo</td>
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<td>need foundation</td>
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<td>convenience</td>
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<td>alignment</td>
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<td>application</td>
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<td>real world samples</td>
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<td>slow process</td>
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<tr>
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<td>manipulate properties</td>
<td>story problems for context</td>
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<td>more examples</td>
<td>starting activity</td>
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<td>struggle</td>
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<td>to model</td>
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<td>pH</td>
<td>math is a tool</td>
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<td>practice</td>
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<tr>
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<td>solve exponential equations</td>
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<tr>
<td>vast range</td>
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<td></td>
</tr>
<tr>
<td>trouble estimating</td>
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</tbody>
</table>
Appendix K: Lesson Outline

Understanding Earthquake Magnitudes:
An Introduction to Logarithms

The Richter Scale:
A *logarithmic* scale where each increase of 1 on the Richter scale means the magnitude of the earthquake is 10 times greater.

It helps us to more easily compare a very large range of quantities.

<table>
<thead>
<tr>
<th>Richter scale of earthquake magnitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>magnitude level</td>
</tr>
<tr>
<td>-----------------</td>
</tr>
<tr>
<td>less than 1.0 to 2.9</td>
</tr>
<tr>
<td>3.0-3.9</td>
</tr>
<tr>
<td>4.0-4.9</td>
</tr>
<tr>
<td>5.0-5.9</td>
</tr>
<tr>
<td>6.0-6.9</td>
</tr>
<tr>
<td>7.0-7.9</td>
</tr>
<tr>
<td>8.0 and higher</td>
</tr>
</tbody>
</table>

Every increase of 1 in the Richter scale means the magnitude of the earthquake is 10 times greater.
But what is a logarithm?!

Logarithms can be used to scale very large or very small numbers that are easier to comprehend.

They are in disguise!

Logarithms are Exponents!

\[ 3^2 = \]

Another way to write this:

\[ \text{same as} \]

\[ 5^3 = \]
The Richter Scale uses logs that all have a base of 10

\[ 10^1 = \text{or log} \]
\[ 10^2 = \text{or log} \]
\[ 10^3 = \text{or log} \]

Estimate: \[ 10^{2.5} = \]

**BUT WHY DO WE NEED LOGS?!**

**Seismograph**—like a "sensitive pendulum that records the shaking of the Earth"

Dr. Richter (1935) studied records from many earthquakes and realized that some earthquakes made very small waves whereas others produced large waves.

![Image of a seismograph and a person]

To make it easier to compare the sizes of the waves he recorded, Richter used the **logarithms** of the wave heights on seismograms measured in microns, which is \(1/1000\)th of a millimeter!

So what if something was 30 microns? What would that be in millimeters? In meters?
Examples of earthquakes on Richter scale:

How much stronger was 1989 Loma Prieta (CA) earthquake than 2011 East Coast earthquake?

Compare in microns? millimeters? meters? Yuck!

OR...

Use logs (which are exponents)!

1.2 units larger on Richter scale, so $10^{1.2}$ times greater =

The 7.0 earthquake is about 16 TIMES as strong as 5.8 earthquake.

Will you ever see logarithms again?

YES!!