ABSTRACT

BROWN, MICHELLE CETNER. The Implementation of an Interdisciplinary Co-planning Team Model Among Mathematics and Science Teachers. (Under the direction of Allison McCulloch).

In recent years, Science, Technology, Engineering, and Mathematics (STEM) education has become a significant focus of numerous theoretical and commentary articles as researchers have advocated for active and conceptually integrated learning in classrooms. Drawing connections between previously isolated subjects, especially mathematics and science, has been shown to increase student engagement, performance, and critical thinking skills. However, obstacles exist to the widespread implementation of integrated curricula in schools, such as teacher knowledge and school structure and culture.

The Interdisciplinary Co-planning Team (ICT) model, in which teachers of different subjects come together regularly to discuss connections between content and to plan larger interdisciplinary activities and smaller examples and discussion points, offers a method for teachers to create sustainable interdisciplinary experiences for students within the bounds of the current school structure. The ICT model is designed to be an iterative, flexible model, providing teachers with both a regular time to come together as “experts” and “teach” each other important concepts from their separate disciplines, and then to bring their shared knowledge and language back to their own classrooms to implement with their students in ways that fit their individual classes.

In this multiple-case study, which aims to describe the nature of the co-planning process, the nature of plans, and changes in teacher beliefs as a result of co-planning, three pairs of secondary mathematics and science teachers participated in a 10-week intervention with the ICT model. Each pair constituted one case. Data included observations, interviews,
and artifact collection. All interviews, whole-group sessions, and co-planning sessions were transcribed and coded using both theory-based and data-based codes. Finally, a cross-case comparison was used to present similarities and differences across cases.

Findings suggest that the ICT model can be implemented with pairs of mathematics and science teachers to create a sustainable way to share experience and expertise, and to create powerful interdisciplinary experiences for their students. In addition, there is evidence that participation with the ICT model positively influences teacher beliefs about the nature of mathematics and science, about teaching and learning, and about interdisciplinary connections. These findings seem to hold across grades, school type, and personal experience. Future implementation of the ICT model on a larger scale is recommended to continue to observe the effects on teachers and students.
The Implementation of an Interdisciplinary Co-planning Team Model
Among Mathematics and Science Teachers

by
Michelle Cetner Brown

A dissertation submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

Mathematics Education

Raleigh, North Carolina

2017

APPROVED BY:

_______________________________  _______________________________
Allison McCulloch, PhD            Margaret Blanchard, PhD
Committee Chair

_______________________________  _______________________________
Karen Keene, PhD                  Temple Walkowiak, PhD
DEDICATION

Even youths grow tired and weary, and young men stumble and fall, but those who trust in the Lord will renew their strength. They will soar on wings like eagles, they will run and not grow weary, they will walk and not be faint. Isaiah 40:30-31

I dedicate this dissertation to my daughter, Regina. Even when you think it’s too difficult, or you are too tired, or you just want to give up, remember that all you have to do is spread your wings and let God provide the air to lift you up.
BIOGRAPHY

Michelle Cetner Brown was born in 1982 on Long Island, NY. She graduated from Longwood High School in 2000. In 2003, she graduated magna cum laude from New York University with a Bachelor of Science degree in Mathematics Education, upon which, she taught at Flushing High School in Flushing, NY for 2 years. During that time, she worked extensively with the Geometer’s Sketchpad program, and edited a series of discovery lesson books written by Paul Cinco.

In 2005, Michelle moved to Washington, NC. She taught at Washington High School for 3 years, and then DH Conley High School in Greenville, NC for the next 5 years. During that time, she completed a Master of Arts in Mathematics and a Master of Arts in Mathematics Education at East Carolina University (ECU). Throughout Michelle’s ten years of teaching high school, she has taught most classes ranging from Algebra 1 through Calculus, at remedial, standard, honors, and AP levels, and also coordinated and encouraged students to attend numerous math teams, math contests, and math fairs. Beginning in 2012, Michelle taught college algebra classes at Pitt Community College and undergraduate mathematics education classes at ECU, as well as supervised student teachers through ECU.

Michelle stopped teaching in 2013 to attend graduate school at NC State University full time, and to work as a research assistant on the NSF funded “Noyce Mathematics Education Teaching Scholars” (Noyce METS) program as a mentor to in-service teachers who graduated from the program. Upon completing coursework in 2015, Michelle stopped working for Noyce METS in order to spend time as the after-school program coordinator closer to home in Greenville, NC at Charles June Karate, where she had been a long time
instructor. In 2016, Michelle also agreed to teach classes at Greenville Learning Center and Christ Covenant School as she finished work on her dissertation.

Through her variety of experiences, Michelle has had multiple opportunities to present at conferences, submit papers for publication, and mentor teachers through professional development. Upon receiving her degree, Michelle would like to continue to mentor teachers, and to continue pursuing her research interests into ways that teachers can make learning more connected, conceptual, and relevant for students.
ACKNOWLEDGMENTS

I would like to thank my advisor and committee chairperson, Dr. Allison McCulloch for her patience and support throughout my doctoral program. She encouraged me to pursue my research vision and think about the potential impact of my work on the field. Dr. McCulloch has been a great mentor, and pushed me professionally and personally to do things I didn’t think possible. I would also like to thank my other committee members, Dr. Karen Keene, Dr. Margaret Blanchard, and Dr. Temple Walkowiak, for the support that they have provided. In addition, I would like to acknowledge the role that Dr. Jimmy Scherrer played in the formation of the idea of Interdisciplinary Co-planning Teams, which began as a project in his learning sciences class along with Mariana Pereyra Perez.

I would like to thank pastor and friend Bob Wynn for the constant support and inspiration that you have provided me. Your focus on mentoring and relationships contributed to the growth of the ICT model. More importantly, you helped me through many late nights and early mornings among the other circumstances of life through some key scripture verses and reminding me that God’s got this.

Finally, to my husband, Bill Brown, and my daughter, Regina Lopez, you have given me your constant support and understanding throughout this entire process. Without your patience and grace, I would have never gotten to this point. Thanks!
TABLE OF CONTENTS

LIST OF TABLES.................................................................................................................. ix
LIST OF FIGURES.................................................................................................................. x
CHAPTER 1: INTRODUCTION.................................................................................................. 1
  Statement of the Problem...................................................................................................... 1
  The Interdisciplinary Co-planning Team Model ................................................................. 2
  Purpose of the Study........................................................................................................... 3
  Design................................................................................................................................ 4
  Definition of Terms.............................................................................................................. 5
CHAPTER 2: REVIEW OF THE LITERATURE........................................................................... 7
  Why Curriculum Integration............................................................................................... 7
    Defining Curriculum Integration......................................................................................... 9
    Professional Recommendations......................................................................................... 12
  Benefits to Students........................................................................................................... 14
  Effects on Teachers............................................................................................................ 22
  Obstacles to Integration..................................................................................................... 27
  Research Regarding Teacher Planning............................................................................... 29
    What Planning is and Why it is Important ...................................................................... 29
    The Tyler and Yinger Debate ......................................................................................... 31
    Planning as a Mental Process.......................................................................................... 36
    The Role of Experience.................................................................................................... 38
    Planning for Curricula..................................................................................................... 40
    Common Planning and Co-planning................................................................................ 41
  Research Regarding Teacher Beliefs................................................................................ 43
    History of Beliefs............................................................................................................... 44
    Defining Beliefs and Other Constructs........................................................................... 46
    Teacher Beliefs Regarding Mathematics and Science................................................... 51
    Beliefs Regarding Teacher, Learning, and Curriculum.................................................. 54
    Inconsistencies Between Beliefs and Practice............................................................... 60
  The Interdisciplinary Co-planning Team (ICT) Model......................................................... 61
    The ICT Model................................................................................................................ 62
    Affordances of the ICT Model......................................................................................... 64
    Feasibility Study: Algebra and Chemistry.................................................................... 71
    Pilot Study: 8th Grade Science and Mathematics............................................................ 76
  Conceptual Framework..................................................................................................... 88
  Chapter Summary............................................................................................................. 92
CHAPTER 3: METHODS........................................................................................................... 94
  Research Design................................................................................................................ 95
  Participants....................................................................................................................... 98
    ECHS School.................................................................................................................. 99
    ICMS School..................................................................................................................100
Research Question 3: In what ways does participation with the ICT model influence teachers’ expressed beliefs regarding a) the nature of mathematics and science; b) teaching and learning; and c) making interdisciplinary connections?

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discussion</td>
<td>311</td>
</tr>
<tr>
<td>Limitations of the Study</td>
<td>315</td>
</tr>
<tr>
<td>Implications</td>
<td>315</td>
</tr>
<tr>
<td>Implications for Teachers</td>
<td>316</td>
</tr>
<tr>
<td>Implications for Teacher Leaders</td>
<td>320</td>
</tr>
<tr>
<td>Implications for Researchers</td>
<td>323</td>
</tr>
<tr>
<td>Conclusions</td>
<td>324</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>326</td>
</tr>
<tr>
<td>APPENDICES</td>
<td>367</td>
</tr>
<tr>
<td>Appendix A</td>
<td>368</td>
</tr>
<tr>
<td>Appendix B</td>
<td>370</td>
</tr>
<tr>
<td>Appendix C</td>
<td>371</td>
</tr>
<tr>
<td>Appendix D</td>
<td>373</td>
</tr>
<tr>
<td>Appendix E</td>
<td>375</td>
</tr>
<tr>
<td>Appendix F</td>
<td>376</td>
</tr>
<tr>
<td>Appendix G</td>
<td>380</td>
</tr>
<tr>
<td>Appendix H</td>
<td>381</td>
</tr>
<tr>
<td>Appendix I</td>
<td>383</td>
</tr>
<tr>
<td>Appendix J</td>
<td>384</td>
</tr>
<tr>
<td>Appendix K</td>
<td>387</td>
</tr>
<tr>
<td>Appendix L</td>
<td>389</td>
</tr>
<tr>
<td>Appendix M</td>
<td>392</td>
</tr>
<tr>
<td>Appendix N</td>
<td>395</td>
</tr>
<tr>
<td>Appendix O</td>
<td>400</td>
</tr>
<tr>
<td>Appendix P</td>
<td>416</td>
</tr>
<tr>
<td>Appendix Q</td>
<td>430</td>
</tr>
</tbody>
</table>
**LIST OF TABLES**

Table 1. *Summary of participants* ........................................................................................................... 99
Table 2. *Student performance on North Carolina End of Course tests* (NCDPI, 2013a)......100
Table 3. *Student performance on North Carolina End-of-Grade tests* (NCDPI, 2013b)......101
Table 4. *Alignment of research questions and data collection* .................................................................112
Table 5. *Miller and Smith co-planned topics and connections by planning session* .................131
Table 6. *Jones and Williams co-planned topics and connections by planning session* ...........181
Table 7. *King and Taylor co-planned topics and connections by planning session* ...............230
Table 8. *Larger and smaller activities and connections across cases* .................................................295
Table 9. *Comparison of larger activities and their origins* .................................................................298
**LIST OF FIGURES**

*Figure 1.* Redrawn mathematics/science continuum (Roebuck & Warden, 1998, p. 328) ... 6

*Figure 2.* Alignment of definitions of integrated and interdisciplinary curricula. Adapted from Drake (2007), Huntley (1998), and Roebuck & Warden (1998). .................... 11

*Figure 3.* The interdisciplinary co-planning team model ........................................ 63

*Figure 4.* Days 15 – 19 of a 90 day block schedule: Co-planning algebra and chemistry .... 72

*Figure 5.* Conceptual co-planning framework .................................................................... 90

*Figure 6.* Embedded multiple-case intervention design ........................................... 97

*Figure 7.* Implementation of the ICT model with teachers ............................................ 105

*Figure 8.* List of codes used in determining nature of co-planning process .................. 122

*Figure 9.* ICT process code occurrence for Miller and Smith case ............................. 143

*Figure 10.* ICT process code occurrence for Jones and Williams case ........................ 197

*Figure 11.* ICT process code occurrence for King and Taylor case ............................. 242

*Figure 12.* Codes by case, sorted by total number of occurrences ............................... 280

*Figure 13.* Network diagram of codes and quotations for Miller and Smith case .......... 282

*Figure 14.* Network diagram of codes and quotations for Jones and Williams case ....... 283

*Figure 15.* Network diagram of codes and quotations for King and Taylor case ..... 284

*Figure 16.* Continuum of interdisciplinary activities ................................................... 297

*Figure 17.* Teacher movement along the math-science continuum. ............................. 314
CHAPTER 1: INTRODUCTION

Statement of the Problem

In recent years, Science, Technology, Engineering, and Mathematics (STEM) education has become a significant focus of numerous theoretical and commentary articles (e.g., Moore & Smith, 2014; Roberts & Cantu, 2012) as researchers have increasingly advocated for active and conceptually integrated learning in classrooms (e.g., Drake, 2007; Huntley, 1998). Drawing connections between previously isolated subjects, in particular mathematics and science, has been shown to increase student engagement (Czerniak et al., 1999), performance (Becker & Park, 2011), and critical thinking skills (Vars, 2001). In addition, students of integrated curricula may be more globally competitive (Roberts & Cantu, 2012) because of their ability to see relevance between in-school and out-of-school endeavors (Frykholm & Glasson, 2005).

Professional organizations such as the National Council of Teachers of Mathematics (NCTM) and the National Science Teachers Association (NSTA) call for an emphasis on problem solving and critical thinking skills, as well as other overlapping mathematical and scientific practices (NCTM, 1989/ 2000/ 2014; NSTA 2012). The Common Core Standards in Mathematics (CCSS-M, 2010) and the Next Generation Standards in Science (NGSS, 2013) further encourage connections between mathematics and science, and between these subjects and other disciplines. In fact, efforts have been made since the first NCTM Standards (1989) were released to introduce interdisciplinary and integrated education models. Despite their successes (e.g., Becker & Park, 2011; Froyd & Ohland, 2005), these have been mostly local or limited in nature because of obstacles such as teacher experience.
(Moore & Smith, 2014), teacher knowledge (Philipp, 2007), tradition (Czerniak et al., 1999), comfort levels (Nadelson et al., 2012), and the structure of school itself, including bell schedules (Czerniak et al., 1999) and standardized curricula and tests (Vars, 2001). Perhaps because of these obstacles, empirical work in integrated STEM education is often limited in depth (e.g., the introduction of a technology course into a curriculum) or scope (e.g., changing a specific program, but not the overall curriculum), which may not make broad structural changes to the teaching and learning of science and mathematics (Vars, 2001).

The challenge then is that of creating and implementing a model which encourages the benefits of integrated education yet is flexible enough to fit into the current structure of schools in a significant and sustainable way. The Interdisciplinary Co-planning Team (ICT) model, described below, is proposed as a solution to that issue.

**The Interdisciplinary Co-planning Team Model**

The *interdisciplinary co-planning team* (ICT) model, in which pairs of teachers from two different school subjects come together to discuss content and plan larger activities as well as smaller examples and discussion points for use in their classes, may offer a way for teachers to create an interdisciplinary experience for students within the bounds of the current school structure. The ICT model is designed to be an iterative, flexible model, providing both teachers with a regular time to come together as “experts” and to “teach” each other important concepts from their separate disciplines. Then, the teachers bring their new, shared knowledge back to their own classrooms to implement interdisciplinary connections with their students in ways that fit their individual situations. The emphasis is shifted from
simply following the textbook to conceptual understanding, and teachers gain the knowledge and confidence that may have been obstacles to interdisciplinary education in the past.

Prior to this study, the ICT model had been implemented twice by the researcher. The first was a study involving two teacher researchers to demonstrate feasibility of the model in long term and daily planning (Cetner & Pereyra, 2014). The second piloted the ICT model with two classroom teachers to gain a preliminary understanding of how the model works with teachers’ planning and teaching practices in the structure of schools, which allowed for the refinement of the model for use in this study (Cetner, 2016). The ICT model and each of the preliminary studies will be discussed in further detail in Chapter 2.

**Purpose of the Study**

The primary purpose of this study is to describe the nature of the co-planning process for middle and high school teachers when they participate with the Interdisciplinary Co-planning Team (ICT) model. To do this, a professional learning experience intervention was designed for 6 middle and high school teachers (3 math-science pairs), and the co-planning process was examined for each pair. Since the planning process and the plans created may be inextricably intertwined, a decision was made to analyze the plans that each teacher pair made as well. Furthermore, literature reveals that teacher beliefs, which are usually relatively static, may be changed through experiences that vary from the normal (e.g., Philippou & Christou, 2002). As such, the final goal of the study was to examine teacher beliefs both before and after the intervention to determine if implementation of the ICT model would encourage teachers to change their beliefs regarding the nature and teaching of mathematics and science and the use of interdisciplinary connections.
The focus for this study was on the co-planning and the plans, and not the implementation of plans because the process and the plans have not yet been studied for the ICT model, and in order to study the implementation of plans, it may be necessary to have a description of the process that is used to produce the plans. In addition, the focus for this study was teachers and not students because the literature reveals that planning is largely an individual mental task (Milner, 2001), and student growth may depend predominantly on individual teacher factors (e.g., Becker & Park, 2011).

Based on the above goals, three research questions were explored:

1. What is the nature of the co-planning processes when the ICT model is implemented?
2. What is the nature of teacher plans developed through participation with the ICT model?
3. In what ways does participation with the ICT model influence teachers’ expressed beliefs regarding a) the nature of mathematics and science; b) teaching and learning; and c) making interdisciplinary connections?

**Design**

This study used a qualitative embedded multiple-case study intervention design (Baxter & Jack, 2008; Creswell, 2012). Six teacher-participants took part in the professional learning experience intervention, which included three large group learning sessions and 7 co-planning sessions, facilitated by the researcher. As part of the professional learning experience intervention, the teacher-participants were expected to implement lessons that they co-planned in their classes, and to keep journals in which they reflected on the co-planning process.
Qualitative data collection and analysis were used to capture thick descriptions (Creswell, 2012) of what teachers attended to as they engaged in the ICT model and how use of the model affected individual lesson plans as well as beliefs related to making interdisciplinary connections in teaching. Audio-recorded observations were conducted during whole group professional learning sessions and regular co-planning sessions. This data was triangulated with interview, journal, classroom observation field notes and artifact data collected throughout the study. Further details regarding the intervention, data collection, and analysis are provided in Chapter 3.

**Definition of Terms**

The terms defined in this section will assist the reader to understand the operational use of words and phrases throughout this study. While there may be some disagreement of these terms and phrases, the following definitions should be applied when reading this study.

**Integrated (studies)** refers to a context driven approach in which real-world tasks are carefully designed for students to learn more than one content area concurrently, and no distinction is made as to which discipline any particular content belongs (Czerniak et al, 1999; Davison, Miller & Methany, 1995).

**Interdisciplinary (studies)** refers to classes that are separated by subject content area in space and time, with the intention of drawing as many connections as possible between content areas (Drake, 2007; Huntley, 1998). Tasks are posed whose goal is to draw on and coordinate content from each discipline involved (Czerniak et al, 1999).
Note: Integrated and interdisciplinary studies may be thought of as a continuum with separate subject content areas on the endpoints and true integration falling in the middle, as shown in Figure 1 (e.g., Lonning & DeFranco, 1997; Roebuck & Warden, 1998).


*Figure 1. Redrawn mathematics/science continuum, (Roebuck & Warden, 1998, p. 328).*

**Planning** refers to all activities that teachers do to prepare to teach. This *proactive* (without students) work is distinguished from the *interactive* (with students) work that teachers perform (Jackson, 1968). Planning may draw on a variety of resources (Mumba et al., 2007) and include different products, such as objectives, activities, pedagogical notes (Drake & Sherin, 2006) and mental notes (Lenz, Schumaker & Dashler, 1991).

**Co-planning** is a special type of team planning, usually completed in preparation for teachers co-teaching the same group of students (Walther-Thomas, Bryant & Land, 1996). In this study, the teachers who engage in co-planning may or may not teach the same group of students, but they do meet on a regular basis to discuss content and plan together.

**Teacher beliefs** refers to a complex, but relatively stable system of contextually based personal knowledge (Clark & Peterson, 1986; Philippou & Christou, 2002) which inform thoughts and behavior (Benbow, 1995; Pajares, 1992), are formed by cultural experiences (Pajares, 1992; Pehkonen, 2001), include subjective and objective notions (Furinghetti & Pehkonen, 2002), and are organized in interrelated clusters (Andrews & Hatch, 1999).
CHAPTER 2: REVIEW OF THE LITERATURE

This chapter serves four purposes. The first is to explore literature relevant to curriculum integration in order to form a basis for the Interdisciplinary Co-planning Team (ICT) model. Secondly, literature regarding teacher planning and teacher beliefs is reviewed, because individual teacher planning and beliefs are thought to influence and be influenced by the ICT model. Thirdly, the ICT model itself is described in detail, including results and themes from a feasibility study in 2014 and a pilot study in 2015. Finally, a theoretical framework is presented which was used to analyze the co-planning process and the ways in which it influences and is influenced by individual teacher planning and related teacher beliefs.

Why Curriculum Integration

The idea of integrating subject content that has traditionally been taught in schools as separate domains is not a new idea (Roebuck & Warden, 1998; Vars, 2001). As early as the turn of the twentieth century, Eliakim Moore advocated for the “laboratory method,” which would organize algebra, geometry, and physics into one four-year course and emphasize appreciation as well as practical and theoretical applications of science and mathematics (Moore, 1903). Over the course of the twentieth century, the idea of curriculum integration in the United States has been advocated by a marginal few, but really caught mainstream attention after the NCTM Standards documents were published in 1989 (Czerniak et al., 1999). This attention was compounded by other nationally released documents, such as A Nation at Risk (Gardner et al., 1983), Project 2061: Science for All Americans (AAAS, 1989) and Benchmarks for Science Literacy (AAAS, 1993), all of which advocated for students to
learn how to apply mathematical and scientific concepts to each other and to real world situations.

Throughout the 1990s and into the twenty-first century, many researchers, administrators, teachers, and policy makers looked toward curriculum integration as an answer to many of the problems in education (e.g., Czerniak et al., 1999; Drake, 2007). Drawing connections between previously isolated subjects, in particular mathematics and science, has been thought to increase student engagement (Czerniak et al., 1999), performance (Huntley, 1998), and critical thinking skills (Childress, 1996).

Increased national attention on science, technology, engineering, and mathematics (STEM) education in recent years has led to an influx of STEM schools and programs (Roberts & Cantu, 2012). STEM programs follow various models, including some that use traditional curricula and some that use integrated and interdisciplinary curricula (Becker & Park, 2011; Scott, 2012). Regardless of the specific model employed, most successful STEM schools and programs have been shown to rely on problem solving (Moore & Smith, 2014), and recommendations for STEM high schools include project based learning (Peters-Burton et al., 2014; Lynch et al., 201), which has been recognized in recent years as an effective mechanism to for students to experience math and science (Tseng et al., 2013), sometimes leading to de facto curriculum integration.

Project Based Science (PBS), which may be thought of as subject-specific project based learning, has become commonly accepted in academic circles as the “doing science” that is appropriate and necessary for student learning (e.g., Krajcik et al., 1998; Krajcik et al., 2008; Schneider at al., 2002). PBS includes the same features as problem solving in
mathematics: real life questions, student-directed development of artifacts, engagement in investigations, collaboration, and use of appropriate tools strategically (NCTM, 2014), and emphasizes connections among content areas in order for students to see relevance to the real world (Krajcik et al., 2008) and develop knowledge in meaningful and practice-bound contexts (Handal & Bobis, 2004).

There are many different ways to approach curriculum integration, and just as many definitions and terms (e.g., Huntley, 1998; Drake, 2007). Many authors have reported on the theoretical benefits of an integrated curriculum, and fewer have published empirical studies confirming its effectiveness (Becker & Park, 2011). This review of curriculum integration will begin with a discussion of various definitions and terms that have been used in conjunction with the idea of integrated curricula. It will then discuss the theoretical and empirical literature concerning 1) recommendations from various professional organizations and standards, including models for integrated and other STEM programs; 2) the benefits to students of blending separate content disciplines together; 3) the benefits to teachers in combining mathematics and science in professional development; and 4) the obstacles that exist to creating and maintaining an integrated curriculum.

Defining Curriculum Integration

It is generally agreed upon that, in a broad sense, curriculum integration refers to connecting “various disciplines in some way” (Drake, 2007, p. 25). However, beyond that definition, a large amount of ambiguity of form and purpose exist. Czerniak listed 17 different terms that have been used to describe integration in an effort to explain the ambiguity of the term in literature (Czerniak et al., 1999), and a cursory review of the related
literature may add as many more. Integration can be categorized according to a focus on *process* or on specific *content* (Davison, Miller & Metheny, 1995), or by the amount of student-centered activity present (Vars, 2001). Other definitions claim that the emphasis should be on the extent to which a curriculum has social meaning and deals with real-life problems (Czerniak, 1999).

Some definitions and terms refer to the degree to which that content is combined, using the metaphors of “tomato soup” versus “chicken noodle soup” to describe the amount that the individual parts of study are distinguishable from each other (Czerniak et al., 1999, p. 422). Similarly, STEM programs are often discussed in similar terms: as a *silo*, providing separate classes in mathematics, science, and technology and engineering; *embedded*, implementing technology and problem solving into existing science and mathematics classes; and *integrated*, entwining content and processes (Roberts & Cantu, 2012).

This review defines the terms *integrated* and *interdisciplinary* based on the extent to which traditional subject area content is seen to overlap. Drake’s (2007) team constructed a hierarchy to represent different levels of curriculum integration, in which the top three steps are *multidisciplinary*, *interdisciplinary*, and *transdisciplinary*. In multidisciplinary study, the separate disciplines all attend to one theme in parallel study, whereas in interdisciplinary study, the theme is embodied by one “big integrated assessment task” (Drake, 2007, p. 35), which emphasizes ideas across subjects, rather than within them. Finally, with the transdisciplinary approach, subject content is secondary to context and relevance to students (Drake, 2007). The third edition of Drake’s book (2012) contains language changes regarding
relevance and 21st Century Skills, but keeps the language of multidisciplinary, interdisciplinary, and transdisciplinary.

Huntley (1998) described integration with 3 stopping points: intradisciplinary, with a focus on one discipline at a time; interdisciplinary, with a focus on making connections, but still keeping the disciplines separate; and integrated, with assimilation of concepts from more than one discipline during a lesson.

In mathematics and science education, a continuum as a framework for looking at levels of integration, with true integration falling in the middle has been expressed by several authors, as seen in Figure 2 (e.g., Lonning & DeFranco, 1997; Roebuck & Warden, 1998).

While this continuum is less specific than the hierarchy model, parallels may be drawn between the second and fourth points and Drake’s multidisciplinary level, as well as the third point and the transdisciplinary level, with the interdisciplinary level falling somewhere in between on the continuum. Figure 2 depicts the alignment among the definitions by Drake (2007/2012), Huntley (1998), and the math-science continuum from above.

![Figure 2. Alignment of definitions of integrated and interdisciplinary curricula. Adapted from Drake (2007), Huntley (1998), and Roebuck & Warden (1998).](image-url)
For the purposes of this paper, definitions from Drake (2007) and Huntley (1998) will be combined and adapted: In an interdisciplinary curriculum, the separate classes are taught by different teachers at different times, but efforts are made to draw as many connections as possible between content areas. Tasks are posed whose goal is to draw on and coordinate content from each discipline involved. In an integrated curriculum, one or more teachers emphasize real-world tasks, from which disciplinary content falls, but no distinction is made as to which discipline any particular content belongs. In short, while both focus on drawing connections between discipline areas, the difference would be that interdisciplinary classes are content driven and that integrated classes are context driven.

**Professional Recommendations**

Within the last 25 years, the amount of literature produced by proponents of integrated curricula has increased dramatically, especially in the areas of mathematics and science (Berlin & Lee, 2005; Czerniak et al., 1999). Resources have been created, such as the Great Explorations in Math and Science (GEMS, Lawrence Hall of Science, 2007) and the Activities in Math and Science (AIMS, 1996) activity books, which include integrated activities for students from pre-school through high school (Furner & Kumar, 2007). Furthermore, recommendations have been made for how to integrate, including the use of patterns, data collection, overlapping content, and specific instructional strategies (e.g., Berlin & White, 1992; Czerniak et al., 1999; Furner & Kumar, 2007). The National Science Teacher’s Association (NSTA, 2012) outlined 8 guidelines that all interdisciplinary curricula should meet, including maintaining the integrity of content, providing a variety of opportunities to learn, respecting diversity, and using wide-ranging assessments.
Documents from national professional organizations in mathematics and science education describe the practices of “doing math” and “doing science,” as a form of problem solving that is essential for student engagement and learning, as described above. The Standards document, published by the National Council of Teachers of Mathematics (NCTM, 1989) describes doing math as using mathematical strategies and tools to solve problems from within and outside of mathematics. The Principles and Standards document reiterates the importance of these process standards of problem solving, connections, communication, and representations, stating that curriculum must be coherent and learning should actively build on experience and previous knowledge (NCTM, 2000). The National Research Council’s Adding it Up (NRC, 2001) describes problem solving as the site in which all strands of mathematics proficiency converge. The Common Core Standards (CCSS-M, 2010) describe the importance of NCTM’s problem solving standard, and extend it by asking students to reason abstractly and quantitatively to contextualize and decontextualize mathematical concepts. The first of the three dimensions for the Next Generation Standards (NGSS, 2013) is inquiry in science, which describes problem solving as essential to learning and doing science.

In addition, many organizations, such as the School Science and Mathematics Association (SSMA), the National Council of Teachers of Mathematics (NCTM), the American Association for the Advancement of Science (AAAS), and the National Research Council (NRC) make strong arguments specifically for fostering interdisciplinary connections between mathematics, science, and other subjects (Furner & Kumar, 2007). The NCTM Standards (1989) call for connections among mathematical topics as well as between
mathematics and other disciplines. The Common Core State Standards for Mathematics (CCSS-M, 2010) modeling standard, which is emphasized as a process standard and throughout the Common Core content standards, describes the necessity for students to apply mathematics to other disciplines outside of mathematics. The Next Generation Standards in science (NGSS, 2013) devote entire documents to outlining specific connections that can and should be made between mathematics and science standards. In fact, one of the three dimensions of the Science Standards is crosscutting concepts across all grades of science, which are easily applied to mathematics as well: patterns, similarity, and diversity; cause and effect; scale; proportion and quantity; systems and system models; energy and matter; structure and function; and stability and change (NGSS, 2013). NCTM’s Principles to Actions states that “the mathematics curriculum should not only be coherent but also make connections from the mathematics curriculum to other disciplines,” and actually lists the Next Generation Science Standards as having significant importance in mathematics (NCTM, 2014, p. 75).

Benefits to Students

Beginning in the late 1980s, calls to make school learning more applicable to what students would face once they graduate (e.g., Resnick, 1987) gained popularity as schools, and researchers began to focus on the needs and interests of students (Czerniak et al., 1999). Because integrated approaches are generally student-centered, many recommendations echo the calls for good teaching in general, such as reformed instructional strategies and supports for underrepresented students (Peters-Burton et al., 2014), engaging students in meaningful learning (Furner & Kumar, 2007), and using project-based approaches (Ross & Hogaboam-
Gray, 1998; Tseng et al., 2013). These approaches contribute to the constructivist philosophy of hands-on, minds-on learning (Furner & Kumar, 2007; Handal & Bobis, 2004) that enhances student engagement (Czerniak et al., 1999), and is echoed in most literature that describes the benefits of interdisciplinary learning. Thus, as a form of student-centered learning, integrated studies may create students who are more highly motivated, and who possess higher-order thinking skills (Vars, 2001).

In addition to the benefits of good student-centered learning that is often a part of interdisciplinary and integrated studies, some potential benefits to students come directly from the fact that connections are being made. Curriculum integration can encourage students to access less favored subjects through more favored ones, and ease student anxiety about dealing with complex problems (Ross & Hogaboam-Gray, 1998). Constructivists see integrated curriculum as a way for students to create deep understandings and to make connections among ideas (Czerniak et al., 1999; Kiray, 2012). Supporters from a sociological or situated perspective argue that learning best occurs when situated in context (Furner & Kumar, 2007), and that an integrated curriculum consisting of carefully designed units makes students better prepared for real-life complexity in contemporary society (Ivanitskaya et al., 2002; Vars, 2001). Students are more apt to get the “big picture” (Roebuck & Warden, 1998; Vars, 2001), which helps them to see more relevance between in-school and out of school endeavors (Frykholm & Glasson, 2005; Koirala & Bowman, 2003), making students more globally competitive (Roberts & Cantu, 2012).

**Descriptions of experiences with integrated curricula.** While there still exists far more theoretical literature than empirical, several documented cases exist in which
interdisciplinary projects have been implemented successfully. Practitioner articles exist at the elementary, middle, and high school levels which describe specific integrated, interdisciplinary, or collaborative projects that teachers have done in their classrooms (e.g., Barta & Kyriopoulos, 2014; Bryan, 2012; Horton, Wiegert & Marshall, 2008; McCulloch & Ernst, 2012).

For example, one article describes a project in a small Guatemalan elementary school in which students from kindergarten through 6th grade integrated social studies and mathematics to measure and map their world (Barta & Kyriopoulos, 2014). The students collaborated to construct diagrams of their neighborhood, and the experience produced very powerful effects on student learning and motivation (Barta & Kyriopoulos, 2014). In another article, McCulloch & Ernst (2012) describe an integrated STEM project developed for middle school students in an out-of-school setting involving estuarine ecosystems. The article discusses the project development implementation, and how students drew on their science, technology, engineering, and mathematics knowledge in the completion of the project. In addition to learning and developing critical thinking and engineering skills, the students who participated in this project were found to be enthusiastic about their authentic experiences.

As a last example, in a project directed toward high school students, mathematics educators consulted with science educators to develop an activity in which students constructed matrices to present information about a food chain (Horton et al., 2008). Practitioners are encouraged to modify the information to reflect local species, providing a relevant context for students, and to center discussion on the scientific accuracy of the food
chain represented in the matrix, using the mathematics that they are learning as an avenue for learning important science concepts (Horton et al., 2008).

**Empirical studies.** Few research studies have reported students experiencing integrated curricula or projects. Becker and Park (2011) conducted a meta-analysis in which twenty-eight studies of integrative efforts employing various methods at the K-12 and college levels were identified and analyzed. Criteria for inclusion was that a study was searchable in one of several named databases, published between 1989 and 2009, and examined student achievement quantitatively. Of the 28 included studies, there were 3 at the elementary school level; 9 at the middle school level; 12 at the high school level; and 4 at the undergraduate college level (Becker & Park, 2011). Many of these projects were during informal times, such as summer workshops and afterschool clubs (e.g., Barker & Ansorge, 2007; Lam et al., 2008).

Becker and Park (2011) found that while the integrative approaches are more common at the secondary and college level, obstacles such as standardized testing, lack of proper materials, and insufficient STEM teachers’ collaboration, lead to lower benefits in students’ achievement than at the elementary level. Even so, they found that that at all levels, students who participate in interdisciplinary and integrated projects generally perform better at problem solving, and do no worse than their peers on standardized tests. In addition, students who experience integrated or interdisciplinary learning experiences seem to display more engagement, lower achievement gaps, better attitudes toward STEM fields, increased content knowledge, and higher level thinking skills than their peers.
It is surprising that relatively few research studies that involve integrating different
disciplines have been done at the elementary level, even though elementary teachers
generally have more flexibility with their curriculum and time allotments (Becker & Park,
2011). One likely explanation is that standardized testing in specific content areas drives
classroom instruction to the extent that teachers do not feel that they have time for more
interdisciplinary activities, even in these classrooms. Another possible explanation is that
more opportunities for integrated study already exist for these students through nationally
recognized organizations and afterschool clubs such as 4-H (Barker & Ansorge, 2007). For
example, one study at the elementary level found that 9 to 11 year old students who
participated in an after-school robotics group that sought to integrate engineering, science,
and technology dramatically increased performance on a STEM post-test (Barker & Ansorge,
2007). However, it also concluded that more research is needed about the influence of
informal learning opportunities as well as the 4-H curriculum on students (Barker &
Ansorge, 2007).

At the middle school level, studies of informal learning opportunities exist (e.g., Lam
et al., 2008), but the majority of studies seem to focus on teacher-university partnerships in
which design-based engineering curriculum modules were implemented in science
classrooms (e.g., Cantrell et al., 2006; Doppelt et al., 2008; Freiman et al., 2011; Riskowski
et al., 2009). Cantrell and colleagues (2006) note that implementing design-based
engineering modules combines specific mathematics, science, and technology curricula in a
problem solving format that students can experience in a hands-on manner. Though most
studies only focused on one or a few modules, as a collective they seen to span a variety of
topics, including weather (Lam et al., 2008) electricity (Doppelt et al., 2008), water quality (Riskowski et al., 2009), and video surveillance systems (Freiman et al., 2011). At the high school level, similar attempts have been made to implement design-based learning in existing science classes (Apendoe et al., 2008; Fortus et al., 2005). Overall, these studies found that students who experience design-based learning modules within their science classes sometimes need time to adjust to active learning (Satchwell & Loepp, 2002), but soon exhibit higher levels of thinking on design tasks (Riskowski et al., 2009) and diminished performance gaps (Cantrell et al., 2006), especially for African American students (Doppelt et al., 2008). Students seem more engaged and excited about learning (Cantrell et al., 2006; Lam et al., 2008), possibly because their learning correlates better with the way that they naturally think (Doppelt et al., 2008). Achievement scores for these students were higher than their peers on statewide tests (Cantrell et al., 2006) and other pre- and post-test data (Fortus et al., 2005).

A different approach was used in the high school Mathematics, Science, and Technology (MST) program studied by Ross and Hogaboam-Gray (1998). This MST program was structured to accommodate collaborative integrated group projects that engaged students (at various times throughout the year) in three ways: 1) the sequence of topics was rearranged to support the group projects; 2) teachers emphasized skills that were shared by all three subjects; and 3) less important content was discarded in order to make room for the projects. Students in the MST program were compared to another school in the same district with a similar population through student surveys and interviews as well as a mid-term project and written exam. The student survey revealed that the MST students believed they
were more on-task, collaborative, and motivated, and able to apply their knowledge than their peers, while exam scores remained comparable.

Not all studies at the K-12 level produce positive results. Childress (1996) found mixed results using a quasi-experimental approach in which the experimental group participated in a problem-solving, integrated class and the control group learned content in isolation. In a final project, the students in the experimental group were not more successful than those in the control group, but they did attempt to apply more of what they learned in integrated classes. Freiman et al. (2011) introduced problem based-learning into a school with a one-to-one laptop program. They found that while the laptops created more opportunities for students to collaborate and experience open-ended tasks, they could also be a hindrance to the recursive nature of problem solving if too much emphasis was placed on the final product or presentation.

Kiray and Kaptan (2012), studied the application of their balance model for integration, which is similar to the continuum definitions of interdisciplinary and integrated curricula, but takes into account the need to balance the amount of mathematics and science that students are exposed to over the course of the year (Kiray, 2012). While the integrated curricula used in their study may have provided students with a better understanding beyond the scope of the class, there were no significant differences between experimental and control groups in post-test results, or from pre-test to post-test (Kiray & Kaptan, 2012). It was concluded that a contributing factor to the lack of results was insufficient teacher knowledge, and that teachers without specific content knowledge could actually impede student learning in integrated classes compared to traditional classes (Kiray & Kaptan, 2012).
At the undergraduate level, it is possible that more attempts at integration have been made because of the freedom from standardized testing and curricula. These attempts seem to produce positive gains in student self-confidence (Roedel et al., 1995) and attitudes toward mathematics (Elliott et al., 2001; Farrior et al., 2007), with some studies finding significant results (Roedel et al., 1995) and others finding non-significant results (Elliott et al., 2001) in conceptual understanding of mathematics and science.

Arizona State University developed an introductory course as an integrated curriculum experiment for freshman engineering students. This course integrated concepts from introductory courses in calculus, physics, English composition, and project-based engineering in an active learning environment created through the use of computers (Roedel et al., 1995). They found that students in the integrated course of study improved by 30% on the Hestenes Force Concepts Inventory Test, and showed marked gains in self-confidence.

At the University of Tulsa, researchers implemented Interdisciplinary Lively Applications Projects (ILAPs), interdisciplinary group problem-solving projects, co-written by mathematics faculty and science/technology/engineering faculty to be introduced into Calculus I and Calculus II (Farrior et al., 2007). They found that introducing ILAPs into the program positively influenced students’ perceptions of the nature of mathematics, but they concluded that the program may be more relevant if ILAPs were applied in upper level courses instead of “jam-packed” first year courses (p. 59).

At Oklahoma State University, students improved in their critical thinking and positive attitudes toward mathematics when they participated in an interdisciplinary course *Algebra for the Sciences*, compared to students in traditional college Algebra. However there
were no differences in problem-solving skills between students in the interdisciplinary course and traditional college Algebra course (Elliott et al., 2001).

Froyd and Ohland (2005) discuss several other research studies in which integrated curricula were implemented in higher education. They described integrated courses as communities of learning which build social connections, and found that they improve retention rates and affiliation in engineering by underrepresented groups such as women and minorities. They noted that integrated curricula could create communities of learning for both the students and the instructors, but that collaboration between faculty members was essential in implementation. Though constraints were recognized, such as the complexity of large-scale curricular change, the benefits were seen as an improvement over separate disciplinary content courses.

**Effects on Teachers**

The studies of curriculum integration, described above, focused on student growth, and mention teachers in a more cursory manner. For example, some noted a professional development component as a part of implementation with students (e.g., Cantrell et al., 2006), or lamented that teachers had insufficient knowledge (e.g., Kiray & Kaptan, 2012). The studies in this section report on teacher views of curriculum integration as well as professional development programs and their impact on teachers.

**Teacher beliefs.** Watanabe and Huntley (1998) interviewed instructors of a collaborative teacher education program and found that most saw value in creating connections between disciplines, especially because both disciplines use common tools, such as calculators, similar problem solving methods, and apply to similar real-world situations.
The science instructors thought of mathematics as a tool for science, and the mathematics instructors thought of science as a context for mathematics. However, the instructors also saw barriers to drawing connections between the disciplines in practice: they had too much of their own content to cover, and they said that students did not want to see connections, anyway. In short, most instructors felt that it was not their job and that they were not qualified to teach content from outside of their own in their classes, although over time and through collaboration they did gain respect for each other’s disciplines.

Başkan, Alev, and Karal (2010) interviewed practicing high school mathematics and physics teachers to gain their views on how physics and mathematics lessons could be related or integrated. They found that teachers believe that an interdisciplinary model would be useful, and that there are clear connections among content, but that they did not have ideas of how to go about integrating curricula or drawing connections for students. The teachers mentioned connections in broad terms, such as kinematics and derivatives, real-world problem solving, collaboration, and the possibility of a new syllabus, but were unable to come up with specific activities or ways to draw connections, prompting the researchers to conclude that professional development courses with certain concrete activities or examples would be beneficial to teachers.

**Professional development.** Some programs have been designed to support teachers in implementing integrated science and mathematics activities, as was suggested by Başkan and colleagues (2010). In a LEGO robotics summer professional development program, Hynes and Dos Santos (2007) found that teachers gained confidence in content and feasibility through hands-on opportunities and observing other teachers in action. Similarly,
the Interdisciplinary Science and Engineering Partnership (ISEP), established between two universities and a local school district, found that teachers who attended their summer professional development workshops and engaged in hands-on activities tended to understand and implement the curricula more faithfully in their classrooms the following year (Chawdhary et al., 2014).

Other professional development and teacher preparation programs have been designed to improve teachers’ knowledge and beliefs as they learn about teaching in integrated ways. The Integrated Mathematics, Science, and Technology (MSAT) Program was developed in Ohio to improve pre-service and in-service teachers of mathematics, science, and technology (Berlin & White, 2012). This program included three integrated content courses, which explored the connections between mathematics, science, and technology, and three integrated pedagogy courses, which explored standards, instructional and assessment models, and issues of equity and diversity. The program focused on pairing concepts, process, and skills in STEM disciplines; familiarizing teachers with instructional strategies and accessibility to resources; and gaining deeper understanding of content. The researchers found that the teacher candidates began with positive attitudes about the value of integration, and thus, did not experience much change in that area. However, the teachers did increase their opinions about integrated teaching being an efficient process and gain a sense of feasibility and comfort with their own ability to find resources and implement integrated curricula.

In the context of a teacher education program, Frykholm and Glasson (2005) report on student experiences and outcomes from a collaborative course which integrates preservice
math and science teachers in the semester preceding their student teaching experience. Initially, the participants conveyed strong convictions about the importance of connecting mathematics and science instruction, but were intimidated and hesitant about both the collaborative aspect and the actual drawing of connections because they were concerned about their own content knowledge and abilities. Throughout the course, the preservice teachers participated in collaborative group projects, such as designing a unit plan. Although the participants were quiet at first in their collaborative experience, they quickly became enthusiastic and often commented about using natural overlaps and they successfully developed integrated units. Participants were tracked through their student teaching experience, and it was found that they continued to make attempts to collaborate and to bring connections into their classes.

Nadelson and his colleagues (2012) partnered with nearby business, industry, government, schools, and universities to hold intensive 4-day summer institutes, attended by 229 in-service teachers representing grades K-12 in Idaho. Their goal was to increase participating teachers’ comfort, efficacy, and perceptions of effectiveness to teach STEM by attending to content, pedagogy, and learning styles. This was accomplished through 32 hours of lectures, panels, and presentations, as well as some other time for teacher planning, networking, and socializing. The researchers found that there were significant correlations among teacher comfort teaching STEM, efficacy teaching STEM, inquiry implementation, and pedagogical discontentment, and that participation in the workshops caused a significant shift in all of these. They concluded that improved efficiency and management of integrated
instruction time can occur through a supportive professional development intervention that builds teachers’ perceptions and knowledge of integrated STEM education.

Basista and Matthews (2002) held 4-week summer institutes in addition to academic year support activities. They held administrator workshops which carried graduate credits at Wright State University, designed to enhance teachers’ understandings of mathematics and science content, interdisciplinary connections, and authentic assessment practices. The summer institutes immersed teachers in inquiry-based learning environments through the use of cooperative groupings to complete integrated activities. The teacher participants were expected to try to modify their teaching practices with their classes, supported by classroom observation visits, feedback, encouragement, and additional workshops throughout the academic year. In addition, principals and assistant principals were invited to participate in administrator workshops and to visit their teachers, both during the institute and during the academic year. The researchers found that the teachers’ confidence increased over time as they continued to implement activities that they learned in their classrooms, but that the teachers struggled to identify the concepts applied during the activities and the hierarchy of the information to be presented. They concluded that using inquiry experiences in professional development had successfully lead participants to construct their own understanding and eradicate common misconceptions using an integrated science and mathematics approach.

Overall, these and other programs have had a positive impact on teachers’ receptiveness to curriculum integration. Teachers have been found to gain a deeper understanding of content as well as strategies for implementation in most programs, and
these studies suggest that with more programs such as these, teachers may become more familiar and comfortable with curriculum integration.

**Obstacles to Integration**

The main reason that curriculum integration is not more prevalent in schools today is that schools are not structured to sustain it (Vars, 2001). Bell schedules and other administrative structures, particularly in high schools, make it difficult to plan and implement cross-curricular projects (Czerniak et al., 1999; Johnson, Charner & White, 2003). In many states, specific standards are written for each class to cover a large amount of content, and mathematics teachers in particular worry that integration will be just another topic added to an already overloaded curriculum (Pearson et al., 2010; Watanabe & Huntley, 1998). It often takes longer to go more in depth in an integrated curriculum, and there exist concerns about being able to cover all of the material on standardized tests (Czerniak et al., 1999, Farrior et al., 2007).

It may be that many teachers are simply unaware of the benefits that integrative approaches have for students (Becker & Park, 2011). In many institutions, the process of curricular change implies a break from traditional academic disciplines and their philosophical, methodological, and historical differences that individuals are not willing to change (Czerniak et al., 1999). Implementing curriculum integration in institutions requires great commitment among teachers (Childress, 1996), and an understanding that teachers’ beliefs about mathematics, students, teaching, and curriculum influence implementation and are often slow to change (e.g., Czerniak et al., 1999; Holstein & Keene, 2013).
However, even teachers who express positive perceptions of integration seem to have difficulty enacting integrated curricula in practice, perhaps highlighting the fact that many teachers have not had an opportunity to learn in an integrated environment themselves (Başkan, Alev, & Karal, 2010; Czerniak et al., 1999). Teachers can have trouble understanding their own content (Chawdhary et al., 2014), or appreciating the value in each other’s content (Anderson & Krogh, 2010; Watanabe & Huntley, 1998). Teachers also tend to avoid teaching topics with which they feel uncomfortable (Nadelson et al., 2012). When teachers do push forth with topics with which they are uncomfortable or unfamiliar, their lack of content knowledge can create a notable adverse effect on student achievement (Kiray & Kaptan, 2012), and students and parents can react adversely to new curricula (Watanabe & Huntley, 1998), particularly if there is a large change in teaching or assessment methods (Czerniak et al., 1999). The culmination of several of these factors can lead to teachers being quickly frustrated with integrated curricula and returning to the more comfortable traditional curricula (Koirala & Bowman, 2003).

In order to overcome some of these obstacles, there have been calls for educators to work together, both through more professional learning experiences (e.g., Moore & Smith, 2014) and through more common planning and collaboration (e.g., Childress, 1996). The Interdisciplinary Co-planning Team (ICT) model was developed by the author in an attempt to overcome as many of these obstacles as possible by creating a sustainable model that will fit within the structure of schools (Cetner & Pereyra, 2014). The ICT model provides teachers with a regular collaborative planning time to share expertise about content and pedagogy with each other and to discuss interdisciplinary connections in a low-stress
environment. This helps the teachers to direct their focus toward student learning and provides them with the experience and confidence that they need to explore interdisciplinary connections and plan lessons and activities that they can use with their students.

**Research Regarding Teacher Planning**

It has been established through the literature base that students experience many benefits from integrating traditionally separate content areas (e.g., Becker & Park, 2011; Furner & Kumar, 2007; Ross & Hogaboam-Gray, 1998). It has also been established that these benefits do not come from a haphazard implementation of some magical curriculum, and that teachers need to take time to plan for implementation of interdisciplinary studies (e.g., Frykholm & Glasson, 2005; Nadelson et al., 2012; Pearson et al., 2010). The ICT model was developed to provide a sustainable, collaborative environment for teachers to gain the knowledge, language, and confidence necessary to successfully implement interdisciplinary lessons with their students. Since planning is the vehicle through which this learning occurs, this section considers what planning is and why it is important. It then briefly reviews 1) the historic debate in literature surrounding Tyler’s structural model of planning and Yinger’s problem solving model; 2) our current understanding of individual planning as a complex mental process; 3) the role experience plays; 4) literature regarding teacher planning for specific curricula; and 5) literature regarding common planning and co-planning.

**What Planning is and Why it is Important**

Planning is commonly accepted to mean all of the things that a teacher does to prepare for students when students are not present. Jackson (1968) used the term *preactive*
teaching (without students) to mean planning, compared with the act of interactive teaching (with students). It is the “behind the scenes” work that teachers do so that they can make the most of their time with students, which includes, but is not limited to: reading standards and curricula (Dockstader, 2009; Drake & Sherin, 2006; Remillard, 2005) and evaluating the appropriateness, timeliness, and possible student engagement (Milner, 2001; Sanchez & Valcarcel, 1999); choosing and adapting activities to use with students (Goc-Karp & Zakrajsek, 1987; Roche et al., 2014; Swearengin, 2014; Vaughn, 2010; Yinger, 1980); making and revising notes regarding content and presentation (Bocala, 2015; Borko & Livingston, 1989; Brown, 1988); creating and revising timelines and pacing guides (Yinger, 1980); preparing materials for student use (Mumba et al., 2007; Young, Reiser & Dick, 1998); collaborating with other teachers, staff, parents, and administrators (Aydin, 2014; Darling-Hammond et al., 2009; Owen, 2005); and reflecting on prior lessons in order to improve future lessons (Koellner, Jacobs, & Borko, 2011; Kitsantas & Baylor, 2001).

Planning is a flexible, complex, iterative (Davis, 2014; NRC, 2001; Yinger, 1980), pragmatic (Harris & Hofer, 2009) creative design process that requires organization, judgment, and attention to detail (Grimmett & MacKinnon, 1992; Leinhardt, 1983; Vaughn, 2010), but in which the detail is seldom written for others to see (Milner, 2001). Because planning is often invisible to non-teachers (McCutcheon, 1980; Morine-Dershimer, 1977), some early studies actually questioned whether teachers should plan at all (Zahorik, 1970), and tried to demonstrate that planning has no or adverse effect on teaching and student performance (Peterson, Marx & Clark, 1978; Zahorik, 1975).
It is now well-known that planning is an essential precursor to quality interactions with students (NRC, 2001) and for teachers’ emotional needs to feel prepared and in control (Doyle, 1983). This is especially important for less experienced teachers (Morine-Dershimer, 1993; Mumba et al., 2007; Swearington, 2014), and for teachers who are teaching a class for the first time (Borko & Livingston, 1989; Superfine, 2008), or using a new curriculum (Remillard, 2005; Superfine, 2008), including integrated curricula (Childress, 1996).

Planning is often included in teacher evaluation models (e.g., Blanton, Sindelar & Correa, 2006; Jacobs, Martin & Otieno, 2008) and has been included in research handbook chapters (e.g., Clark & Peterson, 1986; Doyle, 1983) and books about teaching (e.g., Farrell, 2002). Teachers’ judgments and decision making skills are valued (Grimmett & MacKinnon, 1992), and teachers are encouraged to thoughtfully consider content as well as student thinking and learning (Ethell & McMeniman, 2000; NRC, 2001; Pearson et al., 2010).

Teachers across the United States are now almost universally allotted some time in their day to plan, but not as much as teachers in other developed countries (Aydin, 2014; Darling-Hammond et al., 2009). This means that teachers in other countries have more time to be reflective (Aydin, 2014) and collaborative (Lenski & Caskey, 2009).

The Tyler and Yinger Debate

Today, it is nearly universally accepted that teacher planning is a necessary part of the work that all teachers do (Blanton, Sindelar & Correa, 2006; Clark & Peterson, 1986), but it has been overlooked (Yinger, 1980), oversimplified (Bullough et al., 2008) and discouraged (Zahorik, 1970) in the past. Books from the 1950s and 1960s contributed to academic thought on planning, but empirical research on teacher planning did not begin until the 1970s
Since then, the research base has steadily expanded from experienced elementary teachers to include preservice teachers at all grade levels, as well as novice and experienced middle and high school teachers.

One of the first discussions on lesson planning came in 1950 when Tyler proposed a linear lesson planning strategy that became known as the “structural method”. The structural method uses four steps to consider student needs: specify objectives, select learning activities, organize and sequence the activities, and specify evaluation procedures (John, 2006; Tyler, 1950; Young, Reiser & Dick, 1998). Many researchers discussed the validity of Tyler’s ideas over the next several decades (e.g., Farrell, 2002; Hall & Smith, 2006; Yinger 1978/1980). An early study of teacher lesson planning concluded that teachers do not typically follow Tyler’s method because they consider content and activities over objectives and evaluation (Zahorik, 1975). In his discussion of the results, Zahorik disapproved of the teachers’ planning methods because he said that teachers should consider content as a means to an end, not an end in itself (Zahorik, 1975). Peterson, Marx, and Clark (1978) also found that teachers discussed content, not objectives.

Yinger and his colleagues may have conducted the most influential early research on teacher planning, characterizing the planning process as cyclic instead of linear (Clark & Peterson, 1986; Farrell, 2002; Yinger, 1978/1980). Yinger claims that his case study is the first descriptive study of teacher planning that used observations to report on a teacher’s regular planning behavior (Yinger 1978/1980). He determined that routinization helps effectiveness, and described a structural model that teachers use for planning which includes yearly, term, unit, weekly, and daily planning levels, as well as a cyclic planning process.
model of problem finding, design, and implementation (Yinger, 1978/1980). Yinger and his colleagues continued to investigate teacher planning, and conducted several smaller studies, confirming Zahorik’s (1975) findings that lesson planning follows an “inductive design process rather than rational decision making” (Yinger, 1980, p. 14), that it revolves around activities, not objectives (Clark & Yinger, 1979), and that the process is strongly oriented toward action rather than self-development (Yinger, 1980). Other conclusions from these studies were: planning is important to teachers and invisible to everyone else; planning during the first few weeks of school is important; planning transforms curriculum into instruction; routines create efficiency and flexibility; communicating plans puts thoughts into action; and teacher reflection aids teacher development (Yinger, 1980).

The 1980s saw a steady increase in attention to teacher planning, aligning into more specific strands of research. Yinger’s activity model gained acceptance (e.g., Anderson & Evertson, 1978; Brown, 1988), even though most teacher education programs still taught Tyler’s structural approach (Goc-Karp & Zakrajsek, 1987; Twardy & Yerg, 1987). Clark and Peterson discussed the two competing views of planning: Tyler’s (1950) linear structural method and Yinger’s (1978) cyclical problem solving method, noting that Yinger’s method is more reflective of what teachers actually do (Clark & Peterson, 1986). They rejected Tyler’s structural method, hesitating to accept another model, and instead calling for further research (Clark & Peterson, 1986).

Others discussed the impracticality of the structural method of planning and discussed the need for teacher education to develop a new model which would be better aligned with research (Floden & Klinzing, 1990; McDonald, 1983). McDonald called for teacher
education programs to teach an activity approach (McDonald, 1983), while Floden and Klinzing favored further research on developing a new method (Floden & Klinzing, 1990).

Several studies built on Yinger’s (1978) different levels of planning (i.e., yearly, term, unit, weekly, and daily). An observational study of two elementary teachers during the opening days of school found that the more organized teacher presented tasks, communicated expectations, monitored students, and provided feedback better, suggesting that planning the beginning of the year is important (Anderson & Everton, 1978). A study of yearly planning using the problem solving model (Yinger, 1978) concluded that teachers think about prior successes, time, student management, and topic selection in the problem finding stage, while lists and reviews of unit topics, the academic calendar, and curriculum materials are considered in the design stage of yearly planning (Clark & Elmore, 1981). Borko and colleagues also found that establishing reading groups was very important to the long term planning of a class, and that yearly planning helps reduce the load of planning lessons throughout the year (Borko, Shavelson & Stern, 1981).

A descriptive study of mathematics teachers’ daily planning found that planning centers on task selection and anticipating student responses, and that alternating between problem solving and routines is important to the reduction of cognitive load (Bromme, 1982). Preservice teachers were found to be preoccupied with daily planning and inexperienced with longer range planning (Griffin, 1983). McCutcheon (1980) encouraged preservice programs to teach planning in a manner more closely resembling practice, a sentiment echoed by others (Floden & Klinzing, 1990; McDonald, 1983), demonstrating that teacher education courses were not readily changing to reflect research in teacher planning. Student teachers coming
from an institution which favored Tyler’s structural model said that professors teach structural planning in an “ideal world,” with no variance in students’ mood, students’ abilities, resources, or instructional management (Goc-Karp & Zakrasjek, 1987). These teachers also tended to consider activities, not objectives when planning, agreeing with the Yinger model (Goc-Karp & Zakaraisek, 1987).

In response to calls to educate children differently, and beginning with NCTM’s Standards (1989) documents, the 1990s provoked debate about many aspects of education (Hall & Smith, 2006). Reforms invaded most aspects of schools, including curricula (Crow & Pounder, 2000), standards, assessments, technology, and professional development (USDOE, 2003). Research continued to prescribe (e.g., ADI, 2012; Bybee et al., 2006) and describe (e.g., Vaughn, 2010) teachers’ lesson planning in the United States, and studies emerged from other countries (e.g., Yildirim, 2003).

Lenz and colleagues found that the majority of science teachers’ planning is spent on determining content, organizing activities, and motivation, and that in order to be efficient with limited time and resources, teachers’ goals for planning need to be widely useful and relevant (Lenz, Schumaker & Dashler, 1991). English as a Second Language (ESL) instructors followed a cyclic model of planning, including timetabling, determining curriculum, relating social contexts, and perceiving meaningful incidents (Cumming, 1993). English teachers began with state standards, adding professional rigor to planning (Dockstader, 2009), with most planning time short-term and creative in nature, addressing student engagement and practical knowledge (Milner, 2001). A study of superior teachers found the same – teachers plan at different levels, they do not use Tyler’s systematic
planning, and they focus on materials, activities, and assessments (Young, Reiser & Dick, 1998). This study, like many others, did not take the stance that this must be a good way to plan because superior teachers are doing it, rather that preservice programs should work harder to teach systematic planning (Young, Reiser & Dick, 1998).

Some teacher educators held hard and fast to the systematic lesson plan (e.g., Young, Reiser & Dick, 1998), but others encouraged flexibility (Ball, Knobloch & Hoop, 2007). Many books about teaching methods contain chapters about lesson planning (e.g., Farrell, 2002), some of which have opposing viewpoints. Farrell writes “An effective lesson plan starts with appropriate and clearly written objectives” (Farrell, 2002, p. 32). On the other hand, Hoffman (1996) claims that real planning is pragmatic, and that unit and lesson planning should be more like a map, keeping teachers informed of the route, but leaving flexibility. Reynolds sits in the middle, describing the complex and recursive nature of planning that makes experienced teachers effective, yet claiming that novices with a less well developed schema may need a simpler, linear model (Reynolds, 1992). The Common Core Action Guide for Instructional Planning seems to have tried to simplify planning as well, providing worksheets for different levels of lesson plans, noting in its directions that the completion of the worksheets is not a linear process (ADI, 2012).

Planning as a Mental Process

Teacher planning is mostly a mental process, without detailed written plans (Milner, 2001; Morine-Dershimer, 1977). McCutcheon (1980) found that the richest source of teacher planning was not the plan book at all, but a complex mental dialogue that ran even during nonteaching activities. Since planning is pragmatic and situated (Harris & Hofer, 2009) as
well as action oriented (Yinger, 1980), it would be very difficult, if not impossible, for teachers to commit to paper in a usable form the entirety of the complexity and detail which they plan. Teacher plan books were compared to grocery lists, with reminders of activities forming a history of what has been taught each day, and which only included details for substitute teachers and administrators (Goc-Karp & Zakaraisek, 1987; McCutcheon, 1980). In these and other studies, teachers wrote daily lesson plans much less often and less detailed than the researchers anticipated (Goc-Karp & Zakarajsek, 1987; Twardy & Yerg, 1987).

Teachers use various forms of commercial materials as a resource in planning (Sanchez & Valcarcel, 1999), and often follow a textbook (Remillard, 2005; Sullivan et al., 2012; Yildirim, 2003), or adapt existing curricula (Drake & Sherin, 2006). While some teachers rely heavily on state documents and standards (Dockstader, 2009), most rely more on commercial materials (Sullivan et al., 2012; Yildirim, 2003). Teachers who do diverge from curricula often use it as a starting point (Superfine, 2008), and then choose activities to fit content (Roche et al., 2014). Many use unit notebooks that they create and refine over time to contain notes about curricula as well as the adaptations and activities that they used (Brown, 1988). Teachers’ reliance on commercially written curricula and other resources as well as their own notebooks may enable them to write less detailed daily plans that resemble shopping lists because the details are contained elsewhere, and being pragmatic (Hoffman, 1996) and pressed for time (Aydin, 2014), teachers do not have a need to recreate them.

Milner (2001) observed that while long term planning is important, it takes a very small part of teacher planning time. Most time spent planning is at the weekly and daily levels, possibly because of the greater level of detail required (Milner, 2001). One way to
deal with the high level of detail needed is that many teachers make easily adaptable plans (Vaughn, 2010), which may be changed throughout the lesson as the teacher improvises to take into account student difficulties (Borko & Livingston, 1989). Routines, which are well known by the teacher, but seldom written, are used to efficiently segment the planning and teaching time into various activities, (Leinhardt, 1983). This allows teachers to consider content and activities above other goals, and to rely on mental planning for many of the details of the daily lessons (Sanchez & Valcarcel, 1999).

**The Role of Experience**

With the popularity of the situative theory of learning (Lave & Wenger, 1991), several studies have been conducted which consider teaching as a craft knowledge (e.g., Grimmett & MacKinnon, 1992). Dewey’s ideas of learning by doing have been revived (Ethell & McMeniman, 2000; Horn, 2005), with projects such as a web-based cognitive apprenticeship for lesson planning (Liu, 2005) and lesson study (Lenski & Caskey, 2009) showing positive results. Some institutions are holding hard and fast to the systematic lesson plan (e.g., Young, Reiser & Dick, 1998), but others are encouraging flexibility (Ball, Knobloch, & Hoop, 2007) and are experimenting with more situated models, such as the use of stories (Doyle & Holm, 1998). Novice teachers learn from their colleagues through collaborative planning (Horn, 2005), and are more concerned with increasing their cognitive toolbox than creating detailed lesson plans (Bullough et al., 2008). Lesson study, which began in Japan as a type of action research, is a collaborative approach which has produced positive results of teachers sharing expertise through its pragmatic and cyclical process of collaborative lesson planning, observation, and reflection, creating enthusiasm among
teachers (Lenski & Caskey, 2009). In these studies, the planning environment represents the complex juggling of information along with instructional problem solving (Davis, 2014). Teachers’ judgments and decision-making skills are valued (Grimmett & MacKinnon, 1992), and teachers are encouraged to use reflective inquiry (Ethell & McMeniman, 2000), enhancing their complex cognitive schemas, a much more natural approach than the structural model that is commonly taught (Hall & Smith, 2006).

There is a wide variety of studies involving the planning of student teachers, possibly because of their availability, willingness, and potential influence as the next generation of teachers. Results echo those of studies of expertise, including that student teacher planning is a cyclic process of consulting partner teachers, examining curriculum, identifying topics, formulating goals and objectives, identifying standards, developing activities and assessments, and gathering materials (Mumba et al., 2007). They focus more on activities than content, and that they make few connections between pedagogical and content knowledge (Penso & Shoham, 2003). Student teachers’ objectives often focus on a narrow range of skills and miss many skills all together (Baecher, Farnsworth & Ediger, 2013), but they grow in specificity and organization in planning over time (Morine-Dershimer, 1993). Practice opportunities, prior content knowledge, and field experience contexts contribute the most to student teachers’ selection and use of tasks (Swearington, 2014). Student teachers with behaviorist epistemologies feel more prepared with detailed lesson plans, while constructivist student teachers felt that detailed lesson planning hindered creativity (Knobloch & Hoop, 2005). Regardless of epistemological orientation, student teachers whose beliefs are congruent with their institution enjoyed planning, saw a purpose, and felt more
confident, while those with incongruent beliefs felt frustrated and hindered in planning, and abandoned the approach they had been taught very quickly (Knobloch & Hoop, 2005).

**Planning for Curricula**

Part of the excitement that began in the 1990s and continues today in education is about curricula. Older studies of implementation of interdisciplinary curricula concluded that perhaps it is too complex for novice teachers to attempt (Roskos & Neuman, 1995; Roskos, 1996). Supports and organizational planning strategies were created, such as planning wheels (Palmer, 1991) and integration ladders (Harden, 2000). Many reform curricula intentionally support teacher learning (Remillard, 2000), and include objectives, activities, and pedagogical notes (Drake & Sherin, 2006). Studies were conducted regarding teachers’ planning with them as a part of curriculum development that all teachers do, and Remillard emphasized the differences between the design arena of selecting and designing tasks and the construction arena of enacting the curriculum with students (Remillard, 2005). A suggested model of curriculum use is for teachers to read, evaluate, and adapt the curriculum for their students (Drake & Sherin, 2006), and studies have found that teachers do use curriculum as a starting point for lesson planning (Superfine, 2008), but that their narrative identity shapes the extent to which they use the curricula in planning (Drake & Sherin, 2006).

Collaborative planning has been found to be important to interdisciplinary curricula (Roskos, 1996), and teachers who engage in more common planning regarding interdisciplinary curricula gain support from planning together (Owen, 2005) and engage in more interdisciplinary team activities (Flowers, Mertens & Mulhall, 2000).
Common Planning and Co-planning

Currently, many schools are encouraged to form professional learning communities (PLCs, e.g., NCDPI, nd) or professional learning teams (PLTs, e.g., Hickey & Zuiker, 2005; NASSP, 2006). Just as individual planning is described as a creative, iterative process (Reynolds, 1992; ADI, 2012), team planning is also described as a highly iterative process, with teachers often overtalking each other and circling back to discuss topics often (Engestrom, 1998). Teams can engage in common planning and collaborative planning, but often do not meet regularly enough to discuss details of daily planning. This limits planning to broader unit or term planning or other topics, such as student behavior (Horn, 2005).

Engaging in team planning is beneficial to teachers (Roskos, 1996), and allows the opportunity to verbally communicate plans and ideas that would otherwise remain unwritten (Yinger, 1980). Teachers who plan together engage in legitimate peripheral participation to gain access to an otherwise unseen arena of planning by other teachers, a form of cognitive apprenticeship (Lave & Wenger, 1991; Zagal & Bruckman, 2010). The verbalization that develops from common planning encourages teachers to engage in reflective inquiry, which aids in teacher growth (Ethell & McMenniman, 2000).

Overall, teachers who engage in common planning gain support and community from their peers (Owen, 2005; Flowers et al., 2000). They form communities of practice (Brown & Duguid, 1991), which help to shape teacher identities (Philipp, 2007). This is especially important for novice teachers, who benefit the most from forming study groups (Norman, 2011), consulting experienced partners (Mumba et al., 2007) and collaborative planning (Horn, 2005). However, teachers in other countries are generally allowed more time for
collaboration than teachers in the United States (Aydin, 2014; Darling-Hammond et al., 2009), a problem that stems from the importance of teacher planning begin overlooked for so many years (Blanton et al., 2006; Clark & Peterson, 1986).

Co-planning is a special type of team planning, usually completed in preparation for teachers co-teaching the same group of students (Walther-Thomas, Bryant & Land, 1996). Most academic literature focuses on special education and general education teachers, but studies of co-teaching with student teachers are beginning to emerge as well (e.g., Scantlebury, Gallo-Fox & Wassell, 2007). There are many prescriptive articles about co-teaching (e.g., Dieker & Rodriguez, 2013) and some about co-planning (e.g., Murawski, 2012), but because of its newness, there are few empirical studies regarding co-teaching (Murawski & Swanson, 2001; Scruggs, Mastropieri & McDuffie, 2007), and far fewer on co-planning.

Co-planning literature does not fit the structural versus activity-based dialogue of other planning literature. Results of a meta-analysis of co-planning studies demonstrate the nature of most discussion on co-planning: it helps to have a regular co-planning time, most co-teachers do not co-plan enough, co-teachers do not plan enough for individual students, and shared responsibility is preferable for co-teaching but happens rarely (Scruggs, Mastropieri & McDuffie, 2007). In *Ten Tips* for co-planning, the same type of advice is found: e.g., establish a regular time, select an appropriate place, have an agenda and snacks (Murawski, 2012). Other themes revolve around trust (Walther-Thomas, Bryant & Land, 1996), the role of the special education teacher (Dieker & Rodriguez, 2013), and the importance of co-planning (Murawski, 2012).
Themes in co-planning in empirical research are relatively the same as they are in prescriptive literature: teachers do not do enough of it (Hang & Rabren, 2009), co-teachers do not have the equal levels of input or respect (Murawski, 2012; Scantlebury, Gallo-Fox & Wassell, 2007), and teacher reflection produces positive effects on teacher knowledge (Siry, 2011). In action research, giving teachers planning prompts (Swanson & Bianchini, 2014) and providing feedback and suggestions were found to enhance co-teaching (Ploessl & Rock, 2014), but neither of these studies described the process of co-planning.

**Research Regarding Teacher Beliefs**

Teacher planning is a complex and ongoing mental dialog (Milner, 2001; Morine-Dershimer, 1977), which is deeply influenced by the teacher’s conceptions about mathematics (Handal, 2003) or science (Lederman, 1992), about teaching (Knobloch & Hoop, 2005; Lumpe, Haney & Czerniak, 2000; Wilson & Cooney, 2002), about students (Bray, 2011; Cross, 2009), and about curriculum (Lloyd 1999a/1999b; Remillard, 2005; Superfine, 2008). Results from various studies confirm that teachers’ beliefs greatly influence what they do in the classroom (Handal & Herrington, 2003), that they differ in individuals (Beswick, 2004) and contexts (Hoyles, 1992), that they are resilient (Czerniak et al., 1999), that they vary in intensity (Pajares, 1992), and that they can be changed through professional development (Brosnan, Edwards & Erikson, 1994).

This section will use available literature to briefly review the history of academic literature regarding teacher beliefs. It will then: 1) define beliefs and briefly compare beliefs with related constructs, such as conceptions and emotions; 2) describe our understandings of what teachers think about mathematics and science; 3) review specific teacher beliefs about
teaching, learning, and curriculum in mathematics and science; and 4) discuss apparent contradictions between teachers’ beliefs and practice.

**History of Beliefs**

Throughout modern history, notions such as *logical thinking*, *mathematics*, and *science* have been regarded as absolute and opposing emotions (Zan et al., 2006). The study of belief was mostly conducted within the field of psychology, with researchers such as Rokeach, McGuire, and Scheffler originating many commonly used definitions (Cooney, Shealy & Arvold, 1998; Pajares, 1992; Phillip, 2007). During the latter part of the 20th century, new views of knowledge came forth (e.g., von Glasersfeld, 1982), new standards were introduced (e.g., NCTM, 1989), curricular reforms were made (Lloyd, 1999a/1999b; Remillard & Bryans, 2004; Yates, 2006), and education became more highly politicized (Lerman, 2002; Philipp, 2007). All of these factors contributed to the emergence of the areas of research involving teachers’ beliefs about mathematics (Philipp, 2007), science (Lumpe, Haney & Czerniak, 2000), and the teaching and learning of mathematics and science (Lederman, 1992; McLeod, 1992).

Aside from a great assortment of independent studies, meta-studies (Hoyles, 1992), reviews (Pajares, 1992; Pehkonen, 2001), handbook chapters (Jones & Carter, 2007; Phillip, 2007), and entire books (Leder, Pehkonen & Torner, 2002) are devoted to the topic of teachers’ beliefs regarding mathematics and science. Instruments have been developed and used with teachers and students, including the *Mathematics Attitude Scale* (Fennema & Sherman, 1976, as cited by Zan et al., 2006), the *Attitudes and Beliefs about the Nature of and the Teaching of Mathematics and Science* (McGinnis et al., 1997), the *Mathematics*

Earlier literature tended to be broader, such as the handbook chapter Teachers’ Thought Processes (e.g., Clark & Peterson; 1986), but literature became more specialized over time, such as the handbook chapter Mathematics Teachers’ Beliefs and Affect (e.g., Philipp, 2007). Beliefs also constitute a large consideration in other research handbook topics, such as professional development in science (Luft & Hewson, 2014). Possibly because beliefs are a cultural construct (Correa et al., 2008), a variety of literature emerges from countries around the world, including Australia (e.g., Howard, Perry & Lindsay, 1996; Nisbet & Warren, 2000), Canada (Mura, 1995), China (Correa et al., 2008), Finland (e.g., Pehkonen, 2001), Germany (Torner, 2002), Greece (e.g., Chrysostomou & Philippou, 2010), Hungary (Andrews & Hatch, 2000), Spain (Llinares, 2002), Taiwan (Chen, 2008), and Turkey (e.g., Aydin et al., 2010).

Other similar or overlapping constructs, such as views, conceptions, knowledge, attitudes, values, and emotions have been studied in relation to beliefs (McLeod, 1992; Philipp, 2007), and attempts have been made to create and refine definitions (Cooney, 2002; Furinghetti & Pehkonen, 2002) and frameworks (Peterson et al., 1989; Raymond, 1997). Empirical research tends to concentrate around two participant groups: preservice teachers (e.g., Benbow 1993/1995; Enemaker, 1996; Shilling, 2010) and elementary teachers (e.g., Fennema et al., 1996; Nisbet & Warren, 2000; Raymond, 1997), possibly because of their availability or because of their importance to the future of student learning.
Defining Beliefs and Other Constructs

There is no consensus in mathematics education literature about the definition of beliefs. Cooney referenced Scheffler (1965), saying that a belief “is a cluster of dispositions to do various things under various circumstances” (Cooney, 2002, p.20). Pajares (1992) examined the literature concerning beliefs in mathematics education and found an array of terms and themes, but no clear definition. Furinghetti and Pehkonen (2002) sent out a questionnaire to notable researchers in mathematics education with 9 characterizations of beliefs and received back a variety of responses. None of the characterizations were chosen by all researchers, but #3 “conceptions are a person’s general mental structures that encompass knowledge, beliefs, understanding, preferences, and views” was agreed with by 17 of the 18 votes. The highest amount of votes for a characterization of beliefs was #7, “an individual’s understandings and feelings that shapes the ways that the individual conceptualizes and engages in mathematical behavior,” which received 11 of 18 votes. Other definitions of beliefs consider a state of mind (Vinner, 1999), and contain cognitive, affective, and behavioral components (Pajares, 1992).

For the purposes of this paper, beliefs will be defined as a complex, but relatively stable system of contextually based personal knowledge which inform thoughts and behavior, formed by personal and cultural experiences, including subjective and objective notions, and organized into interrelated clusters.

Beliefs are complex. Teachers concurrently hold different types of beliefs, such as beliefs about subject matter and beliefs about pedagogy (Cooney, 2002), and this system of beliefs becomes more complex over time and with experience (Levin & Wadmany, 2006).
Beliefs and other cognitive and affective structures are entangled, and different beliefs may be prioritized under different circumstances (Pajares, 1992). Further complicating the study of beliefs is the fact that beliefs are not always explicit to the holder (Vinner, 1999) or the researcher (Ambrose, Clement & Phillip, 2004). Thoughts inside teachers’ heads are invisible to us (Clark & Peterson, 1986), and we can only infer beliefs from behavior (Hart, 2002) and self-reports (Levin & Wadmany, 2006). Researchers conduct observations and design instruments to measure “latent psychological constructs that serve as proxies for the actual beliefs” (Nathan et al., 2010).

Beliefs are stable. Although beliefs can change through reification (Llinares, 2002), by active reflection and professional development (Basista & Matthews, 2002), by internal conflict (Cooney, Shealy & Arvold, 1998) and contradictory situations (Pehkonen, 1999), and by other powerful experiences (Philippou & Christou, 2003), they generally act more as obstacles to change (Pehkonen, 1999) because they are usually well established by the time a person is in college (Pajares, 1992). Researchers have found that it is usually easier to assimilate new beliefs, even if they are contradictory, than to accommodate existing beliefs, and that the earlier a belief is incorporated, the more difficult it is to change (Pajares, 1992). Moreover, there is evidence that the intensity of beliefs is also stable (Philippou & Christou, 2002); that surface beliefs may be disregarded for deeply held beliefs in given situations, but they are not discarded (Levin & Wadmany, 2006).

Beliefs inform thoughts and behavior. There is not a consensus about whether beliefs influence teachers’ planning (Borko, Livingston & Shavelson, 1990; Nathan & Koedinger, 2000a), particularly with a given curriculum (Middleton, 1999). However, all
people hold beliefs, and they seem to be the best indicators of the decisions that individuals make (Pajares, 1992) about instruction (Cross, 2009), classroom activity (Brickhouse, 1990; Wilson & Cooney, 2002), the role of the teacher and pupil (Benbow, 1995), and routines (Llinares, 1999; Vinner, 1999). In fact, beliefs and routines support each other because of their unchanging nature (Vinner, 1999) and strongly influence perception (Pajares, 1992), influencing other issues such as the pace of educational reform (Handal & Herrington, 2003).

Beliefs are formed by experience. Beliefs are situated (Hoyles, 1992) and may be formed by university studies, professional views, in-service training, prior school experiences (Pehkonen, 2001), cultural experiences (Correa et al., 2008), or membership in social groups (Cross, 2009). Thought processes and views may be a precursor to beliefs (Pajares, 1992). There is considerable debate over whether beliefs need to change in order to change practices, or vice versa, because of the notion that beliefs influence practice, but experience influences belief (Lerman, 2002; Philipp, 2007); hence, beliefs may have a cyclic (Lerman, 2002) and self-fulfilling nature (Clark & Peterson, 1986).

Beliefs are subjective and objective. They may also be contextual or dualistic (Cooney, Shealy & Arvold, 1998). Beliefs are sometimes thought of as the conscious and unconscious thoughts (Cross, 2009) that intertwine the cognitive and affective domains (Goldin, 2002; Pehkonen, 2001), but are generally considered cognitively weaker than knowledge (Wilson & Cooney, 2002) because they are based on evaluation and judgment rather than objective fact (Pajares, 1992). Further separating belief and knowledge, beliefs have a stronger affective component (Hart, 2002), are personally defined (Furinghetti & Pehkonen, 1999), and sometimes reject reason and research (Turner, Christiansen & Meyer,
Beliefs are held in clusters. Beliefs form interrelated systems (Leder, Pehkonen & Torner, 2002), which are mostly sensible (Leatham, 2006) and organized (Luft & Roehrig, 2007), but not necessarily logical (Chapman, 2002). Teachers act in situations in which multiple conflicting beliefs are activated at once (Bray, 2011), and through these situations one can recognize beliefs as an expression of the self in context (Lerman, 1999) and understand these beliefs in relation to other beliefs that the individual holds (Pajares, 1992).

Other constructs related to beliefs. Pajares (1992) provided a list of terms which are often used in conjunction with beliefs, including: attitudes, values, judgments, axioms, opinions, perceptions, conceptions, dispositions, implicit theories, mental processes, practical principles, and perspectives. Many of these and other constructs are studied in conjunction with beliefs, often without being explicitly defined (Philipp, 2007). Cooney (1985) studied views; Clark & Peterson (1986) reported on personal theories; Frykholm (1995) studied perceptions and philosophies; McGinnis and colleagues (1997/1999) studied attitudes; Basista and Matthews (2002) as well as Riggs and Enochs (1990) studied confidence and self-efficacy; Amirali and Halai (2010) studied insights and understandings; and Cullen and Greene (2011) studied attitudes and motivation.
Researchers generally agree that conceptions are the most general notion, encompassing knowledge, beliefs, understanding, preferences, views (Furinghetti & Pehkonen, 1999; Holstein, 2012), commitments, intentions, and affect (Philipp, 2007). In literature, the word conceptions is often used as a catch-all to mean understanding (e.g., Knuth, 2002a/2002b), beliefs (e.g., Andrews & Hatch, 1999), or a subset of beliefs regarding a specific topic (e.g., Pehkonen, 2001), but even the word conceptions has held different meanings from one text to another (Cooney, 2002).

Conceptions can be divided into cognition and affect (McLeod, 1992; Philipp, 2007). Cognition, or knowledge, may be regarded as more universal or more personal depending on the researcher’s worldview (Lave & Wenger, 1991; Philipp, 2007), but it is generally regarded as objective (Pajares, 1992) and consensual (Philipp, 2007). Affect can be described as “disposition, tendency, emotion, or feeling attached to an idea or object” (Philipp, 2007), and made up of emotions, attitudes, and beliefs (Pehkonen, 2001; Philipp, 2007). Goldin (2002) proposed that affect is central to cognition because it stabilizes belief and meaningfully encodes information such as feelings, sufficiency of understanding, and expectations (Goldin, 2002).

Knowledge is usually divided into categories based on what it is about, i.e., knowledge about teaching, knowledge about subject matter (e.g., Ball, Thames & Phelps, 2008; Cooney, 2002), while affect is often categorized based on stability, i.e., emotion, attitude, and belief (e.g., McLeod, 1992; Philipp, 2007). Emotions are feelings or states of consciousness, distinguished from cognition because they change rapidly and are felt intensely, and may be positive or negative (Philipp, 2007). Attitudes are manners of acting,
feeling, or thinking that show disposition (Philipp, 2007), but are felt less intensely and for longer periods of time than emotions (McLeod, 1992). While emotions are usually an aesthetic response based on an experience (Cullen & Greene, 2011), attitudes are often held about a construct and built over time (Philipp, 2007; Philippou & Christou, 2002). Values can be considered separately from attitudes (e.g., Goldin, 2002), but are generally considered a part of attitudes (Philipp, 2007).

Beliefs, as described above, can be viewed as the mediator of cognition and affect (Llinares, 2002), because they are more stable and objective than attitudes, but more subjective than knowledge (Philipp, 2007). As stated above, the lines between all of these constructs are blurred from one researcher to the next, making it difficult to separate and define them, and many authors do not attempt to define them, or use various terms interchangeably, even within their own works (Philipp, 2007).

**Teacher Beliefs Regarding Mathematics and Science**

Many studies explore teachers’ beliefs about mathematics and science, which influences their views of teaching and learning each subject (Cronin-Jones, 1991; Perkkila, 2001). While some studies simply consider the amount of agreement that teachers express toward reform movements (e.g., Battista, 1994; Bray, 2011; Frykholm, 1995), many others consider teachers’ beliefs about the nature of mathematics (e.g., Handal, 2003) and science (e.g., Lederman, 1992; Thomas, Pedersen & Finson, 2001), and the teaching and learning of mathematics (Benbow, 1993; Wilson & Cooney, 2002) and science (Lumpe, Haney & Czerniak, 2000). This section will briefly describe the various frameworks and findings regarding teachers’ beliefs about the nature of mathematics and science.
Beliefs about mathematics. Many researchers regard teachers’ beliefs about mathematics on a continuum from authoritarian to problem solving (Handal, 2003; Mura, 1993). Except in carefully chosen case studies (e.g., Beswick, 2007; Roddy, 1992), teachers tend toward the traditional authoritarian view (Amirali & Halai, 2010; Andrews & Hatch, 1999; Paksu, 2008; Perkkila, 2001; Stuart & Thurlow, 2000; Thompson, 1991). This includes beliefs such as: math is numbers, rules (Andrews & Hatch, 2000) and computation (Cross, 2009), math requires a good memory, mathematicians do problems quickly in their heads (Frank, 1990), mathematical ability is innate (Paksu, 2008), problems should be solved in less than 5 minutes (Stuart & Thurlow, 2000), the answer, gotten in the correct way, is what counts, and success in problem solving is remembering a unique procedure for each problem type (Pehkonen, 2001).

Constructivist epistemologies view knowledge in more subjective terms (e.g., Wilson & Cooney, 2002; Peterson et al., 1989; Philipp, 2007), and common constructivist beliefs about the nature of mathematics include that: mathematics is not fixed (Frykholm, 1995), math is experience, math is play, math is language (Nisbet & Warren, 2000), mathematics is a tool for problem solving (Roddy, 1992), math is problem solving (Andrews, 2007). Mathematics education researchers also consider discourse and argumentation an important part of mathematics (Herbel-Eisenmann et al., 2011; Yackel & Cobb, 1996).

University mathematicians (Mura, 1993) and mathematics educators (Mura, 1995) were asked the definition of mathematics, and 14 themes emerged. 10 themes overlapped between groups: math is the study of formal axiomatic systems; logic, rigor, and accuracy; a language; design and analysis of models abstracted; problem solving; the study of patterns; a
creative activity; a tool for science; reference to specific topics; and other, such as difficulty or circular definitions (Mura, 1995). The mathematicians included truth, and the reduction from complexity to simplicity (Mura, 1993), and the mathematics educators added culturally determined content, and inductive thinking and generalization (Mura, 1995). These themes are mostly consistent with the constructivist view of mathematics, which means that instructors at the university level see mathematics as a different type of entity than those at the k-12 level.

**Beliefs about Science.** As with mathematics, many researchers regard teachers’ beliefs about science on a scale from traditional to inquiry based (e.g., Luft & Roehrig, 2007; Mansour, 2013). Like mathematics teachers, science teachers tend toward a traditional view, including that science is an objective body of knowledge (Wallace & Kang, 2004) produced by a rigid and universal scientific method (Bergman, 2014), and that terminology takes precedence over principles (Gallagher, 1991). Teachers tend to believe that science is more procedural than creative, and that science and its methods are absolute proof of various theories and phenomena (Bergman, 2014). They tend to see scientific theories as theory-driven rather than inductive, and progress is viewed as the accumulation of facts rather than changes in theory (Brickhouse, 1990; Gallagher, 1991). One evidence of this is that they tend to judge students’ scientific arguments more positively if they agree with their own preconceived notions, and more negatively if they show sound reasoning, but do not agree with their own pre-conceived notions (Sampson & Blanchard, 2012).

In-service and pre-service teachers alike tend to have little knowledge of the history or philosophy of science, possibly because of the nature of the content classes offered at the
university level (Gallagher, 1991). However, beginning teachers’ beliefs may change more readily than their more experienced peers (Luft & Roehrig, 2007), especially through focused professional development programs (Luft & Hewson, 2014).

**Beliefs Regarding Teaching, Learning, and Curriculum**

Teacher beliefs about teaching, learning, and curriculum are intertwined (Wallace & Kang, 2004), since these are generally considered together (Cronin-Jones, 1991), especially when planning for instructional tasks (Wallace & Kang, 2004). Claims about teachers’ views of teaching and learning are more varied and complex than their views about the subject of mathematics or science, possibly because of the focus on human activity (Bergman, 2014; Turner, Christiansen & Meyer, 2009).

Many researchers consider teacher beliefs about teaching and learning on a spectrum from transmission to problem solving (e.g., Beswick, 2005; Carney et al., 2014; Mansour, 2013; Paksu, 2008; Perkkila, 2001; Shilling, 2010). For example, one well known framework proposed by Ernst describes the instrumentalist, platonic, and problem solving views of teachers (Perkkila, 2001), and has been useful to differentiate between types of beliefs that teachers express regarding mathematics. In this framework, the instrumentalist view describes the teacher as the instrument who conducts knowledge to the submissive student. The platonic view, named after Plato, is that student understanding of important concepts is most important, and while important knowledge is still transmitted from teacher to student, the emphasis is on the student discovering the important concepts. The problem solving view is that mathematics is created by the student, and that the teacher is only a facilitator (Carney et al., 2014; Handal, 2003; Paksu, 2008; Perkkila, 2001; Shilling, 2010).
Other researchers have also studied teacher beliefs about teaching and learning regarding their epistemological beliefs about structure, stability, sources of knowledge (Esterly, 2003; Luft & Roehrig, 2007), simplicity, and certainty of knowledge, (Chrysostomou & Philippou, 2010; Kim et al., 2013), social context (McLeod, 1992), and their views about students (e.g., Kaplan, 1991).

Beliefs about teaching. Some studies reveal a transmission view of teaching (Mansour, 2013): that teachers’ goals are behavioral rather than cognitive (Battista, 1994; Mansour, 2013), that teaching is telling (Philipp, 2007), especially about facts and vocabulary (Cronin-Jones, 1991), and that the teacher’s role is to cover the textbook material (Gallagher, 1991), tell students if they are right or wrong and to support routines in class (Llinares, 1999) and prepare students for tests (Bergman, 2014). Often, teachers bring their own performance anxiety with them to teaching (Zan et al., 2006), along with a desire to protect students from the difficulties that real-world problems might present (Perkkila, 2001).

Other studies find that teachers’ beliefs about pedagogy are less traditional than their views about mathematics and science (Andrews & Hatch, 1999; Barkatsas & Malone, 2005; Wallace & Kang, 2004). Teachers in these studies tend to focus on the individual student (Andrews & Hatch, 1999), posing questions (Wallace & Kang, 2004), building confidence (Frykholm, 1995), discovering the world around them (Mansour, 2013), using pedagogical authority (Wilson, 1999), inducting students into widely accepted ways of thinking (Beswick, 2004), and thinking that purposeful inquiry is fun (Beswick, 2007).

While teachers’ epistemological beliefs are often consistent with their teaching methods (Mansour, 2013), there is growing concern that teachers, and in particular beginning
teachers, with tendencies toward student-centered activities and instruction will develop more traditional practices in the absence of student-centered support or professional development (Luft & Roehrig, 2007). Many teachers note the importance of inquiry based teaching, which includes designing experiments, collecting data, and drawing conclusions, but they perceive barriers to implementation in their classes (Wallace & Kang, 2004). These teachers believe that the need to be efficient in explanation and covering curriculum is more valuable in schools than inquiry (Wallace & Kang, 2004). They also believe that they do not have the ability to bring about structural change because of external pressures (Haney, Czerniak & Lumpe, 1996). However, it has been shown that teachers will move toward more student-centered beliefs and approaches with appropriate specialized supports (Luft & Roehrig, 2007). These teachers may need role models such as other teachers with constructivist beliefs who are more likely to detect alternate student conceptions, have a richer repertoire of teaching strategies, and use more effective strategies (Hashweh, 1996; Herbel-Eisenmann et al., 2011; Sampson & Blanchard, 2012).

Beliefs about learning and students. The constructivist viewpoint on learning, which has dominated the reform movement, is that children should construct their own knowledge, and instruction should be sequenced and performed in relation to and to facilitate children’s construction of their own knowledge and problem solving skills (Frykholm, 1995; Peterson et al., 1989). Furthermore, children think about mathematics differently than trained adults, and children should do as much of the thinking as possible (Bray, 2011; Herbel-Eisenmann et al., 2011). This is vastly different from the traditional transmission view, in
which students are empty vessels that willingly accept an already developed body of knowledge (Mansour, 2013).

Fennema and colleagues (1996) used 5 levels to discuss teachers’ beliefs in relation to the constructivist viewpoint. They are: 1) children learn best by being told how to do math; 2) questioning idea of showing; 3) problem solving with direct instruction; 4) problem solving without direct instruction; 5) problem solving and using knowledge of children’s thinking to guide decisions. Empirical studies have found teachers at each of these levels: those who think students learn by practice and drill (Nespor, 1987), value practice over understanding (Cross, 2009), who believe that when students work with connections, they see relevance (Roddy, 1992), who think students learn more through problem solving and cooperative learning (Nespor, 1987), and who believe that learning is developing knowledge in meaningful and practice-bound contexts (Handal & Bobis, 2004).

Teachers tend to score either high or low on their belief of all elements of constructivism together (Peterson et al., 1989), but many confuse students’ apparent interest and involvement or their ability to list facts with comprehension or explanation (Sampson & Blanchard, 2012; Turner, Christianson & Meyer, 2009). This may be because some teachers’ beliefs about learning conflict with their beliefs about students. For example, teachers may want students to explore rich problem situations but do not feel an obligation to hold students responsible in assessments (Wilson, 1999).

Teachers might also believe that older students are not interested in mathematics (Beswick, 2004) or science (Bergman, 2014), or certain students lack natural talent (Fennema et al., 1990). Gender bias exists, even for teachers who work with talented students,
especially among male teachers (LaLonde, Leedy & Ruck, 2003). Teachers with strongly held beliefs are more likely to adapt instruction to their view of students than attempt change (Turner, Christianson & Meyer, 2009).

**Beliefs about curricula.** Studies of teachers’ beliefs about mathematics curricula revolved around the reform movement beginning with the NCTM (1989) *Standards*. Since teachers tend to use textbooks in mathematics more religiously than in any other subject (Nespor, 1987), teachers’ beliefs about the text became an object of study in mathematics education, especially as a part of various intervention programs (Lerman, 1999). Some studies are more general in nature, while others involve interactions with specific curricula.

Brosnan and colleagues (1994) found that the *Standards* required a significant shift in teachers’ beliefs about teaching and learning. They thought that using reform curricula with a focus on the *Standards*, may help teachers to change their beliefs about mathematics (Brosnan et al., 1994), to understand learners, and to see subject matter as interactive (Lloyd, 2002). However, beliefs are slow to change (Pehkonen, 1999; Levin & Wadmany, 2006), and there have been mixed results. Some teachers clung to new curricula because of a fear of missing something, while others hardly used it at all (Brosnan et al., 1994). Ball (2002) found similar discrepancies in teachers’ views of highly detailed teachers’ guides.

Nathan and Koedinger (2000a/2000b) found that teachers’ beliefs about the difficulty of algebra problems aligned with textbooks over researchers’ empirical findings (Nathan & Koedinger, 2000a). Middle school teachers’ beliefs were closest to the research findings, so it was theorized that high school teachers may have an *expert blindspot* (Nathan & Koedinger, 2000b).
In science, reform curricula were not written early on to guide the teacher as it was in mathematics, but it was found that some teachers follow textbooks almost exclusively compared to other resources, even when stating purposes for learning science that include understanding natural world and developing critical thinking and reasoning skills (Bergman, 2014; Gallagher, 1991). When asked, these teachers did not have an understanding of which scientific theories are more important than others, citing the curriculum guide as reasons for instructional decisions (Duschl & Wright, 1989). Other teachers with a more constructivist epistemology consider rely less on a set curriculum (Luft & Roehrig, 2007).

Teacher implementation of curricula may be seen as intermittent and narrow, adopting and adapting, or thorough piloting (Remillard & Bryans, 2004). Teachers put their beliefs and views into a curriculum upon implementation (Cronin-Jones, 1991; Remillard & Bryans, 2004), and while they may like the idea of the curriculum, some found it restricting (Lloyd, 1999a), fragmented (Handal & Bobis, 2004), or inefficient (Berlin & White, 2012) because of the incompatibility between the curricular and their own instructional approaches (Lloyd, 1999b). This is similar to the incompatibility that some student teachers felt toward their institution’s epistemology, limiting their planning (Knobloch & Hoop, 2005).

Some teachers continue to use an ill-fitting curriculum without making changes because of a belief in the authority of the textbook (Gallagher, 1991; Lloyd, 1999b), while others alter their beliefs over time with use (Middleton, 1999; Nathan et al., 2010). Teachers of both reform and integrated curricula who begin with a positive attitude often do not change their attitudes with curricular use, but they do experience changes in perceptions of feasibility (Berlin & White, 2012; Middleton, 1999) and teacher and student efficacy
(Watanabe & Huntley, 1998; Nathan et al., 2010). These results are similar to those noted by researchers who implemented interdisciplinary professional development and noted changes in perceptions of feasibility (Basista & Matthews, 2002; Nadelson et al., 2012).

**Inconsistencies Between Teacher Beliefs and Practice**

Numerous researchers have reported inconsistencies between teachers’ espoused and attributed beliefs (Gallagher, 1991; Speer, 2005). In general, teachers’ practice tends to be more traditional than their espoused beliefs (Nathan & Koedinger, 2000b; Perkkila, 2001), even with the use of technology (Chen, 2008) and reform curricula (Middleton, 1999), leading to differences between the intended and enacted curricula (Cronin-Jones, 1991). This may be due to the complexity of teachers’ beliefs (Barkatsas & Malone, 2005) as well as the insufficiency of current instruments to entirely infer them (Speer, 2005). In particular, self-reported beliefs may not compare well to observations of practice because of a lack of shared understanding among researchers and teachers about descriptive terms (Speer, 2005).

Another theory is that teachers may hold conflicting beliefs clusters without even being aware of the conflicts (Chen, 2008; Wallace & Kang, 2004). For example, some elementary teachers believe that mathematics is best taught through problem solving, but through their desire to protect children from the difficulties in thinking mathematically, they take a more traditional approach (Perkkila, 2001). Others use problems to motivate lessons, but do not have students explore alternate solution paths (Cooney, 1985), revealing inconsistencies between deep and surface beliefs similar to many teachers’ use of technology (Li, 2007). Some beliefs may be held more publically because they are more culturally acceptable, such as beliefs of exam preparation and efficiency in covering the curriculum,
while other beliefs may be held more privately, such as inquiry-based learning goals that stand in contrast to culturally supported goals (Wallace & Kang, 2004).

Finally, since beliefs are situated and depend on context (Hoyles, 1992; Mansour, 2013), some claim that the source of inconsistency lies in external pressures (Handal, 2003): to have students perform on tests (Chen, 2008), to conduct class in a similar way to other teachers (Raymond, 1997), to follow other social norms (Barkatsas & Malone, 2005) and to enact unfamiliar curricula (Andrews & Hatch, 1999). This may be why beginning teachers, who are often more vulnerable to these external pressures, seem to have the most inconsistency between their espoused beliefs and practice (Brickhouse, 1990). In fact, when teachers are working in conditions that support their beliefs, belief and practice seem consistent (Turner, Christianson & Meyer, 2009), and with time, beliefs change to endorse previously incongruous curricula (Middleton, 1999).

**The Interdisciplinary Co-planning Team (ICT) Model**

While it may be optimal to form a truly integrated education experience for students (Roebuck & Warden, 1998), there are other factors that make full integration difficult to achieve, such as bell schedules, standardized curricula and tests (Johnson, Charner & White, 2003; Vars, 2001). It my opinion that school structure and culture, as well as teacher knowledge and beliefs, must be accounted for in order to affect lasting change.

The *Interdisciplinary Co-planning Team* (ICT) model was created as an alternative that is flexible enough to overcome some of the more pervasive aspects of school structure (in particular middle and high school structure) that have made limited attempts at integrated curricula in the past. This section describes 1) the ICT model and its features; 2) affordances
of the ICT model; 3) a feasibility study of the ICT model involving researchers; and 4) a pilot in which the ICT model was implemented with classroom teachers.

**The ICT Model**

In the ICT model (Figure 3), teachers from different disciplines are paired and participate in co-planning sessions on a regular basis, during which they discuss concepts and practices from each other’s disciplines and the connections that can be drawn between the content areas. To do this, each teacher explains the major concepts from his or her content to the other, and then the teachers draw parallels between the content together. Once the teachers are satisfied with their own understanding, they then collaborate to develop interdisciplinary activities, examples, and discussion points to use within each classroom.

After the teachers co-plan, they go back to their own classrooms, ready to implement the plans that they created. Bringing classes together to do integrated activities and projects would be considered an optional component of the ICT model that may enhance some activities, but is not necessary for the successful planning and implementation of interdisciplinary lessons.

One last core feature of the ICT model is that it is iterative, so that after teachers implement plans in their own classrooms, they come back together to reflect on their lessons, discuss student understanding, and make changes as necessary. They then proceed to co-plan future lessons, thus restarting the cycle.
ICT co-planning time can also be devoted to discuss the concepts that students should learn, common misunderstandings and areas of difficulty, and connections between the concepts from both disciplines. In the ICT model, once teachers are paired together, each teacher should be intentional about trying to learn concepts from the other’s curriculum. During this time, the teacher pairs should also intentionally look for and create examples and activities that would help students to develop conceptual understanding and consider practices from both subject areas.
Affordances of the ICT Model

The ICT model is meant to be flexible, and to transcend many of the factors noted by Czerniak et al., (1999), Vars (2001), and others that may have limited or discouraged integrated or interdisciplinary teaching in the past by working within the current school structure to create true and lasting results that do not require major policy changes. The following sections will briefly describe ways that it: shifts the focus from isolated subjects to interdisciplinary learning; encourages attention to student learning instead of specific curricula; encourages collaboration in a format that facilitates social trust and shared language; enhances teacher expertise and knowledge; provides teachers time to adjust; and is sustainable in our current school culture.

**Shifts focus to interdisciplinary.** The ICT model shifts the focus from viewing each subject as a separate entity to looking for and finding ways in which content areas overlap and ways in which school classes, separated by subject discipline, can be brought together. If students are not in both teachers’ classes, they should still benefit from the interdisciplinary connections that both teachers are working to draw in the class that they do attend.

As noted in the section about integrated curricula, this focus on interdisciplinary connections can have far-reaching effects for students, such as increased problem solving and communication skills (Moore & Smith, 2014), increased interest and engagement (Morrison, Roth McDuffie & French, 2015), increased retention of concepts (Neulight et al., 2007), and improved test scores (Becker & Park, 2011).

**Encourages attention to student learning.** The ICT model was constructed to be flexible enough to transcend specific curricula, and to focus teachers on learning goals
instead of textbook pages. Teachers should experience an increased focus on concepts and processes instead of practicing questions for standardized tests (Vars, 2001) and an increased focus on student understanding (Lewis et al., 2012), both of which are important components for student growth.

This is not to say that textbooks, standardized documents, and other materials should not be used as resources, because there is value in using curricula as a starting point (Superfine, 2008) and being pragmatic so as not to have to recreate what others have already done (Hoffman, 1996). This does mean, however, that teachers would be adapting curricula to fit their classes and their students, possibly leading to more inquiry-based learning (NGSS, 2013), problem solving (CCSS-M, 2010) and project-based learning (Krajcik et al., 2008).

**Encourages collaboration.** Obviously, the ICT model is built around teacher collaboration, which has a powerful impact on teacher learning (Desimone, 2009) by encouraging teachers to leave norms of isolation (Fisler & Firestone, 2006), and is significantly associated with active learning (Garet et al., 2001). The ICT model could be used for pairings of teachers across any subjects at any grade level. At the lower grade levels, it should not be assumed that one teacher who teaches multiple subjects would be effective at creating interdisciplinary lessons on their own. Teachers generally stay inspired longer and are more creative when they work together (Hickey & Zuiker, 2005; NASSP, 2006).

Co-planning teachers would also be encouraged to contribute to each other’s goals and to share responsibility and resources (Swanson & Bianchini, 2014). Collaboration encourages the development of a community over time, which has also been found to create synergy (Lewis et al., 2012), increase teacher reflection (Butler et al., 2004; Cinta Munoz-
Catalan et al., 2010; Silver & Suh, 2014), and enhance leadership (Loucks-Horsley & Stiles, 2001).

Currently in many places, schools are encouraged to form professional learning communities (PLCs, e.g., NCDPI, nd) or professional learning teams (PLTs, e.g., NASSP, 2006), but PLCs have a limited effect when teachers do not have a clear goal or focus on student learning (Graham, 2007). Schools could modify their current PLT model to create ICTs between teachers that share similar students or student groups, which may provide focus and coherence for teacher teams that were lacking.

**Encourages social trust.** In order to optimize the positive impacts of collective participation, social trust must be developed over the course of teacher collaboration (Borko et al., 2008). Without a high level of social trust, teachers may tend not to exhibit productive collaboration (Lewis et al., 2012), or not make lasting changes to their practices (Fisler & Firestone, 2006). One purpose of creating pairs for co-planning instead of larger groups is to provide teachers with a more comfortable setting to develop social trust with each other than to have to express opinions and possible misconceptions in front of a whole group. This low-stress environment in which teachers can develop social trust is essential to productive discourse and critique during reflection on their practice (Borko et al., 2008).

The pairings can also be maintained with more integrity from one year to the next compared to larger groups in schools that have more teacher turnover, allowing teachers to build on the trust that they establish from one year to the next.

**Encourages shared language.** Through collaboration, teachers can develop a shared language (Owen, 2005), which is important for drawing connections (McDonald, Kazemi &
Kavanagh, 2013). One important aspect of the ICT model is that teachers focus on discussing the content of both subject areas with each other in order to draw connections between the subjects. This includes the vocabulary and definitions involved, which should lead both teachers in a pairing to discuss the similarities and differences in subject-specific vocabulary. For example, the baseline data in science may be called the initial value in mathematics, and the connection and significance among these terms may only be discovered through discussion of the terms themselves.

The development and use of a shared language has not been discussed in detail in literature related to integrated or interdisciplinary education (McCulloch & Ernst, 2012), but its importance is noted in related fields. McDonald, Kazemi & Kavanagh (2013) discussed the need to use a common language to facilitate collective activity and growth in the field of teacher education. Century et al. (2012) recognized the need for common language in order for researchers to collaborate and further their research. Staker and Horn (2012) described the difference that common language makes to learning when using technology in a blended learning environment. Baird, Coy and Pocock (2015) described the need for children to build on a shared language when learning different concepts within the subject area of science.

All of the above researchers describe the importance of emphasizing definitions and vocabulary that serve as avenues of communication between seemingly unlike settings. These avenues of communication should remain open in order to maximize the number and depth of connections made when collaborating in a variety of venues, as noted above, but especially when creating interdisciplinary lessons through ICTs.
**Enhances expertise.** From a situated perspective, the ICT model encourages the collaboration that Froyd and Ohland (2005) found were essential to successful implementation of integrated curricula because each teacher is the “expert” in his or her own content area, and is encouraged to explain the content to the other teacher in the pairing. The affordance for both teachers to act as experts, even as they are collaborating to increase their own understanding in each other’s content area, contributes to the social trust and shared language, described above, that develops between paired teachers. Teachers develop schema for their own content and that of the other teacher, as well as the connections between them, through practice instead of in isolation. Legitimate participation, the development of expertise through practice instead of separate from it (Lave & Wenger, 1991) encourages teacher development through a focus on teaching instead of teachers (Hiebert & Morris, 2012).

**Increases teacher knowledge.** Collaboration in general leads to increased pedagogical and content knowledge (Bruce et al., 2010), which is important for drawing deep connections (Philipp, 2007). In addition the ICT model encourages an in-depth content focus, which influences teachers’ opportunity to learn (Ingvarson et al., 2005), and is associated with increases in teacher knowledge and changes in teacher practice (Garet et al., 2001). In science in particular, where content knowledge needs to be updated as information and theories change over time, a focus on content is particularly valuable (Loucks-Horsley & Stiles, 2001), but not always present (Boyle et al., 2005).

Teachers that engage in interdisciplinary co-planning have opportunities to increase their knowledge in their own content area through describing concepts to the other teacher,
and to develop knowledge in the other content area through legitimate participation developing interdisciplinary plans. This should increase several different types of teacher knowledge, as described by Ball and colleagues (2008), including content knowledge for teaching, knowledge of content and curriculum, and knowledge of content and students. This is particularly important in the content area in which each teacher is less experienced, and may have common content knowledge, but not the specialized content knowledge needed to develop connections for students. For example, a science teacher may be able to solve problems that deal with proportions, but not know the best way to help students with such a problem.

**Provides time to adjust.** Numerous researchers agree that change is a gradual process, which requires support and effort over an extended period of time (Boyle et al., 2005; Bruce et al., 2010; Guskey, 2002). The ICT model gives teachers time to adjust, considering the change to interdisciplinary learning as a process instead of a one-time event. For example, teachers who use a traditional curriculum to guide content decisions in their classes would find it easier to discuss big ideas from each unit and to draw connections than to abandon their traditional curriculum completely to create fully integrated lessons. These teachers, who would be easily frustrated with a fully integrated approach, may find comfort in creating a goal of making interdisciplinary connections once per week and expanding as time goes on throughout the semester or year. The relaxed environment in which teachers can create long-lasting changes at their own pace is possibly a contributing factor to the social trust that may be formed through co-planning pairs.
The ICT model encourages continual teacher reflection, an important factor in teacher growth over time (Desimone, 2009). As an iterative process that uses reflection on prior activities to inform new activities, the ICT model allows teachers time to adjust to the change from teaching one subject in isolation to a more contextual approach.

**Is sustainable.** The ICT model was created as a pragmatic alternative that is flexible enough to overcome some of the more pervasive aspects of school structure (in particular high school structure) that have limited attempts at integrated curricula in the past. Teachers do not need to alter their schedules, but may if the time and opportunity allow. Teachers may opt to combine their classes for interdisciplinary activities and projects, or to keep them separate throughout the year. Student schedules do not need to be changed in order to participate, because students will benefit from the teachers’ co-planning whether the student is in one or both classes.

Teacher schedules do not need to be altered because co-planning pairs may meet before or after school or during common planning times. Routines, which are thought to increase the efficiency of planning (Sanchez & Valcarcel, 1999) and reduce the teacher’s cognitive load (Bromme, 1982) are created as the teachers co-plan regularly, so that even if they discontinue regular co-planning sessions, the tendency will still exist for teachers to keep a focus on collaboration and interdisciplinary connections. In addition, because teachers regularly meet to discuss the connections between the disciplines, they may tend to consider interdisciplinary connections more regularly during other planning times as well.

The ICT model does not rely on a specific curriculum, because the focus is on developing the connections between subject matter for student understanding, and the teacher
can determine the extent to which any curriculum is followed or altered, just as teachers do when piloting new or reform curricula (Remillard, 2005). Both teachers are experts in their own subject, and participating legitimately in the other, so that they are comfortable with minor changes over time instead of being overwhelmed with large and immediate changes. Increasing teacher comfort levels with an accumulation of change may help to sway their beliefs about the nature of, teaching of, and learning of mathematics and science, which are generally relatively stable constructs (Handal, 2003).

**Feasibility Study: Algebra and Chemistry**

To demonstrate the feasibility of using the ICT model for long and short term collaborative planning, the model was used to plan for an Algebra course and a Chemistry course at the high school level (Cetner & Pereyra, 2014). The collaboration focused on daily and weekly planning. Using Chemistry and Algebra, which have offered challenges to past attempts at integration (Froyd & Ohland, 2005), to create a strong interdisciplinary pairing gives more legitimacy to the idea that pairings can be made between any mathematics and science content areas, and need not be restricted to those that are more intuitive, such as Calculus and Physics. In addition, both teacher-researchers involved (myself and a graduate student in science education) had considerable amount of time and experience in the areas of Algebra and Chemistry, which made it possible to collaborate meaningfully and predict student understandings in a way that would be expected of classroom teachers over the course of a semester or a year.

In order to demonstrate that interdisciplinary connections do not rely on the choice of curriculum materials, a common textbook was chosen for each course and adhered to as
closely as possible for both content and pacing. It is assumed that individual teachers would not create the exact same pacing guide because each teacher would consider their students, current standards, or other criteria to construct their own pacing. However, for the purpose of this study, we stayed within the bounds of the pacing and order of content suggested by the textbook to demonstrate the feasibility of co-planning for interdisciplinary connections regardless of content.

| 15. | Chapter 3 test 4-1 Introduction to matrices | 6-2 Classifying the elements 6-3 Periodic trends | Continue discussion of organization between math and chemistry. Write sections of periodic table as matrices with corresponding matrices for energy level and atomic radius. **Algebra:** examples of periodic table trends and matrices. **Chemistry:** examples of ionic size and translation of graph: number of electrons in outer shell vs. atomic energy and vs. atomic radius (as translations of graphs similar to abs. value). |
| 16. | 4-2 Operations with matrices Review chapter 6 | Algebra: use periodic table examples and discuss properties within each example. |
| 17. | 4-3 Multiplying matrices Chapter 6 test 7-1 ions | Chemistry: relate ionization to absolute value (1 away in either direction is still 1 away). |
| 18. | 4-4 Transformations with matrices 7-2 Ionic bonds and compounds | Activity: Have students create models of crystalline structures and notice properties, create 2D and 3D coordinate systems to describe where the atoms lie within each molecule; apply matrix transformations to their models; determine what the transformations do to each model. Emphasize properties of transformations and properties of crystalline structures. |
| 19. | 4-5 Determinants 7-3 Bonding in metals Review chapter 7 | Review and reuse activity, create examples around it. |

Figure 4. Days 15 - 19 of a 90 day block schedule: Co-planning algebra and chemistry.

We created a table to organize the connections that they discussed. The first column listed the algebra pacing and the second column listed the chemistry pacing, as outlined in the textbook. After the columns that represent pacing for both courses were created, the teachers discussed the curricula together, day by day. Each thoroughly described the content in each section, and then they discussed the big ideas and if and how they related. A third
column was created in the table, which listed in brief form all of the connections that were identified. A portion of the table is shown above in Figure 4.

Activities, examples, and discussion points. The connections that were identified tended to take on the form of activities, examples, and discussion points, and by the end of the first few units, it became obvious that it was necessary to have all of these components in envisioning the enacted curriculum in each interdisciplinary class. Larger activities from which both content areas can be explored were generally found on a weekly basis, with smaller examples and discussion points filling in almost every day in between. That is not to say that each day had all three components, or that each day had to include any components. There were some days in which the content diverged so completely that no connection was written, and the teachers deemed it more appropriate to state that there was no connection than to force a connection which would lead to a superficial treatment of the content.

For example, Figure 4 outlines an activity on day 18 in which students create 3D models of crystalline structures in order to think about chemical and structural properties. The 3D models in science are described through the 3D coordinate system in mathematics. Matrix transformations are applied and discussed in the context of whether they change the crystalline structure or preserve it. In the days preceding this activity (day 15 in Figure 4), both classes would have had discussions about the similarities and differences in organization in mathematics and science, introducing matrixes in mathematics and the periodic table in science. Examples from the periodic table and from the crystalline activity would be used whenever applicable in understanding matrix operations (days 16 and 19 in Figure 4).
Because activity is considered one of the driving forces of an integrated or interdisciplinary curriculum (e.g., Drake, 2007), each activity that was created was included in the planning table only if it helped students to achieve a deep understanding of both mathematical and scientific concepts. Activities that were only surface or cursory in nature (e.g., used terminology but did not encourage development of conceptual understanding) were not included in the planning table, because it was the our viewpoint that superficial activities would detract from, rather than add to student understanding in a meaningful way.

While larger activities were planned once every one to two weeks, examples and discussion points which connect the Chemistry and Algebra content and processes arose almost every day of planned instruction. This was seen as a fundamental part of the continuity of the class, because without daily examples and discussion points, there would be a sense of disconnect between the two content areas in the time between the activities. Examples were often given in the form of short problems that students solve, or as part of the problems solved and discussed by the class as a whole. Examples are also different from activities in that they generally belong in one class or the other. For instance, examples in a Chemistry class may focus on how equations and graphs can be used to represent a concept, whereas algebra examples may use concrete instances of a Chemistry concept to create a problem situation, equation, or graph. In many cases, the same graph or diagram may be used in both classes, but the emphasis would be different.

Like examples, discussion points are the glue that holds the interdisciplinary classes together. Without discussion, students would be doing little more than completing isolated activities, and a true interdisciplinary model would be impossible. Unlike examples,
however, discussion points may also be short moments or tie-ins in which parallels are drawn without an expectation that students will solve problems related to the connection being discussed.

**Other considerations.** We found that it was easier to make deeper connections when big ideas were considered before the details of each section. In creating the coordinated pacing guide, a shift in procedure was made about halfway through that reflected the efficiency of looking at the big ideas for each chapter and then discussing the details of the content. This helped the discussion of vocabulary and concepts that were new to them without getting lost in the details of instruction. This discussion helped to develop a shared language, particularly about vocabulary terms which use different words between the subjects, but conceptually mean the same or similar things.

It also became useful to look not only at what was being taught in the same day, but what concepts could be drawn upon that were already used previously in the semester from each class. For example, algebraic systems of equations became important in Chemistry in creating and solving molecular equations, which happened approximately 2 weeks after the topic of systems of equations in Algebra. Since the concept of systems of equations was already learned in algebra, it would be useful to make the connection in Chemistry at the appropriate time. This type of prerequisite knowledge happened several times over the length of the two courses.

Our desire to push students beyond the scope of the textbook was also noticed. Primarily in Chemistry, this is because we noted that the students would be able to go much further into the concept if the students were able to complete the associated mathematics. In
Algebra, a similar reasoning was employed: different types of contextual problems would be able to be posed beyond the scope of the textbook because students would be prepared to handle the science content. It is also important to note that the tasks that were presented are only a portion of what would be done in each class because the inclusion of new connections between the Algebra and Chemistry does NOT imply that other connections should not be made in each class as they would be in general.

**Conclusions.** The use of the ICT model to co-plan interdisciplinary lessons between an algebra class and a chemistry class demonstrates the flexibility and feasibility of the model, which adapts to the needs of students, as well as fitting the needs of the standards of the course in the state or district. It was easy to use pre-existing curricula as a resource and pacing guide, and many instances of interdisciplinary activities, examples, and discussion points were found through discussion of concepts that would be taught each day. The design of the ICT model is such that a traditional class schedule can still be followed, and activities may be completed in either class, or both classes could be brought together. Big ideas can be coordinated and connected easily, even without rearranging content, but if teachers are allowed to rearrange the order in which some units are studied, it may be helpful to make even further connections.

**Pilot Study: 8th Grade Science and Mathematics**

In order gain a preliminary understanding of teachers’ use of the ICT model in a school setting, it was piloted with a pair of experienced 8th grade teachers over seven weeks in the fall of 2015 (Cetner, 2016). The purpose of the pilot was to refine discussion and implementation of the ICT model with teachers, test data collection and analysis techniques
for the current study, gain a preliminary understanding of how the model affects teacher planning, and target affordances and limitations of use of the model with teachers.

A case study design was chosen because it is an effective way to explore the complexity of interdisciplinary co-planning in a setting that is bounded in space and time (Creswell, 2007), but the boundaries between the intervention and the context are not clearly evident (Yin, 2013). In the pilot study, the pair of teachers were treated as one case because they formed one co-planning team and planning sessions were spent together.

Both teachers were highly experienced in their respective subject areas. Mrs. Smith (pseudonym), the science teacher, taught high school science for 12 years before taking a position at the district level. She then left the district position to teach 8th grade science and had been teaching 8th grade science for 2 years. Mrs. Miller (pseudonym), the mathematics teacher, had been teaching for 15 years, and had been at the current school for 2 years. Despite their experience, this study is the first attempt that either has made to connect mathematics and science content on a regular basis. Both teachers were enthusiastic about their participation in the study.

The intervention for this pilot study was simply to introduce the ICT model to both teachers and to facilitate its implementation during four co-planning sessions. The teachers were introduced to the model with a verbal description accompanied by an information page similar to the one in Appendix A. They created plans during co-planning sessions, which they then used in their teaching. In addition, they completed journal reflections which answered specific prompts so that they could benefit from the process of reflection (Ethell & McMeniman, 2000). The journal entries were also used as a data source for analysis.
Additional details about the intervention, as well as how the pilot study helped to refine discussion and implementation of the ICT model with teachers are expanded on in chapter 3.

The major source of data for this pilot study was observation of the co-planning sessions, with audio data captured by a Livescribe pen. In addition, observations of classroom teaching, artifacts (e.g., planning notes and created worksheets), teacher reflections, and interview data were used to triangulate analysis of the planning observation data. Data was analyzed using the open coding phase of grounded theory (Birks & Mills, 2011; Glaser & Holton, 2004). Additional details regarding data collection and analysis for the pilot study and the ways they influenced that for the proposed study are explicated in Chapter 3.

Preliminary findings about how the ICT model affects teacher planning, as well as a brief discussion of notable affordances and limitations are presented in the remainder of this section.

Teacher planning with the ICT model. It has already been established through literature that planning is a complex process (e.g., Davis, 2014; NRC, 2001; Yinger, 1980), and the assimilation of interdisciplinary co-planning into the planning process makes it even more so. This section is divided into two parts: 1) a brief description of the regularly scheduled co-planning sessions that both teachers attended regularly with myself as facilitator, and 2) preliminary findings about how participation with the ICT model affected the teachers’ individual planning.

The co-planning sessions. I attended and facilitated all four of the regularly scheduled co-planning sessions in addition to audio-recording each session for later analysis.
During the first session, I was highly involved in helping the teachers to look for interdisciplinary connections, but in subsequent sessions, spent less time directing the conversation and more time observing the two teachers. For example, during the first session, after the teachers described their content, they did not go further to explore possible connections until I suggested and expanded on several ways in which the science lab and mathematics activity that the teachers described were actually closely related. During the later sessions, both teachers explored resources together and initiated ideas about an interdisciplinary project that the students could complete.

A routine was established in which the teachers began by each commenting on the content they just completed in each class, which included a description of activities and content as well as reflective thoughts about their implementation of the interdisciplinary components of the lessons with students. They each used the prior content as an entryway to describe the content that they were expecting to teach within the following week or two, including activities or other details if they were known. They then asked each other clarifying questions about specific content and activities while looking for connections in the content that they could expand on in their classes.

After each teacher described the content separately and they refined their understanding of each other's content and found connections, they focused on the connections and discussed specific ways in which to emphasize the connections with their students. This part of the co-planning process aligns with Yinger’s model which portrays teacher planning as “purposeful problem solving” (Yinger, 1978, p. 27). For example, during one session, after each teacher described the concepts to be taught and potential ideas for
activities that they were contemplating, they both focused their attention on how to redesign the activities so that connections between the science and mathematics content would be made.

This design process took approximately half of the planning time for that session, with the remaining time split between the descriptions at the beginning and a wrap-up at the end in which each teacher stated which responsibilities that she would attend to in order to prepare for the upcoming week. Thus, for this pair of teachers, co-planning time seems to be split into segments which align with both Yinger’s (1978) cyclic design process for planning and Tyler’s (1950) objectives-based decision-making model. Since individual planning is mostly a mental process (Milner, 2001) and co-planning teachers need to communicate objectives, concepts, and pedagogical reasoning more explicitly in order to create plans, it may be that teachers usually engage in both types of processes, but they are more readily seen during the collaboration present in co-planning.

Although time was spent equally across the four co-planning sessions describing content (45 minutes total), adapting or designing activities (44 minutes total), and drawing connections (46 minutes total) between mathematics and science content, the timeline for this routine varied widely depending on the co-planning session. For example, during the first co-planning session, more time was spent describing the content and more clarifying questions were asked because the teachers needed a reference point from which to build. Mrs. Miller said that her math class is moving toward solving linear equations, and Mrs. Smith asked, “do you mean: a number plus 8 equals 12, what’s the number?” Mrs. Miller clarified: “We did that this week. So, next week we’ll get into solving basic one-step and two-step
equations. And multi-step. And then after that, we have to go through and start talking about two variables.” A similar exchange occurred surrounding the content in Mrs. Smith’s science class, which was about cellular respiration and energy. During the second week of co-planning, content was not discussed at this depth because both teachers were continuing the same units that they had already discussed. Instead, more time was spent refining specific plans they had already made and discussing scheduling concerns, such as review and test dates and time in class lost due to other school-wide activities.

Finally, co-planning sessions appear to be cyclic, not only in that they follow a routine of reflection, description of content, and activity design, but also in that the teachers use this time to engage in reflection of prior lessons in order to plan new lessons. For example, the teachers planned an implemented a lesson in which students collected data and discussed findings relating to cellular respiration during exercise in their science class. They then brought their data to the mathematics class, where they discussed dependent and independent variables, graphing, and linear functions. During the next co-planning session, the mathematics teacher (Mrs. Miller) expressed frustration that the students did not collect data correctly, which made it difficult to use the data. In planning a second iteration of this type of lesson, the teachers prepared by having generic data ready to distribute to students who did not have good enough data of their own to use. This created the continuity that the teachers were missing the first time around.

**Individual planning with the ICT model.** By the time the participating teachers left each co-planning session, they had a good idea of how their plans would fit together, and had discussed specifics of how students could engage in activities, but they still had to do the
work of finalizing plans for instruction in their classrooms. This included, but was not limited to: creating worksheets, locating and organizing materials, and thinking through specific questions and explanations to use with students.

Because planning is a continual mental process (McCutcheon, 1980; Milner, 2001), it would be impossible to observe each individual teacher plan in the way that co-planning sessions are observed. Instead, semi-structured and unstructured interviews, discussed in chapter 3, were used to create descriptions of individual planning for each teacher and of how interdisciplinary co-planning became a part of the planning routine.

As Yinger (1978/1980) suggested that all teachers do, both teachers in this study engaged in different levels of individual planning, including long-term, weekly, and daily planning. Mrs. Smith mapped out the science course during long-term planning during the summer and the beginning of the school year, and then planned each unit in weekly chunks, adjusting the long term plan throughout the year, aligning with findings by Anderson and Evertson (1978). Mrs. Smith stated that she designs her daily lessons by reviewing standards, looking for resources to determine which activities students should complete, comparing her lesson with the 5E format (engage, explore, explain, elaborate, evaluate), and making adjustments as needed. This may be an example of the planning that Reynolds (1992) describes, which is recursive and complex, but follows a simple model in order to ensure that important components are accounted for.

Mrs. Miller’s planning level structure was similar to Mrs. Smith’s, with long-term planning at the beginning of the school year and weekly and daily planning throughout the year. Since Mrs. Miller’s class had textbooks whereas Mrs. Smith’s class did not, Mrs. Miller
tended to follow the textbook for content, and then look for resources and activities that
would engage students and fit the content. For example, Mrs. Miller used a ready-made
jumping jack activity which she found from an external resource to fit the next section of the
textbook, about finding relationships among independent and dependent variables. This
aligns with literature that states that teachers often follow a textbook when one is available
(Remillard, 2005; Sullivan et al., 2012) or at least use it as a starting point (Superfine, 2008).

Neither teacher seemed to use detailed written lesson plans, but they did discuss the
complexities of what they think about during planning, corroborating literature from Milner
(2001) and others (e.g., McCutcheon, 1980; Morine-Dershiner, 1977) that planning most
often forms a complex unwritten mental dialog, even during non-teaching activities. Both
teachers also listed plans on the board for students to refer to which resembled the grocery
lists that McCutcheon (1980) described. Though they did not have notebooks per say, such as
Brown (1988) suggested, both teachers did keep collections of curricula and other resources
that they have found or made over time. As Hoffman (1996) suggested, these collections did
help both teachers to remember detailed plans without having to recreate them in lesson plan
format. For example, Mrs. Smith was easily able to locate and retrieve resources for a variety
of lessons created by herself and fellow science teachers when prompted during a co-
planning session. Many of the resources are in the form of worksheets or laboratory
activities, of which she produced two copies: one that was blank for students and one with
teaching notes in the margins.

The interdisciplinary co-planning team model seemed to fit well into the existing
planning routine that both teachers had established before the model was known to them.
Since the ICT model is pragmatic in the same way that individual planning is, (Hoffman, 1996), the teachers did not express feelings that co-planning time was wasting their time or an additional task to complete. The nature of daily planning did not seem to change, but the continual mental dialog (McCutcheon, 1980; Milner, 2001; Sanchez & Valcarcel, 1999) now included frequent reference to interdisciplinary connections. Mrs. Miller noted that conversations between herself and Mrs. Smith did not stop at the end of regularly scheduled co-planning sessions, and that they had many follow-up conversations in passing, during other planning times, and during other scheduled duties. These conversations are usually more student or content specific and brief, such as Mrs. Miller asking Mrs. Smith if the data would fit to the coordinate graphs if all of the axes were pre-labeled from 1 to 10; or Mrs. Smith asking Mrs. Miller if Johnny was present in class for the jumping jack activity.

Mrs. Smith also remarked that regularly participating in co-planning sessions helped to bring the search for interdisciplinary connections in her lessons to the forefront of her mind for all of her planning, including lessons that were not discussed during co-planning sessions. This includes finding resources and activities, as well as considering ways to lead students to understand and connect concepts in mathematics and science. These resources and ideas were brought into co-planning sessions, and as noted above, at the end of each session, both teachers left each session with a to do list so that lessons that were co-planned could be finalized to implement with students. These summaries of items that each teacher would complete in order to teach a lesson were helpful to make sure both teachers had a common understanding of plans that were created together, but also necessary to make best use of their limited co-planning time.
Affordances and limitations. As described above, the ICT model has many affordances, including its interdisciplinary nature, focus on student learning, inherent collaboration and social trust, flexibility leading to more adjustment time and sustainability, and opportunities to develop shared language, expertise, and teacher knowledge. In particular, this section will highlight the social trust, expertise, and sustainability that was evident in implementation of the ICT model with teachers.

Social trust. Literature reveals that collaborative planning is important to interdisciplinary curricula (Roskos, 1996), and teachers support each other (Owen, 2005) and engage in more activities (Flowers et al., 2000). However, in department planning, teachers may often over-talk each other in an attempt to be heard (Engstrom, 1998). Teachers engaging in interdisciplinary planning with the ICT model do not seem to have this problem because there are only two teachers collaborating.

The benefits of collaboration are preserved, but the teachers may be able to communicate more effectively with less competition in the room, developing a greater sense of social trust and leading to more in-depth communication. They also do not need to worry about one teacher having more status or power than the other as witnessed by Murawski and Swanson (2012) in studies of special education co-planning because both teachers are academic teachers.

Although the teachers appeared to be fairly comfortable working together before the pilot study began, subtle changes in their interactions during co-planning sessions were still noticed, such as their willingness to ask detailed questions regarding unfamiliar content and to offer suggestions about interdisciplinary connections. At the beginning of the study, it was
evident that both teachers were unaccustomed to discussing specific content or pedagogy in depth with each other. For example, Mrs. Miller described the mathematics content during the first session as: “So next week we’ll get into solving basic equations. And then after that, we have to go through and start talking about two variables.” The science teacher did not volunteer many clarifying questions, so I asked clarifying questions to move the planning forward. By the last session, however, as a part of Mrs. Miller’s description of content, she stated, “They are taking the average, like these two… and then they are graphing the average like this… so it’s a bar graph.” Aside from being more verbally descriptive, both teachers were noticeably more comfortable discussing specific content with each other compared to the beginning session.

**Expertise.** Co-planning may encourage legitimate peripheral participation, a form of cognitive apprenticeship (Zagal & Bruckman, 2010), as each teacher gains access to the other’s unseen arena through making plans for teaching. Each teacher in the pilot study is an expert in her own content, but a novice with the other teacher’s content and in making interdisciplinary connections, giving the teacher a unique opportunity to be an expert and novice concurrently. Novices tend to lack confidence in their own abilities (Leinhardt, 1983), be less willing to deviate from a script (Borko & Livingston, 1989), and focus more on specific activities, making fewer connections between pedagogical and content knowledge (Penso & Shoham, 2003).

Borko and et al. (1990) found that experts can act like novices in some regards when presented with new situations, but are generally able create structures and routines to incorporate new situations into their already well-developed schemas. The example above of
learning to discuss content in detail is one way in which the teachers acted similarly to novices initially, and then incorporated their new co-planning setting into their existing schema. As another example, the teachers began to change regarding the contents of their interdisciplinary plans. They began by focusing on large activities, and their first two co-planning sessions produced one connected activity in which students collect data in their science class. After reflecting on the lesson, the teachers became aware that other connections exist which could be discussed, and began creating examples to connect the disciplines in more intricate ways. It is assumed that this type of shift would continue to occur as the teachers become more comfortable co-planning and have more experience looking for interdisciplinary connections.

**Sustainability.** As noted above, the teachers who engaged in the ICT pilot study seem to spend a lot of time outside of regularly scheduled sessions engaging in interdisciplinary co-planning, as it became a part of their daily planning routine. However, this constant attention to interdisciplinary co-planning may quickly fade if a regular co-planning time is not determined and adhered to. Since planning is pragmatic (Hoffman, 1996), part of the sustainability of the ICT model is that teachers are constantly asking each other questions, getting into each other’s content, and figuring out how to approach students with their interdisciplinary lessons. On the weeks that we skipped having a regular co-planning session, the teachers revealed that they talk to each other less often because there is less to talk about.

Overall, the teachers in this pilot study used the ICT model to discuss the science and mathematics content that they were planning with each other and to plan interdisciplinary lessons, which they implemented with their students. The teachers expressed enthusiasm
about participating throughout the experience, and as time went on, they gained confidence in planning and implementing interdisciplinary lessons with their students. Their awareness of the types of connections they could make between mathematics and science increased. In particular, they found that they could use data that is intended to teach science concepts such as conservation, energy, and resources, and use it to discuss both mathematical and scientific concepts together.

The biggest changes were in their beliefs about the subject matter that they do not regularly teach. For example, the science teacher moved from thinking that mathematics is learned through direct instruction and independent practice to understanding that more active learning strategies make the mathematics applicable to student experiences. At the end of the pilot study, both teachers stated their intention to continue regular co-planning sessions throughout the spring semester.

**Conceptual Framework**

Teacher beliefs and planning practices form a complex relationship, not only within each component, but with each other and with everything else that teachers do. Planning is a complex and ongoing mental dialog (Milner, 2001; Morine-Dershimer, 1977), which is deeply influenced by the teacher’s beliefs about students (Bray, 2011; Cross, 2009), about curriculum (Lloyd 1999a/1999b; Remillard, 2005; Superfine, 2008), about teaching (Knobloch & Hoop, 2005; Lumpe, Haney & Czerniak, 2000; Wilson & Cooney, 2002), and about mathematics (Handal, 2003) or science (Lederman, 1992). This internal dialog then influences any additional collaboration that the teacher may have (Horn, 2005; Scruggs, Mastropieri & McDuffie, 2007), and the act of teaching itself (Drake & Sherin, 2006).
However, the influence is not unilateral (Clark & Peterson, 1986; Lerman, 2002). Every experience a teacher has serves to influence the teacher’s beliefs (Ethell & McMeniman, 2000), particularly if the experience is much outside of the teacher’s expectations (Lerman, 2002; Phillip, 2007). This includes the experiences of teaching (Pehkonen, 2001), collaborating (Desimone, 2009; Nadelson et al., 2012; Roskos, 1996), and exploring new resources and curricula (Andrews & Hatch, 1999; Ball, 2002; Brosnan et al., 1994). Moreover, some beliefs may be more central and others more peripheral (Li, 2007; Wallace & Kang, 2004), and it is possible for experiences to affect some beliefs more easily than others (Handal, 2003; Wallace & Kang, 2004), especially given different external pressures (Barkatsas & Malone, 2005; Handal, 2003; Raymond, 1997), leading to actions that seem inconsistent with stated beliefs (Gallagher, 1991; Speer, 2005).

The conceptual framework described in this section (Figure 5) has been developed using the available literature and the pilot study in order to reveal the reciprocal relationship that is being studied among the ICT model, the planning process, teacher beliefs, and teaching practices. The solid arrows represent components that research has shown directly influence each other. The dashed arrows signify that teaching practices influence beliefs and teacher co-planning through reflection, since the model is iterative in nature. For example, planning directly influences plans, and plans directly influence teaching practices and outcomes, but then teaching outcomes influence future planning through reflection (Siry, 2011; Yinger, 1980). (Note: in this study, only beliefs, the planning process, and plans for teaching are being studied. Teaching implementation and outcomes are peripherally present.
through teacher reflections, and are expected to influence and be influenced by plans and beliefs, but are not the focus of this study.)

Teacher beliefs act as an umbrella for this framework under which all thoughts and actions are mediated (Handal & Herrington, 2003; Pajares, 1992), in a similar way to the model presented by Woodbury and Gess-Newsome (2002). The umbrella in the diagram lists beliefs by the categories that they are commonly found in research: about math and science (e.g., Handal, 2003; Lederman, 1992), teaching and learning (e.g., Knobloch & Hoop, 2005; Bray, 2011), and curriculum (Lloyd 1999a/1999b). I hypothesized that beliefs about interdisciplinary curricula may have an influence on planning interdisciplinary connections, so a third category was created to consider beliefs about interdisciplinary curricula.

The planning process, teacher plans, and teaching implementation may all be considered to be a part of teaching practices, as in the model presented by Woodbury and
Gess-Newsome (2002), but they are considered separately in this framework so that the nature of co-planning could be discussed separately from the teachers’ plans and teaching practices. Co-planning is considered as a part of the planning process for each teacher, evidenced by the teachers in the pilot study who each completed other planning activities both before and after each regular co-planning session. Affordances of co-planning are listed as factors that may contribute to the planning process, as well as other factors that were observed during the pilot study.

The teachers then take the products of their co-planning sessions and refine them individually to create plans for teaching their students. Some of these plans may be written and some may be mental notes, according to findings by Lenz, Schumaker and Dashler (1991). Plans are then used for teaching, which is performed by each teacher in his or her own class. Factors from literature which influence teaching are noted, such as portrayal of content (Roche et al., 2014), expert blind spot (Nathan & Koedinger, 2000b), and adherence to a textbook or script (Borko & Livingston, 1989).

All of this is set against the background of teacher factors (e.g., prior experiences, pedagogical and specialized content knowledge), and external factors (i.e., administration, school-wide activities, student factors), as expanded on by Woodbury and Gess-Newsome (2002). While these factors are not being directly measured for this study, they do have a prolonged effect on each teacher’s planning, beliefs, and teaching practices, as well as the entire co-planning process. Some of these factors, such as teachers’ knowledge or student factors, may affect teacher planning and beliefs enough that they will need to be noted in analysis in order to paint a fuller picture of the co-planning process.
Chapter Summary

The literature review in this chapter is divided into three main parts: curriculum integration, teacher planning, and teacher beliefs. Curriculum integration caught mainstream attention and grew in popularity throughout the 1990s after the NCTM Standards documents (1989) were published, and many benefits of interdisciplinary and integrated education were discussed (Vars, 2001). Despite the optimistic attitude of researchers toward curriculum integration, however, there are several obstacles to creating sustainable integrated and interdisciplinary classes in schools (Czerniak et al., 1999), including overloaded curriculum and standardized testing (Vars, 2001), the physical and cultural structure of schools (Watanabe & Huntley, 1998), and the knowledge, beliefs, and comfort levels of teachers (Chawdhary et al., 2014; Koirala & Bowman, 2003; Nadelson et al., 2012).

The ICT model was created as a flexible solution for teachers to create an interdisciplinary education experience that overcomes many of the obstacles reported above. This chapter discussed the affordances of the ICT model and previous pilots which demonstrate the feasibility and usefulness of the model in long and term interdisciplinary planning, and which inform the theoretical framework at the end of the chapter.

Teacher planning is the work that teachers do to prepare for students when students are not present (Jackson, 1968; Drake & Sherin, 2006; Aydin, 2014). Planning is now known to be an iterative, flexible design process that is an essential part of the craft of teaching (Yinger, 1980; Grimmett & MacKinnon, 1992; Vaughn, 2010), with complexity increasing as teachers gain experience (Ethell & McMeniman, 2000). Collaboration may be the most effective form of apprenticeship (Horn, 2005), which allows teachers to vocalize important
aspects of planning, which are often unseen and unknown (Owen, 2005; Siry, 2011; Zagal & Bruckman, 2010), particularly for interdisciplinary curricula (Flowers, Mertens & Mulhall, 2000; Roskos, 1996). Co-planning is often used in other contexts (e.g., Scantlebury, Gallo-Fox & Wassell, 2007; Walther-Thomas, Bryant & Land, 1996), and no research has been found regarding the use of co-planning in interdisciplinary education.

Teacher beliefs, the mediator between the cognitive and affective domains of cognition (Llinares, 2002), are also much more complex than once thought (Philipp, 2007). Beliefs influence all aspects of teaching that are under teacher control (Handal & Herrington, 2003), including curricula and instruction (Cross, 2009; Remillard, 2005) and planning (Borko, Livingston & Shavelson, 1990). Most research regarding teacher beliefs has considered beliefs about mathematics and science (Perkkila, 2001) and teaching and learning (Benbow, 1993; Wilson & Cooney, 2002). The relationship between teachers’ espoused beliefs and practice has been studied (e.g., Speer, 2005), demonstrating that teachers consider different elements, including external pressures (Turner, Christianson & Meyer, 2009), when describing their beliefs and implementing them (Barkatsas & Malone, 2005).

The framework section of this paper describes the reciprocal relationship among teacher beliefs and teacher planning, plans, and implementation. Teacher beliefs influence the overall planning process (Handal & Herrington, 2003) as well as teachers’ ability to co-plan interdisciplinary lessons (Lerman, 1999), and the experiences of planning and teaching influence teacher beliefs (Basista & Matthews, 2002; Middleton, 1999; Phillip, 2007). The following chapter will discuss in detail the plan to further explore the reciprocal relationship between the ICT model, teacher planning and co-planning, and teacher beliefs.
CHAPTER 3: METHODS

The purpose of this study was to capture the nature of the co-planning process for middle and high school teachers when the Interdisciplinary Co-planning Team (ICT) model is implemented through a structured professional learning experience. Since the planning process and the plans that teachers create may be inextricably intertwined, a goal of the study was to describe the nature of the plans that teachers create through the co-planning process. Furthermore, since teacher planning and beliefs are directly related, another goal of this study was to capture the ways in which teacher beliefs, especially as they relate to interdisciplinary connections in teaching, evolve through implementation of the ICT model. Based on these goals, three research questions were explored:

1. What is the nature of teachers’ planning processes when the ICT model is implemented?

2. What is the nature of teacher plans when using the ICT model?

3. In what ways does participation with the ICT model influence teachers’ expressed beliefs regarding a) the nature of mathematics and science; b) teaching and learning; and c) making interdisciplinary connections?

While the ICT model may be used with teacher pairings between any subjects and at any grade levels, this study focuses on pairings between mathematics and science teachers at the middle and high school levels. The effects of the ICT model on actual teaching practices were not considered, nor were effects on student achievement, behavior, or beliefs. Restricting the focus of the research questions in this way created the opportunity to analyze
the planning process, planned teaching practices, and their interaction with expressed teacher beliefs in a more thorough manner.

A qualitative embedded multiple-case study intervention design was used with the researcher acting as facilitator. The intervention was designed as an extended professional learning experience for all participant teachers, and included scheduled co-planning sessions for teacher pairs as well as large-group times for reflective discussion and sharing. Data collection included audio-recorded observations of all group sessions and co-planning sessions, artifact collection, and unstructured teacher interviews throughout the intervention. Semi-structured pre- and post- intervention interviews were also conducted. The data was analyzed qualitatively using several layers of coding to describe the nature of the planning process, teacher plans, and expressed beliefs with implementation of the ICT model. Validity and reliability for this study are considered at the end of this chapter, as well as limitations to the methods.

**Research Design**

This research study employed a qualitative embedded multiple-case intervention design, in order to gather and examine data regarding the nature of teachers’ planning processes, plans, and beliefs during implementation of the ICT model. Case studies are an effective way to explore a real-life, contemporary bounded system through in-depth data collection (Creswell, 2012), especially when the boundaries between phenomenon and context are unclear (Baxter & Jack, 2008; Yin, 2013). Yinger noted that through case study, “concepts, methods, and processes gradually surface in the data as a result of spending extended amounts of time observing and describing the teacher’s decision behavior” (Yinger,
Yinger (1978/1980) and others (e.g., Clark & Yinger, 1979; Clark & Elmore, 1981; Peterson, Marx & Clark) set a precedent for case study of individual teacher planning. Other case studies have been conducted by Borko and colleagues (e.g., Borko & Livingston, 1989; Borko & Shavelson, 1998; Borko et al., 2008) among others (Cumming, 1993; Holstein, 2012; Milner, 2001; Young, Reiser & Dick, 1998).

The choice to use multiple cases for this study was inspired by Swearington (2014), who used multiple cases to provide insight and depth into lesson planning by student teachers at different field-experience school sites. Multiple cases enable the researcher to explore differences within and between cases (Baxter & Jack, 2008) and offer the logic of replication (Creswell, 2012). In addition, the multiple-case study design can provide a rich description of the exchanges between teachers (Josephson, 2014). Multiple cases are commonly used in school innovations, such as new curricula or procedures, where a goal is to build a general explanation that fits each individual case, even though the cases will vary in their details (Yin, 2013).

Three pairs of experienced mathematics and science teachers participated in this study, and each teacher pairing constituted one case. The cases were bounded in time by the length of the intervention. The pilot study confirmed that each individual teacher should not be a separate case because the teachers in the pair interact so thoroughly over the course of the intervention that separating them would lead to an incomplete picture of co-planning. However, because of the individual nature of planning and beliefs, the individual teachers were embedded units within each case. Viewing each teacher as an embedded unit within the larger case provides the ability to analyze data within the subunits separately, between
different subunits, and across all subunits (Baxter & Jack, 2008). Figure 6 provides a visual depiction of the multi-case structure of the study.

Figure 6. Embedded multiple-case intervention design.

The intervention (professional learning experience and implementation of the ICT model with teachers) was embedded in the case study. All 6 teachers involved in the study participated completely in the intervention, including large group sessions, 7 co-planning sessions, individual pre- and post-intervention interviews, and weekly written reflections. Two additional teachers (one additional team) agreed to participate in the study, but they dropped out without participating in co-planning sessions, so they were not included in the results. It was not practical to use control and experimental groups as has been done by some researchers in the past (e.g., Zahorik, 1975; Twardy & Yerg, 1987; Kitsantas & Baylor, 2001) because of the descriptive nature of the study. Intervention makes control and experimental groups difficult to achieve (Confrey et al., 2004) because links in real world interventions are too complex for experimental methods (Yin, 2013). Further, researchers have successfully tracked progress over time without a control group (e.g., Ploessl & Rock,
2014; Doyle & Holm, 1998). The details of the intervention are discussed in the intervention section, later in this chapter.

**Participants**

The participants in this study form a convenience sample of teachers who were willing and able to participate in the timeframe and geographic location of the researcher. Principals from two different schools in eastern North Carolina were contacted via email and gave permission for teachers in their schools to participate in the study. The principals were provided a script to invite their respective mathematics and science teachers to participate (Appendix B), as well as a revised brief summary of the study with teacher expectations (Appendix C). Both principals responded that their teachers were willing and able to participate.

During the initial meeting with the teachers, the study was described and informed consent forms were provided (Appendix D). The consent form provided permission to observe participants co-planning and teaching and to audio-record co-planning and whole-group observations and to write field notes. It also allowed the collection and analysis of artifacts that teachers produced during the intervention and audio-recorded interviews at the beginning and end of the intervention. Because of the sample size in the study, it was impossible to ensure anonymity, but teachers were assured that personal comments were kept confidential and that pseudonyms were used when reporting for all schools and teachers involved. (Note: for each pair of participating teachers, the mathematics teacher was named with the pseudonym that begins with the letter that comes first alphabetically. Teacher pairs are Ms. Miller and Ms. Smith, Mr. Jones and Ms. Williams, and Mr. King and Ms. Taylor.)
The participants’ pseudonym, school, grade level, subject matter, and years of experience are summarized in Table 1, below.

Table 1.  
*Summary of participants.*

<table>
<thead>
<tr>
<th>Case</th>
<th>Teacher</th>
<th>School</th>
<th>Subject/Grade Level</th>
<th>Years experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Miller</td>
<td>ICMS</td>
<td>8th grade Math</td>
<td>15</td>
</tr>
<tr>
<td>1</td>
<td>Smith</td>
<td>ICMS</td>
<td>8th grade Science</td>
<td>17</td>
</tr>
<tr>
<td>2</td>
<td>Jones</td>
<td>ECHS</td>
<td>Math 1 (9th grade)</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Math 2*</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Williams</td>
<td>ECHS</td>
<td>Physical Science (9th grade)</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>King</td>
<td>ECHS</td>
<td>Advanced Functions (10th grade)</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Math 2*</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Taylor</td>
<td>ECHS</td>
<td>Biology (10th grade)</td>
<td>5</td>
</tr>
</tbody>
</table>

Note: Mr. Jones and Mr. King both taught Math 2, as denoted by the asterisk*, but they focused their discussions on the other class that they taught.

Each participating school, and their participating teachers, is described briefly below.

**ECHS High School**

The high school, which will be called ECHS for the purposes of this study, is an early college high school, housed on a community college campus in a rural area. The school serves approximately 200 students in grades 9 - 13 (62% white, 20% black, 18% Hispanic – NCDPI, 2013a) who participate in dual enrollment high school and community college classes, increasing enrollment in college classes as grade level increases (ECHS, 2015).

The school recruits low-income first-generation college students with average GPAs, and most students in this school continue on to finish community college and 4 year degrees, which the principal attributes to their focus on student accountability (Granados, 2015). As shown in Table 2, end-of-course passing rates for the English II, Math I and Biology exams from this school are much higher than rates from the district and state (NCDPI, 2013a).
ECHS has two full-time mathematics teachers and two full-time science teachers who teach all of the 9th and 10th grade mathematics and science classes on campus. All four of these teachers participated in this study. There is one additional mathematics teacher, who is employed part-time and teaches advanced mathematics, who did not participate in this study.

Of the participating teachers, the first pair was Mr. Jones, who teaches mathematics to mostly 9th grade students, and Ms. Williams, who taught 9th grade Physical Science. The second pair was Mr. King, who taught mathematics to mostly 10th grade students, and Ms. Taylor who taught 10th grade Biology. The participating teachers are described more fully in the results section, as a part of their case descriptions.

**ICMS Middle School**

The middle school, which is called ICMS for this study, is located in the center of a small city. The school serves approximately 600 students in 6th, 7th, and 8th grade (NCDPI 2013b) who are divided into teams by grade. The school building, which was once a high school building, is divided into separate hallways for each grade level. Students (21% white, 69% black, 4% Hispanic, 5% assorted other) attend this school because they live within the attendance boundaries (NCDPI 2013b). As shown in Table 3, students’ end-of-grade passing rates from this school are much lower than the district and state average (NCDPI 2013b).
The 8th grade team had two mathematics and two science teachers who initially agreed to participate in this study. The teachers were paired according to the majority of students that they have in common. Ms. Smith and Ms. Miller shared most of their students over the course of the day, as did Ms. Roberts and Ms. Lewis, so they were paired accordingly. Ms. Lewis and Ms. Roberts withdrew from the study without completing any co-planning sessions, so their case was not included in the results section. Ms. Smith and Ms. Miller were the only teachers participating in the study who already had experience with interdisciplinary co-planning because they participated in the pilot study.

**Intervention**

The ICT model was implemented through a situated, multi-faceted professional learning experience, which researchers agree is more effective than a detached, single-faceted approach (Desimone, 2009; Garet et al., 2001). Each teacher participated in 3 whole-group sessions along with the other participants from their school, as well as 7 co-planning sessions with their partner-teacher, facilitated by myself. Details for this experience are described further in the following section, as well as in Appendices E through J.
The decision to act as researcher-facilitator has precedence, in studies in which the professional development itself is being assessed (e.g., Basista & Matthews, 2002; Frykholm & Glasson, 2005; Nadelson et al., 2012; Seidel et al., 2011), and in which a related model or construct is refined or described (e.g., Doyle & Holm, 1998; Kiray & Kaptan, 2012; Lenski & Caskey, 2009; Liu, 2005). The current study considers the influence of the ICT model on teacher plans and beliefs, and not specifically the professional learning experience, but it can be assumed that without a robust professional learning experience, implementation of the model would have a minimal effect. In this way, the current study is similar to a study conducted by Doyle and Holm (1998) in which student teachers were taught a storytelling method of lesson planning, and then themes were found, not in the success of teaching the storytelling method to students, but in the use of the method itself.

**Overview of the Professional Learning Experience (PLE)**

The PLE, which is diagrammed in Figure 7, lasted 10 weeks. It began with teachers at each school participating in a whole-group professional development session to introduce the ICT model. During this session, which was approximately one hour in length, I described the premise of interdisciplinary co-planning teams and the study itself, and then the teachers formed their interdisciplinary co-planning teams (pairs). Benefits to teachers and students were briefly mentioned, and teachers discussed the commitment that would be needed, and the data that would be collected. The teachers were told “we come from our different subjects, we plan together, we go back to our different classrooms, we teach what it is, but we try to make the connections as much as possible. We come back, reflect, do it over again.” Time was reserved for the teachers to participate in an interdisciplinary activity
(Appendix F) and to begin co-planning with their partner, but this time was spent addressing teacher concerns about their ability to participate in interdisciplinary co-planning given time and other constraints, so the teachers did not actually complete the intended activity during the first whole-group session.

The next phase of the PLE was that the teachers actually participated in co-planning sessions. Beginning after the initial introduction, and at least one time per week throughout the remainder of the intervention, the teacher pairs met to co-plan, using the ICT model. During each teacher pair’s first co-planning sessions, a basic outline (Appendix G) based on the pilot study for co-planning sessions was modeled, in which each teacher provides a synopsis of what they did in their class for the prior week, and an overview of their plans for the upcoming week. Teachers then discuss each of their subject matter and determine connections that can be made in their classes. Finally, they determine examples, activities, and discussion points that they can use with their students.

Each co-planning session was facilitated by myself as the researcher-facilitator. I mostly asked clarifying questions, especially during the first few sessions for each teacher pair, which helped to engage the teachers in discussing their content at a deeper level. Particularly in the case of Jones and Williams (first and third year teachers, respectively), I asked questions, such as, “What do you mean by that?” and “How do you explain that to students?” in order to encourage the teachers to explain their content to each other. Once these lines of communication were opened, it was rare that I needed to continue to ask questions or suggest connections because the teachers would then have a clearer path to do that themselves. After the first few sessions, I was able to step back, and the teachers took the
lead in the co-planning process, similar to the support and withdrawal period that Ploessl and Rock (2014) used with an E-coaching system for teaching teacher planning and instruction.

Teachers were expected to use the ideas that they generated during co-planning sessions in teaching their students. Throughout the intervention, the teachers were asked to complete and email journal (reflection) entries following specific prompts (see Appendix H) so that they could benefit from the process of reflection (Garet et al., 2001), and so that they could record their thoughts as they had them, similar to the data collection by Bullough and colleagues (2000). Time was devoted to discussing teacher reflections at each co-planning session in order to capitalize on the iterative nature of planning (Engestrom, 1998; Reynolds, 1992). In addition, I observed the teaching of select co-planned lessons in order to provide additional feedback about the planning and implementation of the lessons, which is important to professional growth (Desimone, 2009; Ploessl & Rock, 2014).

After the fourth co-planning session, the ECHS teachers reconvened as a large group instead of co-planning pairs and debriefed about their experiences so far. An additional purpose of convening as one large group was to promote a sense of community among all participants (Butler et al., 2004; Lewis et al., 2012). The teachers were asked a series of questions for discussion (Appendix I) during this whole-group meeting. These included general questions regarding their thoughts about interdisciplinary co-planning, specific successes and obstacles, and any other thoughts or suggestions.

After the 7th co-planning session, the teachers in both schools convened one last time as a wrap-up to the study. Teachers were prompted to consider and reflect on the connections that they had made over the course of the intervention by categorizing by the amount of time
they spent on them in their class and the importance that they felt they had to their teaching. In addition, they worked with their partners to rank factors which could influence their success in co-planning. Finally, this last session included opportunities for teachers to engage in discussion about their personal beliefs and experiences in co-creating and implementing interdisciplinary plans, since this type of discussion can help teachers to refine their beliefs through collective participation (Desimone, 2009) and feel professionally connected to their colleagues (Garet et al., 2001). The complete activities for this session can be found in Appendix J. At this time, the intervention officially ended, but teachers were encouraged to continue the co-planning routine that they established.

Figure 7. Implementation of the ICT model with teachers.
The alternating whole-group, teacher pairing structure of this PLE intentionally gave teachers opportunities for collective participation as a community (Fisler & Firestone, 2006) as well as opportunities to be the expert and dig deep into their content in a low-stress environment that is directly tied to their teaching (Borko et al., 2008). Optimally, the whole-group sessions would occur in a common area or classroom of the each participating school, and the co-planning should occur in either teacher’s classroom or some other space in the school where teachers feel comfortable talking and planning. The following section will detail some of the specific research-based decisions that were made regarding the development of the ICT PL experience.

**Features of the ICT Professional Learning Experience (PLE)**

The PLE described above was designed to include several features that are widely considered important to effective professional development (Desimone, 2009; Garet et al., 2001). These features, including duration, active learning, coherence, content focus, teacher reflection, and collective participation are discussed below. Other considerations of context which may affect teacher learning to use the ICT model are also discussed.

**Duration.** Both time span and contact hours are essential elements to consider for effective professional learning, and are significantly associated with other important features of professional learning (Desimone, 2009; Garet et al., 2001). Numerous researchers agree that, particularly because change is a gradual process, teachers need to be supported over a period of time (e.g., Boyle, Lampranou, & Boyle, 2005; Bruce et al., 2010; Guskey, 2002). As noted in the description of the ICT model, this time for support is a feature of the ICT model itself, and thus, is seen in the PLE. While this professional learning could not span
years as others have done in the past (e.g., Basista & Matthews, 2002; Berlin & White, 2012), teachers engaged for a period of 10 weeks and at least 9 contact hours, and were encouraged to continue to co-plan after the intervention had officially ended.

In addition, since the teachers were actually engaged in some aspect of the PLE during each week of the study, this immersion may have helped to create changes in practice that would not naturally occur with only monthly meetings. For example, in the pilot study, Mrs. Smith commented that the regular co-planning schedule helps to keep the search for interdisciplinary connections at the forefront of her mind at all times.

**Active learning and professional learning.** First and foremost, the term *professional learning experience* (PLE) is being used to describe the situated nature of the implementation of the ICT model instead of the more common *professional development*. The idea that teachers need more sophisticated methods of learning than show and tell workshops came about with the educational reform movement of the 1990s (e.g., Lieberman, 1995), and emphasizes the embedded nature of learning that teachers experience, which may have direct impacts on teacher efficacy and teaching practices (Bruce et al., 2010). This ties in with the idea of *active learning*, a core feature of effective professional development (e.g., Desimone, 2009; Garet et al., 2001), which also advocates for tying teacher learning to practice.

The ICT PLE aligns with calls for teacher learning through practice instead of separate from it (e.g., Hiebert & Morris, 2012) because the basis of the PLE is teachers actually planning interdisciplinary lessons that they will use with their students. In this experience, it would be optimal for teachers’ schedules to align so that each teacher in the pairing has the opportunity to observe the other teaching live as a sort of research lesson.
(Lewis et al., 2012), and while this will be encouraged as an option for teachers, it remained as optional in order to preserve the flexible nature of the ICT model.

**Coherence.** For professional development to be effective, it must address the goals of both the school and of individual teachers (Desimone, 2009; Garet et al., 2001). At the school level, the principals of both sites expressed a commitment to teacher collaboration. At ECHS, a further commitment to student accountability was documented, which included a focus on student learning, one of the affordances of teachers co-planning interdisciplinary lessons.

At the teacher level, a priority is to plan effective lessons for their students, since it is well-known that planning is essential to quality interactions with students (NRC, 2001). Teachers, who often do not have enough time for planning and other activities (Aydin, 2014), may appreciate the accountability of the model, which encourages them to spend time creating a tangible product that they can use with students. The teachers in the ICT pilot study came to continually think about interdisciplinary connections, not because they were overwhelmed with more work, but because of the relevance and usefulness to them of creating interdisciplinary activities for use with their students. Thus, a focus on the planning of lessons is consistent with most teachers’ goals.

**Content focus.** A strong focus on content influences teachers’ opportunity to learn (Ingvarson et al., 2005), and is associated with increases in teacher knowledge and changes in teacher practice (Garet et al., 2001). In science in particular, where content knowledge needs to be updated as information and theories change over time, a focus on content is particularly valuable (Loucks-Horsley & Stiles, 2001), but not always present (Boyle et al., 2005). It would be impossible to imagine implementation of the ICT PLE without a focus on
content, since the core activity of the ICT model is to discuss and reflect on each other’s content in depth in order to draw connections between concepts and practices. This content focus is the reason that affordances of the ICT model discussed in chapter 2 include increased shared language, expertise, and teacher knowledge.

**Teacher reflection and outside feedback.** Desimone (2009) describes teacher reflection as a non-core feature of effective professional development, and many researchers consider the importance of allowing teachers a meaningful way to reflect (e.g., Silver & Suh, 2014). Reflection came in three forms in the PLE. First, constant reflection on the implementation of lessons before creating new plans is integrated into the model itself. Time during each co-planning session was set aside to discuss teacher reflections and to address issues that arose in the implementation of plans. Second, aside from the introductory session, the goal of the whole-group sessions was for the teachers to collectively reflect on their accomplishments and troubleshoot the obstacles that they have encountered. Finally, the teachers were asked to write reflective journals, which helped them to regularly consider the affordances and limitations of the plans they had created (Ethell & McMeniman, 2000).

I also provided regular feedback and support to all participating teachers (Loucks-Horsley & Stiles, 2001). This feedback and follow-up between the facilitator and participants created more opportunities for teachers to reflect and learn (Ingvarson et al., 2005), and also gave the teachers a sense of support and efficacy (Guskey, 2002).

**Collective participation and social trust.** One form of collective participation, collaboration by teachers within the same school, grade, or department, has been found to have a powerful impact on teacher learning (Desimone, 2009) by encouraging teachers to
leave norms of isolation (Fisler & Firestone, 2006), and is significantly associated with active learning (Garet et al., 2001). Another form of collective participation, the development of a community over time, has also been found to create synergy (Lewis et al., 2012), increase teacher reflection (Butler et al., 2004; Cinta Munoz-Catalan et al., 2010) and enhance leadership (Loucks-Horsley & Stiles, 2001). Co-planning may encourage teachers to contribute to goals and make decisions, and to share responsibility and resources (Swanson & Bianchini, 2014). In order to optimize the positive impacts of collective participation, however, social trust must be developed over the course of the PLE (Borko et al., 2008). Without a high level of social trust, teachers may tend not to exhibit productive collaboration (Lewis et al., 2012), or not make lasting changes to their practice (Fisler & Firestone, 2006).

Obviously, the ICT model was built around teacher collaboration. One purpose of creating pairs for co-planning instead of larger groups is to provide teachers with a more comfortable setting to develop social trust with each other than to have to express opinions and possible misconceptions in front of a whole group. Using the pairings for reflection and discussion helped teachers to gain confidence in their voice before volunteering their private thoughts and feelings before the whole group.

However, the persistence of the whole group throughout the 10 weeks added another aspect to the collective participation that teachers experience with the PLE. In the whole group, teachers could trade questions, advice, and strategies, and hear their struggles voiced throughout the group. Ideally, all teachers in a cohort would belong to the same school, but even with the teachers at two different schools, they still developed some sense of community in purpose with the other participants. Thoughtful reflection was encouraged both
during the paired co-planning sessions and during the whole-group sessions, and oscillating between grouping types encouraged overall social trust and collective participation.

**Context.** While context often cannot be controlled for in the same manner as many other aspects of professional learning, there are several important elements to consider. The ICT model was created to transcend any particular curricula, but teachers’ personal planning routines (Basista & Matthews, 2002) and beliefs (Handal & Herrington, 2003), especially related to the nature of mathematics and science (Cronin-Jones, 1991; Perkkila, 2001), teaching and learning (Wallace & Kang, 2004) and students (Fennema et al., 1996), influenced professional learning outcomes in this project. For example, a consideration in implementation of the ICT model was teachers’ expressed comfort levels in deviating from the script that they had become accustomed to in their daily teaching. This was not much of an issue with the particular teachers in the pilot study because both of the participants came into the study concerned with student understanding over textbook coverage, but they did express concern that their colleagues do not have the same point of view because “it’s easier just to do bookwork with them,” (quote from Ms. Smith, science teacher).

Some other elements that potentially influenced teacher use of the ICT model are listed in the conceptual framework for this study in chapter 2. They include teacher knowledge, prior experience, and external factors such as administration, school activities, prior experience, and student factors. These factors were not be directly accounted for in the PLE, but an awareness of them was necessary in order to communicate with teachers about issues that are relevant to them.
Data Collection

Qualitative data was collected through observations, artifacts (including journals) and interviews. This ensured that the research questions were explored through a variety of lenses which allow for multiple sides of the situation to be revealed and understood, enhancing data credibility (Baxter & Jack, 2008). Table 4 aligns each research question with the data sources that were analyzed to answer the question. Most data that was used as a primary source to answer one research question was then used as a secondary source to triangulate data for another question (Creswell & Miller, 2000).

Table 4.
Alignment of research questions and data collection.

<table>
<thead>
<tr>
<th>Research question</th>
<th>Primary data sources</th>
<th>Secondary data sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. What is the nature of teachers’ planning processes when the ICT model is</td>
<td>• Observations of co-planning sessions</td>
<td>• Pre- and post- interviews (semi-structured)</td>
</tr>
<tr>
<td>implemented?</td>
<td>• Pre- and post- interviews (semi-structured)</td>
<td>• Co-planning and teaching interviews (unstructured)</td>
</tr>
<tr>
<td></td>
<td>• Co-planning and teaching interviews (unstructured)</td>
<td>• Artifacts (lesson plans, resources, worksheets, journals)</td>
</tr>
<tr>
<td>2. What is the nature of teacher plans when using the ICT model?</td>
<td>• Artifacts (lesson plans, resources, worksheets)</td>
<td>• Observations of teaching</td>
</tr>
<tr>
<td></td>
<td>• Reflective journals</td>
<td>• Teaching interviews (unstructured)</td>
</tr>
<tr>
<td></td>
<td>• Observations of co-planning sessions</td>
<td>• Co-planning interviews (unstructured)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Pre- and post- interviews (semi-structured)</td>
</tr>
<tr>
<td>3. In what ways does participation with the ICT model influence teachers’</td>
<td>• Pre- and Post-interviews (semi-structured)</td>
<td>• Observations of professional learning group sessions</td>
</tr>
<tr>
<td>expressed beliefs regarding a) the nature of mathematics and science; b)</td>
<td></td>
<td>• Observations of co-planning sessions</td>
</tr>
<tr>
<td>teaching and learning; and c) making interdisciplinary connections?</td>
<td></td>
<td>• Observations of teaching</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Co-planning interviews (unstructured)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Teaching interviews (unstructured)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Reflective journals</td>
</tr>
</tbody>
</table>
Observations

Observation is one of the key tools for collecting data in qualitative research (Baxter & Jack, 2008; Creswell, 2012). Observation of co-planning sessions was particularly important for the first research question regarding the nature of the planning process, and the second question regarding the nature of the plans made. A Livescribe pen was used to audio-record and take field notes for all observations. The Livescribe pen is a smart pen, which means that it automatically links points in written notes with time markers for audio data (Weibel et al., 2011), which makes it easier for the researcher to be a participant as observer (Creswell, 2012) and still collect thick descriptions, especially in co-planning and professional development sessions, without worrying about taking detailed field notes. A Livescribe pen was used for observations in the pilot study, and proved to be very useful in capturing audio data and pairing written notes and audio data. Data from the Livescribe pen were later be transferred to the computer for further elaboration, transcription, coding, and analysis. This created the opportunity to reflect further on the discussions that were being observed and to create additional memos while transcribing and coding.

Observations of co-planning sessions. The observation of co-planning sessions may be the most important piece of data that was collected throughout the study because the nature of this co-planning is the major focus of this study. I attended and observed all regularly scheduled co-planning sessions for each teacher pairing. I acted as participant observer (Creswell, 2012) when observing the co-planning sessions. Open-ended field notes were taken using the Livescribe pen during the co-planning sessions. The Planning Observation Protocol (Appendix K, adapted from RTI, 2012-2013) was completed for each
co-planning observation as soon as possible following the observation to reflect on and record overall data and specific examples. The Planning Observation Protocol was used for the pilot study, and modified to include a summary table of new topics that were discussed during co-planning, and who initiated them.

**Observations of teaching.** Teaching observations were used only as a secondary source of data in this study. The primary purpose of the teaching observations was to provide context concerning the plans and decisions that individual teachers make, and to provide feedback to the teachers concerning their co-planning efforts. I acted as a nonparticipant when observing teachers’ teaching (Creswell, 2012). Observations focused on interdisciplinary lessons that have been co-planned. These varied in length from an entire class period to a few minutes within a class period. Open-ended field notes were taken using the Livescribe pen during teaching observations. Since this was a secondary form of data, no additional observation protocol was used. A Teaching Observation Protocol (adapted from RTI, 2012-2013) was used for the pilot study, but this did not seem to help with data collection or analysis because of the secondary nature of the teaching observations. As such, it was not used in this study.

**Observations of whole-group meetings.** I acted as a complete participant during the whole-group professional learning sessions (Creswell, 2012). The Livescribe pen was used so that I could go back and refer to it to take notes after the sessions. In addition, a backup video camera was used during the first whole-group session so that the voices of each individual participant can be identified. During the third whole-group session, two audio recorders were used because the activities dictated that the teachers split into groups and then
These observations were useful in triangulating interview data about teachers’ beliefs concerning the nature of, teaching of, and learning of mathematics and science. They were also useful in learning the teacher’s perspective on the co-planning process. As with the teaching observations, I did not use an observation protocol for these because of their cursory nature in collecting data about teacher beliefs.

**Artifacts**

Artifacts are often a source of data in qualitative research (Baxter & Jack, 2008), but they are usually not used as a primary source (Creswell, 2012). Artifacts take on different forms. In this study, the artifacts that were collected were produced while co-planning, or in service of co-planning. This included, but was not limited to written lesson plans or notes, worksheets that were located or created for students, and any other resources that teachers used for or with their students in the implementation of interdisciplinary lessons.

Reflective journals are another type of artifact that were collected and analyzed. The journal prompts (Appendix H) were emailed to the teachers to complete as a part of their reflection after co-planning each week. Teachers had the option of emailing or printing journal entries in reply to each prompt. All teachers chose to email the journal entries, and for the most part, did so before the next co-planning session each week. The journal artifacts are different from other artifacts in that although journal entries were produced as a result of the co-planning sessions, they were not a product that teachers would use with students.

Each week, there were two journal prompts. One of the journal prompts read, “Did you implement anything in your class this week that you co-planned? If so, please describe it in detail. What did you do? What did your students do? What did you struggle or have
success with, and what did your students struggle or have success with?” The other prompt changed from one week to the next, and either asked about the teacher’s routine or their reflections about the co-planning process (e.g., How is what you are doing with your partner similar or different from what you have done in the past?)

The artifacts and journals together were considered a primary data source in considering the second research question: “What is the nature of teacher plans when using the ICT model?” These, together with observations of plans that were stated by teachers during co-planning sessions, gave a comprehensive picture of individual teacher plans when participating with the ICT model.

Artifacts were also used as a secondary data source to answer research question 1 about the planning process. For example, did the teacher create the artifact or find it, and did they do it during the co-planning session, before, or after? During the pilot study, for example, all of the worksheets that were produced for students were created or found by the teachers in the time between co-planning sessions. Reflection journals were also used as a secondary data source for question 3 about teacher beliefs.

**Interviews**

Interviews are often a primary form of data collection in qualitative studies (Creswell, 2012; Fontana & Frey, 2000). Often quantitative surveys may be substituted for interviews, but in this case, no instrument was found that was sufficient for the purposes of the study. In addition, information from Likert-type surveys may be more likely than semi-structured interviews to obscure subtle differences in beliefs. Formal (semi-structured) and informal (unstructured) interviews (Baxter & Jack, 2008) were used in this study.
The formal interviews (see Appendices L and M) were administered to individual teachers: once before and once after the intervention (named pre- and post- interviews). Each interview lasted between 30 and 60 minutes, depending on the length of the responses from the individual teacher. The formal interviews acted as the primary data source to answer the third research question: “In what ways does participation with the ICT model influence teachers’ expressed beliefs regarding a) the nature of mathematics and science; b) teaching and learning; and c) making interdisciplinary connections?” These interviews were semi-structured so that all participants answered similar sets of questions, but I was at liberty to change a question or follow up as needed (Creswell, 2012).

The questions were adapted from questions used by Evans (2003), Lederman et al. (2002), Luft and Roehrig (2007), McGinnis et al. (1997), and Watanabe and Huntley (1998). The interviews began by asking teachers to describe their teaching and planning routine and beliefs about teaching and learning. Teachers were then asked about their beliefs about the nature of their own subject, followed by the opposite subject, and then interdisciplinary connections. For these questions, there was no difference between the initial and final interviews. Next, the teachers were asked about their expectations or reflections about working with their partner (social trust) and with the interdisciplinary co-planning process. The only difference in questions between the initial and final interviews for this part was the wording regarding temporal events. For example, “How do you expect co-planning to fit or not fit into your regular schedule?” changed to “Describe how co-planning fit or did not fit into your regular schedule.” During the final interviews only, the teachers were asked to describe some of the plans that they created since the intervention began, and to reflect on
whether they thought that their teaching changed or not over the course of the intervention. Lastly, they were asked if they had advice for a future teacher who would consider co-planning. The last set of questions was useful as secondary sources of data for research questions 1 and 2 regarding the nature of co-planning and the plans that teachers made.

The unstructured interviews appeared as casual conversations with participants during and after co-planning sessions and after teaching episodes, and were an opportunity to gain insight into participant thinking during situations which might be otherwise forgotten. Questions regarding specific circumstances were asked when appropriate. In addition, participants often confide in a researcher informally where they would not formally (Creswell, 2012).

All semi-structured and unstructured interviews were recorded with the Livescribe pen, but care was taken during unstructured interviews to make the participant feel like they were engaging in conversation as opposed to answering interview questions. Information that was volunteered during these unstructured interviews, either surrounding co-planning sessions or teaching observations, was used as a secondary source to triangulate the other data sources to answer each research question.

Data Management and Analysis

As was stated above, this multiple-case study used several layers of coding and qualitative analysis to explore the nature of the co-planning process, teachers’ plans, and their beliefs. This section describes: 1) the execution of data management, and 2) analysis of the data to address each proposed research question.
Data Management

All raw data, coding, and analysis was stored on the secure NCSU-Google drive, with a pseudonym key kept in a separate location. Field notes and audio data from observations and interviews that were captured with the Livescribe pen were uploaded as synchronized audio/written PDF files. Original Livescribe files were stored on a separate hard drive that is not connected to a network and stored in a locked cabinet. Artifacts and reflections that were not already electronic were uploaded as PDFs as well, and all paper copies were either destroyed or returned to the participants. Because of the large volume of qualitative data, the data management program ATLAS.ti was used to manage all data. ATLAS.ti has the capability of importing, sorting, and managing audio files as well as .docx and .pdf files, so all file types that are used for data in this study were supported. All files associated with use of the ATLAS.ti program that were not able to be stored on the secure NCSU-Google drive were also stored on the separate hard drive mentioned above.

Data Analysis

All semi-structured interviews as well as observations of co-planning sessions and large group sessions were transcribed in their entirety because of their primary use in answering the research questions. All other observation data (teaching observations and unstructured interviews) and artifacts (e.g., journals, lesson plans, and notes) were used to triangulate the primary data sources and were transcribed as necessary when their usefulness became apparent through further analysis.

The data was coded in several phases, each with a focus on one of the research questions. Data regarding beliefs was coded first. The remaining data, regarding the nature of
the co-planning process and the plans that teachers made, were coded and analyzed together.

The analysis process for each phase is described in the following sections.

**Analysis for beliefs.** I read through all initial and final (semi-structured) interviews, and coded quotations for beliefs based on categories from literature and the conceptual framework. These initial codes were “Beliefs about the Nature of Mathematics” (BINOM), “Beliefs about the Nature of Science” (BINOS), “Beliefs about teaching” (BAT), “Beliefs about Learning” (BAL), and “Beliefs about Interdisciplinary Connections” (BIC). Codes were sorted and read through, and preliminary conclusions about each teacher’s beliefs before and after the intervention were noted. After making notes from the initial and final interviews, I read through all other transcripts and artifacts and coded instances in which teachers either expressed beliefs, or which may have provided evidence for changes in beliefs in each of the above stated categories.

I then went back through and coded all transcripts and artifacts again by teacher and time of the intervention. For example, the code “Jones mid” labeled a quotation as regarding Jones’s belief at the middle of the intervention. “Beginning” referred to the first meeting through the second co-planning session. “Middle” referred to the third through 6th co-planning sessions, including the second whole group meeting. “End” referred to the last co-planning session, last large group meeting, and final interviews. (A complete list of all codes used for this project and their descriptions can be found in Appendix N).

Codes for beliefs were then sorted by teacher, type, and time. I read through each set of beliefs and wrote notes about beliefs and changes in beliefs for each individual teacher. I then considered each pair of teachers as a case and wrote cases according to initial beliefs.
and changes in beliefs, keeping detailed notes about similarities and differences among cases. These cases were revised as necessary as analysis proceeded for the co-planning process and teacher plans.

**Analysis for co-planning process.** Open coding (Glaser & Holton, 2004; Walker & Myrick, 2006) was used to create initial categories for the nature of the teachers’ conversations that took place during the co-planning process. Notes were made about potential categories as I read through all transcripts for evidence of beliefs (above). Then, coding of quotations began with all co-planning sessions for the case of Miller and Smith. Codes were created to describe each type of statement that was made. For example, some of the initial codes were “clarify math,” “talk about students,” and “express value.”

Codes were then refined to be descriptive of categories of comments as they were determined, such as “BELF” for quotations in which a teacher discussed a belief as part of the co-planning process, “CONT” for mentions of content, and “PROJ” for mentions of projects and activities. Initial codes mostly remained as subcategories of each of the larger categories. For example, coding for content “CONT” was listed in 7 subcategories: discuss/clarify math content, discuss/clarify science content, math/science connection, name upcoming topic in math, name upcoming topic in science, mention past topic in math, and mention past topic in science. Rarely, a new subcategory was added as needed. For example, the code ICTP – CONT – related knowledge was added later because of its potential impact to the co-planning process. A list of all codes used regarding the co-planning process is in Figure 8, along with the number of quotations each code is tied to. (A complete list of all codes used for this project can be found in Appendix N.)
After coding each co-planning session for the case of Miller and Smith, I went back and read through each whole group session and interview transcript regarding Ms. Miller and Ms. Smith to note any other statements made about the co-planning process. This decision was made in part because of findings from the pilot study that the teachers do not simply begin and end the co-planning process within the regularly scheduled session itself.

The constant comparative method of analysis was used (Birks & Mills, 2011) to compare quotations to quotations; quotations to codes; codes to codes; codes to categories;
and categories to further gather evidence about the nature of the co-planning process until the data was saturated (Glaser & Holton, 2004). The list of codes was analyzed to note the most prevalent codes, and a visual network was made to look for trends in occurrences of codes.

The most prevalent codes fit into the categories of contents, projects, and students. The substance and nature of all other codes that occurred less frequently was examined, and the decision was made to disregard these codes as a part of the co-planning process because they seemed either inconsequential to the direction of the conversation, or they occurred during only a few co-planning sessions. I then listed all quotations involving codes that occurred frequently and read back through them thoroughly, looking for trends in each code. The case for Miller and Smith was written based on these trends. (At this time, the beliefs for Miller and Smith were also revisited in order to study the relationship between their beliefs and co-planning process.)

After the case of Miller and Smith was written, coding began for the case of Jones and Williams. The categories that were developed for Miller and Smith were used for Jones and Williams, and a code was added in for self-efficacy, which came up several times during each co-planning session with Mr. Jones and Ms. Williams, and seemed to influence the co-planning process for that teacher pair. After the emergence of this code, the Miller and Smith case was reviewed for statements regarding self-efficacy, but this was not an important topic of discussion for Ms. Miller and Ms. Smith as it was for the novice teachers, Mr. Jones and Ms. Williams.
After coding was complete, the same process of reading through all quotations, looking at prevalence and relevance, and creating a visual network was used for the case of Jones and Williams. The same categories (with the inclusion of the self-efficacy category) were used for the case of Jones and Williams as with Miller and Smith because they fit the data. Quotations for each code that occurred frequently were examined for trends in a similar way to the case of Miller and Smith, and the case of Jones and Williams was written. Notes were created relating the co-planning process for the case of Miller and Smith and the case of Jones and Williams, continuing the constant comparison process of analysis (Walker & Myrick, 2006).

The case of King and Taylor was coded in a similar way to the other two cases, using the same codes and comparing them to the data from this new case. The self-efficacy code was kept, and a code for related knowledge was added. (The other cases were reviewed for the related knowledge code, as with the efficacy code, but no widespread use was found.) As with the other cases, I read through all quotations, examined their prevalence, and made a visual network. At this point, the visual network of all three cases were cross-examined, and interesting similarities and differences were noted.

The visual networks, which are shown and compared in the final discussion of co-planning, contain a visual array of each code that was used for the co-planning process. Each code is attached by a thin line to each quotation that was coded as such, throughout each co-planning session transcript. For example, one quotation may be coded as discussing a project in depth and also clarifying mathematics content, and it would be connected to both of those
codes on the visual network. The resulting network depicts which codes combinations were the most commonly used.

Quotations for frequently occurring codes were further examined as in the other cases, and the case of King and Taylor was written. I considered related knowledge as its own category, but it fit better in the context of the data as a part of the “content” category of codes. After the King and Taylor case was written, notes were created relating the co-planning process for all three cases.

After all three cases were written, the cases and all notes were carefully examined in order to ensure consistency and draw cross-case comparisons. A table of comparisons was made across all cases, and the cross-case comparison was written.

**Analysis for plans.** Detailed notes were kept about the plans that teachers made during each co-planning session. In addition, these notes were expanded on throughout the initial coding of co-planning for each teacher pair. These notes supplemented the field notes, reflections, student worksheets, and other artifacts were reviewed to describe the nature of plans that teachers made, since it is known that many teacher plans may be kept mentally and not recorded as other written artifacts. Field notes, which were written throughout the intervention after each co-planning session, included a summary of each topic that was discussed, were particularly helpful in creating a summary of all plans made. Reflections, which included descriptions by the teacher of the plans that were enacted, held insight into the importance that the teacher placed on the various connections that were made. Other artifacts included notes that the teachers took during co-planning sessions and handouts that were given to students.
Once all plans were noted, a table was made to summarize all topics, activities, and connections made for each case. This summary table was compared to the co-planning transcripts as they were read back through regarding the co-planning process. Plans were categorized into larger activities and smaller examples and discussion points, each described in Appendices O, P, and Q. Each of the larger activities was described and examined for physical activity, connectedness and timeliness. The smaller connections were described as a whole for each case. After each case was analyzed separately, plans were compared across all cases for more general cross case comparisons and conclusions regarding type and originality of the connection and related student worksheets, and timeliness and implementation of each connection.

**Validity and Reliability**

A major reason to use a case study is that it is an effective way to explore a real-life, complex situation through in depth data collection (Crewsell, 2012). There is a precedent for case study and for multiple cases study to obtain a rich description of the variety of exchanges that occur during the planning process (Borko et al., 2008; Holstein, 2012; Swearington, 2014).

The use of data driven coding and the constant comparative method ensures the correspondence of the theory to the data, and thus the validity of the study (Glaser & Holton, 2004). Theoretical validity was also addressed through the discussion, which drew the comparisons and points of divergence between the results of this study and the existing literature base.
The use of multiple data sources also lends validity to the study (Creswell, 2012). The primary data source for each research question became a secondary data source for each of the other questions, and in this way, each of the data sources served to triangulate information obtained from the others (Creswell & Miller, 2000). The presence of the post-intervention and other interviews also allowed multiple opportunities for member checking, another procedure for validation (Creswell, 2012; Creswell & Miller, 2000).

Even though the participant group was small, a large amount of data was collected. Reliability was ensured through observation and interview protocols as well as keeping the same facilitator as researcher across all cases (Creswell, 2012) so that treatment across participants did not differ. The ability to audio-record observations and interviews and then transcribe the audio-recordings verbatim also created a more reliable environment for coding because I could relive the experience when necessary instead of relying on a memory that may be vague or confused.

Chapter Summary

This chapter described the qualitative embedded multiple-case study intervention design that was used for the current study. 3 mathematics-science teacher pairs each constituted one case, with the individual teachers acting as embedded cases. The participating schools were described in detail. The 6 participants are described as a part of their case write up in the next chapter.

The intervention, a 10 week professional learning experience with researcher-as-facilitator, focused on teachers doing the act of paired interdisciplinary co-planning, but did include three sessions (at the beginning, middle, and end) for teachers to meet as a larger
group to collaborate and troubleshoot. Features of the professional learning experience were directly tied to the core features of the ICT model, and included its duration, active learning, coherence, content focus, reflection, feedback, and collective participation. Supplementary materials are contained in Appendices E through J.

Data collection included observations, interviews, and collection of artifacts and reflective journals. Each of these data sources was the primary source for one research question, and served as a secondary source for triangulation for the other questions. Observation and interview protocols are contained in Appendices K through M.

Audio-recorded data was collected with a Livescribe pen, and data management was handled through the computer program ATLAS.ti. The constant comparative method of analysis was used, which employs initially open coding, and then comparison of items and codes to look for themes. Primary data sources were initially transcribed verbatim and coded in consideration of each research question, informed by the pilot study and the conceptual framework contained in chapter 2. Secondary sources were used to triangulate themes discovered from the primary sources.

In addition to the validity addressed by constant comparative analysis, reliability is addressed through observation and interview protocols and audio-recorded field notes.
CHAPTER 4: RESULTS

The purpose of this study was to capture the nature of the planning process when the Interdisciplinary Co-planning Team (ICT) model is implemented with middle school and high school teachers. Three teams fully participated in the intervention, including whole group meetings, team co-planning sessions, and individual reflections and interviews.

In this chapter, each of the three co-planning teams is presented as a case. The cases each include results with respect to the co-planning process, actual plans, and changes in beliefs. (Note: For each of the cases, the pseudonym that is first alphabetically is used for the mathematics teacher (i.e., Miller, Jones, King), and the pseudonym that is second alphabetically is used for the science teacher (i.e., Smith, Williams, Taylor.).)

**Miller and Smith: A Case of the Change in Mindset about the Primacy of Interdisciplinary Activities in Planning**

Teachers are very busy people, especially at ICMS. Between Ms. Miller teaching an extra class during her planning period, 8th grade IEP exit meetings, and other events that dot the calendar, it is difficult to find extra time to devote to another project. Ms. Miller and Ms. Smith participated in the pilot study for interdisciplinary co-planning in the fall semester, and came to appreciate the value of making interdisciplinary connections in their lessons for students. When time became scarce in the spring, they made regular co-planning a priority. Part of this resolve came from a shift in their beliefs about interdisciplinary connections, from something the teachers could add to their already packed schedules, to an important part of their daily practice. For Ms. Miller and Ms. Smith, by the end of the intervention, interdisciplinary connections had become a part of their everyday thinking.
Background

Ms. Miller taught 8th grade math, and Ms. Smith taught 8th grade science, both at ICMS. Both were experienced teachers, but neither had been at ICMS long. Ms. Miller was in her second year at ICMS, but had a total of 15 years of teaching experience. Ms. Smith was in her third year at ICMS, with the majority of her 17 years of experience actually in high school biology. Ms. Smith also worked as a science coordinator for the school district for 3 years before returning to the classroom. Ms. Smith taught four class sections of 8th grade science, which all 8th grade students take. Ms. Miller taught four sections of 8th grade math. At ICMS the students are split into teams where each team is comprised of a math teacher, science teacher, English teacher and social studies teacher, with the intent that the teachers share a common group of students. Ms. Smith and Ms. Miller taught on the same team. However, because of scheduling and other conflicts, Ms. Smith and Ms. Miller stated that they only shared about 60% of their students.

Although both teachers had many years of teaching experience, neither had any real experience co-planning, or planning interdisciplinary activities prior to this project. Ms. Smith stated that during her time as a high school teacher, although she attempted to do an interdisciplinary project with a math teacher a couple of times, but it never worked out. Ms. Miller stated that prior to this co-planning experience, she had no experience with cross-curricular or interdisciplinary collaboration. (Note: this is the second semester of being a co-planning team for Ms. Miller and Ms. Smith. They participated as a team in the pilot study in the previous semester, during which they had 4 co-planning sessions over the course of about 6 weeks.)
To present this case, I will first share the nature of the content and activities that Ms. Miller and Ms. Smith planned and carried out in their classes. Next, I will report the findings with respect to the nature of the conversations that took place during the co-planning sessions that led to the planned connections and activities. Finally, I will present the findings with respect to the teachers’ beliefs – both how they influenced the co-planning process and how they shifted as a result of the experience.

**Nature of the Co-planned Interdisciplinary Activities for Miller and Smith**

To provide context for the findings related to the co-planning process, I first report findings related to the actual co-planned connections. In each of the co-planning sessions, Ms. Smith and Ms. Miller generally discussed several math and science topics as well as possible activities. Table 5 lists the math and science topics as well as large activities that were discussed, in order, by co-planning session. For example, during the third co-planning session (CP3), 4 topics in mathematics were included in the discussion, and 5 topics in science. The Bacteria growth lab and Microbe clock activity were discussed, incorporating several of the topics listed.

**Table 5.**

*Miller and Smith co-planned topics and connections by planning session*

<table>
<thead>
<tr>
<th>Math topic</th>
<th>CP1</th>
<th>CP2</th>
<th>CP3</th>
<th>CP4</th>
<th>CP5</th>
<th>CP6</th>
<th>CP7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scientific notation</td>
<td>past topic</td>
<td></td>
<td>Past activity, upcoming</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quadratic expressions</td>
<td>current topic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pythagorean Theorem</td>
<td>planned</td>
<td>mentioned</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Geometry (congruency and similarity)</td>
<td></td>
<td></td>
<td>upcoming</td>
<td>current activity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Geometry (transformations)</td>
<td>future topic</td>
<td></td>
<td>current</td>
<td>planned</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Table 5 Continued</td>
<td>CP1</td>
<td>CP2</td>
<td>CP3</td>
<td>CP4</td>
<td>CP5</td>
<td>CP6</td>
<td>CP7</td>
</tr>
<tr>
<td>-------------------</td>
<td>------</td>
<td>------</td>
<td>------</td>
<td>------</td>
<td>------</td>
<td>------</td>
<td>------</td>
</tr>
<tr>
<td>Geometry (volume)</td>
<td>future</td>
<td>planned</td>
<td>planned</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exponential functions</td>
<td>planned</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ratios</td>
<td></td>
<td>mentioned</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stats (1-var)</td>
<td>future topic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stats (2-var)</td>
<td>past topic</td>
<td>planned</td>
<td>current</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stats (2 way tables)</td>
<td>future topic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Science topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earth History</td>
</tr>
<tr>
<td>Radioactive decay</td>
</tr>
<tr>
<td>Geologic history</td>
</tr>
<tr>
<td>Paleoclimatology</td>
</tr>
<tr>
<td>Moulds and casts</td>
</tr>
<tr>
<td>Diversity of species</td>
</tr>
<tr>
<td>Morphology</td>
</tr>
<tr>
<td>Bacteria and antibiotics</td>
</tr>
<tr>
<td>Science topic</td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>Microscopic measurement</td>
</tr>
<tr>
<td>Density</td>
</tr>
<tr>
<td>Disease</td>
</tr>
<tr>
<td>Biotechnology</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Activity/Lab</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lab practicum</td>
</tr>
<tr>
<td>Pythagorean project</td>
</tr>
<tr>
<td>M&amp;M lab</td>
</tr>
<tr>
<td>Bacteria growth lab</td>
</tr>
<tr>
<td>Microbe clock</td>
</tr>
<tr>
<td>Gapminder</td>
</tr>
<tr>
<td>Biotechnology</td>
</tr>
</tbody>
</table>

Over the course of the 7 co-planning sessions, 7 larger activities were discussed, 6 of which were implemented. The seventh, a lab practicum idea in which students rotate among stations to review math and science concepts before their EOG, was brought up by Ms. Smith during the first two co-planning sessions, but the idea was never thought through or
implemented. In addition to the 6 larger activities, both teachers reported that because they knew what each other was doing in class from day to day, it became easy to briefly mention or draw connections in smaller ways regularly during their classes, even when it was not a part of a larger activity. The next two sections will focus first on each of the larger co-planned activities that were implemented by the teachers, and then, on the smaller connections that the teachers made throughout the intervention.

**Co-planned activities.** Ms. Smith and Ms. Miller thought about interdisciplinary connections typically in the form of large projects and labs. Each of these larger activities that was implemented was accompanied by a student worksheet, which contained either background information, directions, space to record data and answer questions, or a combination of these. Two of the worksheets were adapted from existing projects (the Pythagorean project from mathematics and the M&M lab from science). An original worksheet was created for each of the other four activities.

Five of the 6 activities involved some type of data collection, 2 through physical means, and three from websites or applets. The activities and labs that the teachers co-planned and implemented are described next. The complete activities are included in Appendix O.

**The Pythagorean project.** The Pythagorean project was a pre-existing project that was assigned to the Ms. Miller’s 8th grade math classes in previous years. In this project students construct a Pythagorean spiral by connecting a series of right triangles. This connection came about during co-planning session 1 when it was being described as an upcoming project in math class. Ms. Smith saw the example and recognized the similarities
in shape and look to the way geologic timelines are often displayed. She said, pointing at the different areas of the spiral, “If I give them geologic time, and in geologic time, this many years are in the Precambrian, this many years - if they could figure out what percentage of these to color in to be the certain periods of geologic time.” The final version of the project that was assigned to students in their math class and included directions to draw the spiral and to color in the different periods of geologic history. Directions were also given for all calculations in both the math and science classes, and students handed these calculations in with the project. Since this project was only assigned to some math students and not others, a blank Pythagorean Spiral worksheet was created to give students that were in the “other” math class (which was not assigned the project), so that they could still complete the science portion of the project.

The Pythagorean project seemed to hold a surface level connection between mathematics and science because the directions for the activity included both subjects, but students were not drawing conceptual connections between the content areas. For this project, students first completed the math portion, and then completed the science portion. The connection was also timely because students were learning the Pythagorean Theorem in mathematics at the same time that they were learning Earth history in science.

The M&M lab. The M&M lab was planned by Ms. Smith to explain the concept of radioactive decay to her science students. Ms. Smith described the project the following way, “So they going to have 50 pieces of plain M&Ms? They’re going to put them all in - they’re going to shake a bag, and they’re going to pour out all the candy. The ones that land print side up are decayed, and the ones that don’t are not decayed. And so they’re going to keep
doing this. They’re going to see an exponential change, obviously, because as you go from 50 to 20, their graph is going to look like an exponential graph.” The obvious connection to math would be exponential functions, but Ms. Miller pointed out that 8th grade students do not learn exponential functions, unless they are in the one Math 1 class, most of which are not. Eighth grade math students do learn about graphs in general, however, and the teachers created a list of concepts about the graph that would apply to all students. This included describing the dependent and independent variables; telling whether the graph is linear or nonlinear, and whether it is increasing or decreasing; and to use words to describe characteristics of the graph (i.e., leveling off). The “math” questions were added to the “science” worksheet, and the activity was completed in Ms. Smith’s science class. Ms. Miller reinforced the math concepts that the students should know during her class by finding examples of graphs of radioactive decay to describe during their warmup for a couple of days leading up to the M&M activity.

The M&M lab held a direct connection for students because the data collection and mathematics questions are directly related to the science concept. Both concepts were also timely in that the students were currently learning both the science and the math concepts that were in the activity.

The bacteria growth lab. The bacteria growth lab is the first activity that Ms. Smith and Ms. Miller co-planned that did not already exist in some form before they discussed it. The science class had been monitoring litter leaf bags once a week that they had planted outside several weeks prior. Ms. Smith described the process that the class would do to take samples of bacteria from the bags and incubate them in order to notice biodiversity. During
co-planning, both teachers were discussing the best way to have students compare their bacterial colonies, and Ms. Miller noted that using tracing paper or transparencies to trace the outline of images in order to compare them to others is the way in which she shows students congruence transformations in her math class. This idea was developed into a set of directions that students could follow to compare their bacterial colonies, which included describing their morphology (shapes) through mathematical congruence transformations.

Since similarity and congruence was a current topic in Ms. Miller’s math class, she reported taking several opportunities in her class to discuss what they were doing in science.

The bacteria growth lab held a direct connection for students between mathematics and science concepts because the tools and techniques that they used for comparisons in both classes was the same. The teachers and students drew connections between comparison of size and shape in mathematics and science. The connection was also timely because students were currently learning both of these techniques in their classes.

**The microbe clock activity.** The microbe clock activity was created as a follow-up to the bacteria growth lab. The teachers were talking about whether or not there was a way to count the population of the bacteria in the colonies that the students collected. The microbe clock is an online simulation of the number of bacteria in an uninhibited colony over time, and then after the introduction of antibiotics. Aside from the graphing skills that the students practiced in other labs, the lab that Ms. Smith and Ms. Miller created included questions about scaling and labeling axes, because the number of bacteria in the simulation reach into the hundred thousands (of millions), but the number of replications was in the thousands (of millions), and the number of mutations was in hundreds.
The microbe clock activity held a direct connection for students through data collection and graphing as the M&M lab did. In particular, this lab encouraged students to think about scaling axes, with which Ms. Miller noted that they have difficulty, giving students an intellectual need to think mathematically about which scale works best to represent the data that they were collected through the science applet. This lab was not as timely as the others, however, because Ms. Miller’s class was currently working on geometry, not data collection and graphing.

**The Gapminder activity.** The Gapminder activity was created during the fifth co-planning session to connect scatterplots and lines of fit in math with the study of diseases in science. Gapminder is a website which houses a large collection of data, listed by country, over a variety of topics and issues. Ms. Miller and Ms. Smith explored several ways in which they could use Gapminder with their students, and also explored which data would work best for their students to learn specific concepts. They decided to create a project in which students use Chromebooks in the classroom to access the data tables on the website. For the project, students were told to create or copy a table of data from a list of choices. They then had to graph the data, draw the line of best fit, and find the equation of that line. They also had to verbally describe the graph in context, using the slope and intercept to describe the trend of the disease in a particular country over a set of years, and why they thought it followed the trend that it did. This project was assigned in math class, but students worked on it during both classes over the course of several days, and the grade was shared between both classes. Both teachers relied on each other to answer student questions involving both
subjects, but both also reported deferring to the other when there were questions that they were unsure how to answer.

The Gapminder project held a direct connection for students because they had to collect data regarding various diseases that they were learning about in science, and then use the data to further answer questions about the diseases. The activity was timely because students were currently learning about both disease in science and scatterplots in mathematics.

**Biotechnology job search activity.** The final big activity that was discussed was a biotechnology job search, which connected biotechnology from Ms. Smith’s science class and 2-way tables from Ms. Miller’s math class. Students in Ms. Smith’s class were given a website to research different biotechnology careers. They discussed different ways to categorize their data into 2 non-overlapping categories, such as medical versus non-medical. The activity was planned to continue into Ms. Miller’s class, where they had to poll each other about which career they would choose, and organize their data into 2-way tables. The purpose of creating the 2-way tables was for students to learn to organize data into meaningful categories in mathematics, and to reinforce their study of biotechnology careers in science.

The biotechnology job search activity created a direct connection for students because they had to use statistical techniques and organization to discuss biotechnology careers that they were learning about in science. Although this connection was through data collection, it differed from the other activities that were also through data collection in that the data was not 2 variable data. It was timely because students were using data collection and analysis
techniques that they were currently using in their mathematics class in order to classify and examine data about jobs that they were learning about in their science class.

Of the 6 activities that were implemented, 5 drew connections between math and science topics that were currently being taught in each class. One (the Pythagorean project) would be considered a surface level connection because it did not offer any true connection between math and science concepts. The other 5 contained a direct connection between mathematics and science. It can be said that in each of these cases, mathematical techniques or representations are used to explore science data and concepts, or it can be said that the science provided data and context to explore mathematical concepts and representations. In fact, as the activities were written, and as the teachers reflected about their implementation in their classes, both of these statements seem true, that the mathematics offered a tool for science, and that the science offered a context for math.

**Co-planned math and science connections.** As the intervention progressed and Ms. Miller and Ms. Smith had built an awareness of the content of each other’s courses, they began to discuss ways to make connections more informally than in large activities like those described above. For example, following the co-planning discussion of the microbe clock lab, Ms. Miller mentioned that her class was working on finding volume, particularly of round objects. It was suggested that Ms. Smith probably had some objects that she could measure the volume of with her class, and Ms. Miller collected a variety of science objects that she could use in her class. Ms. Miller and Ms. Smith also discussed the concept of uninhibited bacterial growth, and Ms. Miller took a petri dish so that she could ask her math class about uninhibited bacterial growth, and how many bacteria would fit into the petri dish.
This lead into a discussion of scientific notation, what the problems usually look like, and what students should be able to do. Ms. Smith shared another activity that she had students do in which they marked out geologic times on a roll of register tape to illustrate the lengths of times of different geologic periods of time. These activities were completed in separate classes by each teacher, and over a shorter period of time, but they serve as an illustration of the opportunities that the teachers took to draw connections within their own classrooms as a result of co-planning.

Ms. Smith and Ms. Miller were able to successfully plan and implement both large inter-disciplinary activities and smaller verbal recognitions of connections between the math and science concepts. This is evidence that the ICT co-planning model worked for the two of them within the context of their school structure and belief system. To better understand the nature of the collaborations that took place which led to these activities I next share findings related to the pair’s actual co-planning process as they engaged in the ICT model.

**The Co-planning Process for Miller and Smith**

Ms. Miller and Ms. Smith fit co-planning into their regular individual planning routines. Both before and after co-planning sessions, each teacher used state standards documents, textbooks, and other resources to plan at the yearly, unit, weekly, and daily levels. They varied in how much they relied on the textbook or other resources (Ms. Miller relied on the textbook more), but both teachers reported blocking out units of time for each topic, and then creating and refining lessons to fit within the predetermined allocations of time.
Co-planning seemed to fit in at the daily level of planning, but not at the most detailed level for Ms. Miller and Ms. Smith. Although the co-planning sessions were scheduled once a week, the conversation generally revolved around details of content or activities that would be used within one daily lesson or another. Often, either Ms. Smith or Ms. Miller would discuss details of a lesson, and then determine responsibilities to complete planning during their individual time. In the excerpt below, Ms. Smith and Ms. Miller had just completed a lengthy discussion about measurement of bacteria and scientific notation.

Smith: All right, so cool. I’ll have to work up a worksheet. I’ll make it up in terms of looking at their colonies.

Miller: Do you want me to give you some sample questions they can work on or something?

Smith: Yes, that’ll work.

Miller: Maybe whatever day you’re really planning to hit the scientific notation, maybe the day before we can review it in my class.

Smith: Yeah, we’re going to do this next Thursday or Friday.

Armed with a new understanding of what her students should know and do, Ms. Smith takes on the responsibility to create a worksheet, which will add the finer level of detail to her lesson before it is implemented. Ms. Miller volunteers to provide sample problems, and the teachers confirm the date that the lesson will take place.

In between co-planning sessions, Ms. Miller and Ms. Smith often reported speaking to each other, either in passing or during lunch. During her final interview, Ms. Smith reflected, “For Ms. Miller and I it was a little bit easier because we got to the point where
hey, I’m passing in the hall, hey what are you doing right now? Oh, you’re not doing anything, ok, can we sit down and talk real quick. So it was much more unplanned meetings between us where we just said, hey are you planning anything. Ok, I’ll come see you in 15 minutes. And so that seemed to work best for us.” These mini-sessions became a natural extension of the daily planning that occurred during regularly scheduled co-planning sessions, and kept interdisciplinary connections continually on both teachers’ minds.

During Ms. Smith and Ms. Miller’s actual co-planning sessions, the teachers generally completed multiple tasks, between reflecting on past topics and/or activities, discussing current or upcoming content, and planning future activities. Time was generally spent engaging in content, planning activities, and reflecting on completed activities, but the amount of time spent on each varied from session to session. Although connected activities and projects were planned in almost every session, as time went on, there were fewer mentions of future topics and possible connections and more in depth discussion of the activity that was currently being planned. For example, during each of the first three co-planning sessions, an average of 9 topics were mentioned between math and science in each session. During the fourth session, 7 topics were mentioned. During the 5th, 6th, and 7th sessions, 3, 3, and 2 topics were discussed, respectively. Topics were often discussed over at least two co-planning sessions, so the total number of topics over the course of the entire intervention is far fewer than the sum of topics from each session. (For a list of topics, see Table 5.)

The teachers seemed to alternate mostly between talking about content and talking about particular activities or projects, with comments about students, end-of-year testing,
logistical responsibilities, or particular beliefs inserted throughout. Figure 9 lists the
frequency of the codes that were applied to co-planning session conversations. The list on the
left depicts the codes in order by type, including sub codes. The list on the right depicts the
codes in order by frequency of application. For example, the highlighted code, ICTP –
CONT – discuss/clarify science content (coded for the ICT process, in the category of
content, specifically about discussing/clarifying content) occurred 15 times. On the left, it is
categorized among the content codes. On the right, it can easily be seen that it is the 6th most
frequently occurring code for this teacher pair.

<table>
<thead>
<tr>
<th>Codes</th>
<th>Smith Miller</th>
<th>Miller</th>
<th>Smith</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICTP - BELF - efficacy</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>ICTP - BELF - express excitement/value</td>
<td>6</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>ICTP - BELF - rationale for decisions</td>
<td>4</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>ICTP - CONT - discuss/clarify math content</td>
<td>26</td>
<td>26</td>
<td></td>
</tr>
<tr>
<td>ICTP - CONT - discuss/clarify science content</td>
<td>15</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>ICTP - CONT - math/science connection</td>
<td>21</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>ICTP - CONT - name upcoming topic math</td>
<td>12</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>ICTP - CONT - name upcoming topic science</td>
<td>13</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>ICTP - CONT - past topic in math</td>
<td>5</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>ICTP - CONT - past topic in science</td>
<td>2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>ICTP - CONT - related knowledge</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>ICTP - LOG - other</td>
<td>7</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>ICTP - LOG - responsibilities for connected project</td>
<td>15</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>ICTP - LOG - timeline</td>
<td>16</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>ICTP - PROJ - 1 mention/describe existing project</td>
<td>10</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>ICTP - PROJ - 2 possible project/activity</td>
<td>12</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>ICTP - PROJ - 3 details for connected project/activity</td>
<td>31</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td>ICTP - PROJ - 4 reflect on project/activity/lesson</td>
<td>10</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>ICTP - STUD - about students</td>
<td>26</td>
<td>26</td>
<td></td>
</tr>
<tr>
<td>ICTP - TEST - mention EOG/testing</td>
<td>10</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>TOTALS:</td>
<td>241</td>
<td>241</td>
<td></td>
</tr>
</tbody>
</table>

*Figure 9. ICT process code occurrence for Miller and Smith case.*
As seen in Figure 9, most co-planning time for Ms. Smith and Ms. Miller was spent focused on discussing content, projects and activities, and students. As such, these data will be further examined, and will be discussed in the remainder of this section. Other types of comments (e.g., references to EOG testing) by Ms. Miller and Ms. Smith occurred infrequently, and did not seem to impact planning sessions, so they will not be discussed, except as in reference to content, projects and activities, and students.

**Discussing content and connections.** Ms. Smith and Ms. Miller discussed both past and upcoming content topics related to the 8th grade math and science curriculum. In the earliest co-planning sessions they brought up past topics in math and past topics in science to describe to each other what they had done in previous classes so that they could explain upcoming topics. Once this was no longer needed they tended to focus on upcoming topics and did so once or twice during each co-planning session with the intent of describing upcoming content for each other so that they could then look for look for connections.

The teachers generally used the discussion of specific math and science content as an opportunity to offer ideas for connections, check for feasibility, and find similarities in topics and procedures that they were discussing in their math and science classes. The following exchange is an example of such a conversation:

- **Miller:** Ok, let’s see. I’m going to be doing transformations, which is translations, rotations, and reflections.
- **Smith:** Oh, wait a minute. Is that saying like negative images, almost?
- **Miller:** Like, reflections. In a mirror.
Smith: Moulds and casts. So, you’ve got something that dies, and it settles in sediments somewhere. And that decomposes and leaves behind an exact image.

Miller: You know, it’s like rotations, reflections, dilations. And then they do a dilation project where they have to take a cartoon and blow it up big.

Facilitator: So like if you - if there’s a fossil record in the ground. So here’s your ground, and here’s your little fossil. And you need to translate that somehow to paper, or your computer or whatever it is, because you need to know what that thing is, are you talking about how would you do that - you’d make a mould of it, and - is that what you’re talking about?

Smith: No, it’s really more just the fossil record in terms of how it supports evidence. How it’s supporting evidence that life has changed on this planet. And that they can infer the age of the earth based on the fossil record. Like, things have come and gone. There’s fossils found on this continent that are similar to fossils found on this continent. So, it’s more along those lines.

In this example, Ms. Miller mentioned of an upcoming topic in math, transformations. Then Ms. Smith asked a clarifying question and offered a possible connection between transformations and moulds and casts. However, Ms. Smith ultimately decided that the connection was not feasible for her class because it was too much of a stretch from the point of her lesson. This check for feasibility was important throughout the co-planning process.
because it helped the teachers to ensure that their students would view the connections that they were making as relevant.

Content connections were often offered in reference to specific projects or activities that were being discussed. For example, during the discussion of a microbe clock, Ms. Smith said the following:

Yeah. One of the extensions I can do is this, because we’re actually getting ready to start evolution. Oh my gosh - it just connects. This plant stuff, what we’re doing, it just connects everywhere. So, start the microbe clock to see bacteria in action - how do microbes fight back? Some bacteria are more resistant to antibiotics than others. If a population of bacteria is treated with an insufficient dose of antibiotics, resistant bacteria will survive and continue to replicate, doubling their numbers in just 20 minutes. There’s some math there, in that, right?

Ms. Smith noticed several connections during her brief discussion of the microbe clock. Within her own class, she had been teaching about radioactive decay as a part of geologic and Earth history, with a side project for a different purpose about diversity of species and bacteria. When she stated that the class was getting ready to discuss evolution, she realized that she could draw parallels between all three of these topics, which seemed unrelated before. In addition, she recognized that the growth of the microbes could be described mathematically, and the teachers went on to discuss that it was really the same type of function mathematically as the radioactive decay that she had just finished.

Most often, connections were either couched in or led into segments in which the teachers discussed or clarified content. For example, during another portion of the same
discussion as above, Ms. Miller asked, “What are you doing with scientific notation?” Ms. Smith answered, “I was just thinking that was there some way, because one colony of bacteria can have hundreds of thousands, or even millions of individual bacterial cells. I was just thinking if there was some way to get them to do some estimation, or have them convert big numbers to scientific notation,” which then began a conversation about what students should be able to do and recognize with scientific notation.

While there was significant time spent discussing and clarifying content, the teachers’ discussions related to clarifying math concepts were different from those clarifying science concepts. Quotations involving clarifying math seemed to serve several overlapping purposes, including: the explanation of a concept in general, identifying mathematical language, specific problem solutions, and identifying problems that students should be able to complete. For example, the following excerpt is a short example of the clarification of a math topic, scientific notation. During this excerpt, Ms. Miller introduced scientific notation as the way that students would solve a certain type of problem, She wrote the problem as it would look to students, discussed what students should be capable of doing, discussed calculator usage, clarified about common representations, and explained the rule for solving the problem in two different ways, and solved the problem.

Smith: How does that look if you set it up on paper? Dividing it by 1000.

Miller: They do scientific notation, so they set it up like this, and then they do… [writing]

Smith: So they don’t change that
Miller: Well, you could leave it like that and see what they will do. They need to change it to… [writing]

Smith: Leave that, let me take a picture of that. … That was what I was thinking. Is this something that they have to be able to put in a calculator?

Miller: No

Smith: They don’t do that by calculator?

Miller: They should be able to do that by hand.

Smith: So this is in the non-calculator section. So if they solved for this one, what does it - if I’m a student, and I wrote this one down, what does it look like when I work this one out?

Facilitator: How do your kids do that?

Miller: What, the first one?

Facilitator: Whichever one they most commonly do.

Miller: Well, they probably look at the third one. That’s probably what they see the most. And so, they take that and make that to the third power, and they subtract

Smith: The rule is to subtract.

Miller: So they know when you multiply, you add exponents and when you divide, you subtract exponents. You should get -6 though. -3 minus 3 is -6.

Smith: So the rule is
Miller: The rule is when you multiply, you add the exponents. So, when they see it as this, the rule is when you multiply, you multiply the numbers, which is the 1. But I didn’t write the 1 there. And then you add the exponents, so -3 plus -3 is -6. They know when you divide, you subtract the exponents, so -3 minus 3 is -6.

These conversations allowed Ms. Smith to see the mathematics problem from both the teacher and student point of view concurrently, and to tackle multiple aspects of the problem within a short time.

In contrast, when the teachers’ discussions involved clarifying science concepts, they typically included general explanations of concepts. However, unlike the mathematical conversations, they did not tend to focus on identifying scientific language or representations. If there was a mention of specific language usage or a discussion of representations it was in the service of determining how to incorporate mathematics. For example, Ms. Smith defined rock superposition. “Layers on the bottom are older than layers on the top, unless you’ve got some sort of unconformity in the stratification of the rock layers. Or you also use it like an index fossil. Like, here’s something that we know we have dated radioactively. It’s this old. If you find anything like that again, in any of the layers of rock on earth, you can pretty much estimate that this layer of rock is this old.” In this excerpt, Ms. Smith is not explaining how to represent rock superposition or teach it to students, just explaining the concept. This is different from the segment below, in which the teachers are working to incorporate similarity and congruence into comparing bacterial colonies.
Smith: So comparing this colony to this colony. Let’s say they’re the same color, same shape, but different sizes. Could they still be similar?

Miller: Yeah. Same shape, different size, is what similar is in math.

Smith: Ok. Does color matter, or does it have nothing to do with math?

Facilitator: We like color. We think it’s pretty.

Smith: Ok. And congruent would be what?

Miller: Same shape, same size.

Smith: Perfect.

Miller: Yeah, perfect overlays. So that’s a good way for them to prove that it’s congruent for you is a perfect overlay.

In this segment the teachers are still discussing the concept, but with more of a focus on the language that they would be using to describe the concept to students. The concept is described, and a language for representation “perfect overlays” is mentioned.

Often, even when science and mathematics content are described together, they differ in the specificity and focus. In the segment below, which involves science and mathematics, it can be seen that the science quotations are directed at the specific project, while the math encompasses both a general level and a project-specific level.

Miller: So there’s bacteria growing in there?

Smith: No, they’re not growing yet. We just collected samples today.

And they’re sealed. So the bacteria will grow and you will see
little blobs, kind of like boogery droplets, basically. Like that, right there. And so you’ll see all these different colonies growing, and so that’s where we’re going to look at colony morphology, and we’ll get some fungus growing on here, too. And, so we’re studying decomposition. We went out and samples - took samples from places where we see things decomposing, like leaf litter. And so, we can’t let them grow indefinitely. We can’t, because eventually this nutrient auger will run out.

Miller: So that tape, that’s on there

Smith: This right here is the label. And then this is parafilm. This just seals it so the kids can’t open it, because the auger will dry out and become hard. So that’s it. And so, could they measure these and calculate volume?

Miller: Yeah, they could find the volume of that.

Smith: How do they do it? How do they measure volume of this? Length times width times height?

Miller: Well, if it was a rectangle. Since it has a circular base, they have to find the area of the base, and then multiply times the height.

Smith: Ok, so since it has a circular base,

Miller: They need to know the area of a circle
Smith: It has something to do with pi, doesn’t it? 3.14.

Miller: Pi r squared would be the area, which we call the big B. Because it’s not just the base. It’s the area of the base. And then you take the area of the base, and then you multiply it by how tall. Because what I teach them is you have to cover the bottom, and then you go up. So find the area of the bottom, and then

Smith: And then how high. So they can just take my rulers, and find what the radius is, because it’s half of the diameter, right. And then they do, so pi r squared is the area of the base, and then they can multiply it by the height. And then that’s the volume of the cylinder. Well, heck yeah, we can do that.

In the above excerpt, Ms. Smith is describing bacterial growth in terms of how they will look in the petri dishes. She mentions the “boogery droplets,” the nutrient auger, and the parafilm, all specific to the activity. She asks Ms. Miller about finding the volume of the dish. Ms. Miller answers, not simply in terms of the dish in front of them, but compares the circular base to a rectangle, gives the formula, explains big B and its purpose, and then continues on to finding the volume of the dish. She does this in a way that Ms. Smith can pick up from where she left off and describe what students can do in her class.

Finally, what students can do, or what they should be able to do, seems to enter the conversation during discussion of math content, not science content. For example, during the segment above, Ms. Smith describes what the class is doing in science, and what they expect
to happen, but there is no mention of what students can do or cannot do in science. In the part where they discuss how to find the volume, however, both Ms. Miller mentions how she teaches the concept to students, and Ms. Smith echoes back what they (the students specifically) can do, instead of a general understanding of the problem.

**Discussing projects and activities.** Quotations involving projects and activities were sub coded as either *mention/describe existing activity*, *suggest possible activity*, *details for activity*, or *reflect on activity*. These codes did not necessarily follow an order during co-planning sessions, but the *details for activity* code was used most often.

Existing activities (i.e., those that the teachers had planned to use in their classes prior to this intervention) were sometimes mentioned as a part of a description of upcoming or existing content. These were then discussed in more detail in order to look for connections and ways to engage students in both content areas. For example, in the excerpt below, as a part of describing upcoming topics in mathematics, Ms. Miller described the Pythagorean project that she intended to give to her class. Then, Ms. Smith suggested an idea for a connection between the existing project and the content that she was teaching in her class.

**Miller:** We’re finishing - well, we’re going to do Pythagorean Theorem tomorrow. I’m going to give them a big project that I want them to do.

**Smith:** Ok.

**Miller:** So I’m going to give that to them on Monday.

**Smith:** Pythagorean Theorem, so what is that? A squared plus 2ab -
Miller: a squared plus b squared equals c squared. And they’re going to make a Pythagorean Spiral.

Smith: Oh, ok. So how do they do that?

Miller: They start with 1, and they draw another triangle off of it, and then they have to keep doing it.

Smith: Do you have an example of that?

Miller: I can find one somewhere.

Smith: You know what would be cool, if they could shade it in, based on the chunks of time, like once they make it, and then they say if this represents earth history, what percentage of your spiral would be eaten up with the Precambrian, and the [Paleozoic].

This excerpt was followed by a detailed discussion of how the science connection would look to students, and the best way to give directions to students. This began with Ms. Smith asking questions about the directions for students, and looking for ways to insert science directions into the original document. In doing so, she described the science content, and both teachers discussed phrasing instructions and a timeline. This details for activity part of the discussion was much lengthier than the mention/describe existing activity, suggest possible activity above.

Every co-planning session contained segments in which details for specific projects or activities were discussed. This set of quotations was generally longer and more student focused than any other set of quotations. Often the relationship to students was that the
teachers were thinking of what students should know or be able to do, or how to make the project or concepts more accessible to students. For example, Ms. Smith said regarding the microbe clock, “So what they’re going to be doing, they’re going to be working in groups. I can give them this table, and I can tell them they need to fill in the table. This is the time, and someone’s going to have to be watching, because there’s no way to pause that. They can record numbers as they’re going, and then plot that and it will show exponential growth.” In this quotation, Ms. Smith described possible student directions to Ms. Miller in search of feedback about content and connections, but more about whether the students will be able to complete the tasks that she is setting forth, and what other directions or accommodations she should consider.

Discussion about some activities provided an avenue to discuss common or differing vocabulary terms. For example, in the following excerpt, Ms. Smith and Ms. Miller discussed questions for the bacteria colony activity.

Smith: So, let me ask you, if we had 2 bacterial colonies to trace, let’s say we had colony, colony, colony. And let’s say we had this one. Two different colonies. Let’s say we tried to overlay one. What kind of math questions would I ask them? If these are the two plates of bacteria that they are comparing, How do I relate this?

Miller: How are - ok, when we trace it in the circles, are they measurable, or are they so tiny that you can’t measure them?

Smith: Yes. I’ve got - they will be measuring in millimeters.
Miller: So one is are they congruent or similar. And if they are similar, they would have to prove that they are similar. Now we aren’t doing circles, but the circles are similar because they’re the same shape. So if it was a true - if it was a real circular looking circle as opposed to a squishy looking - you know what I mean.

Smith: Mathematically, it may not be an exact circle.

The mathematical terms *congruent* and *similar* were discussed in the context of the activity, with Ms. Miller providing a concrete and clear question and response to clarify the meaning of each term.

As mentioned above, the final sub code for discussion of larger activities and projects is teacher reflection on activities that had been implemented in their classes. Although the teachers obviously implemented more than what they discussed during regular co-planning sessions, they generally only reflected on activities that were discussed or planned during co-planning sessions.

When the teachers reflected on the activities, it was often in general and non-descriptive terms, except for if they found new connections that they wanted to explain to each other. For example, when asked about the M&M lab, Ms. Smith said, “It went really well. Yeah, they did a good job. They graphed it, and again, it was nonlinear. I just told them what kind of shape was this.” On the other hand, she used much more detail to describe the connections that her class pursued when exploring Gapminder, as evidenced in her reflection below.
Yeah. They were really into Gapminder. They wanted to know what happened in China, when China dipped down. And so I was like, when you have data points, what do you call - an outlier, right? So we did that for China today, with my first period class. Because you know, the trend for all those countries life expectancy - it was per capita income and life expectancy for all those different countries. And the trend was that they were all moving up. But China was all over the place, because they had all these dynasties. So we actually watched China, and China went backwards, and it stayed low, and then it took a dip. And then we went back and we researched it. So we researched it, so we actually linked it to social studies, too.

In the above excerpt, Ms. Smith recounted details of her lesson, which included an introduction to the Gapminder website (just prior to giving students the Gapminder project). This longer description, compared to the 1-line confirmation of the M&M activity, may be because Ms. Smith found new connections with her students that she had not previously discussed with Ms. Miller, and because these new connections provided excitement and engagement for both herself and her students.

Because of the multifaceted nature of discussion of activities and projects, activities were often mentioned across co-planning sessions, often as an idea that was developed in one session, then elaborated or reflected on during another session. Table 5 (above) shows that all co-planned activities that were implemented were discussed during two sessions, with the exception of the bacteria growth lab, which was discussed during 3 sessions.
Discussing students. Students were continually a focus for Ms. Smith and Ms. Miller during their co-planning sessions. Content was often discussed in terms of student understanding and skill level, and what students should or should not know. Projects and activities were often discussed in terms of student accessibility, from directions to content questions, and reflections often focused on student reactions to particular events.

While a few of these quotations involve particular students, or student likes and dislikes, most were about student ability. Both teachers often reminded each other that their students do not perform as well academically as students at other schools. Several times, they made blanket statements regarding students. For example, during a discussion about volume, Ms. Smith asked Ms. Miller if the students should be able to answer a particular question type involving multiple parts. Ms. Miller gave her an inquisitive look, and Ms. Smith answered her own question, “No, they can’t do fancy. They can’t do plain. They struggle with everything. That’s a stupid question. I get that.” This type of comment may have served to ground the plans that the teachers took in reality, but it also served to limit the scope of connections and experiences that the teachers were willing to provide for their students.

Other statements regarding student ability were more reflective of current or past actions in the classroom. For example, as Ms. Miller described her timeline (current topics and upcoming topics), she commented about her students’ achievement for the current topic by comparing it to a topic that had been difficult for students earlier in the year. She said, “And it’s funny how we’re doing geometry, but it’s still involves equations, and they’re like, oh, this is easy. And I’m like you all gave me the blues when we did this before.” In this quotation, even though she described what her students were currently able to do, it was in
terms of their previous underachievement with similar skills. Ms. Smith followed up on this quotation by asking specific questions about what students could do, and with which skills they still had difficulty. Although the quotation shows a negative view of student achievement, it was useful in the context of co-planning to open a discussion of how Ms. Smith might support students in her class to continue to work on difficult skills.

When a specific student was mentioned, it was usually to illustrate a point. For example, when talking about students drawing connections, Ms. Smith said, “One kid had trouble recalling information in my room. He’s normally over there. I was like, if you were in her room, you probably would have remembered it. You’ve got to learn to take what you’re learning in one room, and not just think about it in that one room.” This reflects Ms. Smith’s observation that students are not accustomed to interdisciplinary thinking, and her commitment to continue to provide interdisciplinary experiences for her students. Although infrequent, this type of statement usually tied in to planning for or reflecting on a particular activity, and discussing student accessibility. For example, following the comment above, the teachers discussed specific things they could say to their students during teaching to remind them that they would need to carry particular concepts over into the other class.

Overall, Ms. Miller and Ms. Smith each integrated co-planning into their individual planning routines, and not only talked during regularly scheduled sessions, but developed and expanded on ideas in between sessions as well. During sessions, they mostly discussed content, activities, and students, all of which contributed in unique ways to the development of the plans in the prior section. In the next section, the teachers’ beliefs will be discussed,
both how they influenced and how they were influenced by participating in the co-planning intervention.

**Beliefs and the Co-planning Process for Miller and Smith**

Both the co-planning process and the plans that Ms. Miller and Ms. Smith made were influenced by their beliefs about science and mathematics, about teaching and learning, and about interdisciplinary connections. In turn, some of these beliefs were greatly influenced by the discussions and planning that the teachers experienced as a result of participating in the co-planning intervention. The beliefs discussed in this section are based on the beliefs expressed by each teacher during individual interviews. Beliefs that were expressed during whole group sessions and co-planning sessions were also taken into account in order to verify and triangulate whenever possible. Beliefs in each of the three areas (about the nature of mathematics and science, about the nature of teaching and learning, and about interdisciplinary connections) are discussed separately below.

**Beliefs about math and science.** Ms. Miller and Ms. Smith both began the intervention with strong beliefs about their own subject as being applicable to students and their understanding of the world. Because of their beliefs that the purpose of each subject was application to the student, statements regarding their beliefs about mathematics and science were couched in statements regarding teaching and student learning. Ms. Miller stated, “What is math? Everything. Understanding numbers and how they work in real life. Not just computation, but I try to get [students] to see math in everyday life. So that’s what I try to teach them, that it’s not just pencil and paper and this test, but you can actually apply it to your life.” Similarly, Ms. Smith offered that “Science is skill - like lots of different skills for
investigating the world, asking questions about the world, and a way of understanding the world.” Ms. Smith expanded on this idea when discussing experiments. “There are some experiments - like when we do chemistry experiments, so they can see or experience something that’s otherwise hard for them to imagine.” In planning, both teachers acted on this belief by intentionally creating activities and examples for students to apply their learning. This may have been one of the contributing reasons why Ms. Miller and Ms. Smith planned and implemented several larger activities with their classes.

As the teachers progressed through the intervention, and co-planned more activities and connections to use with their students, these beliefs about the applicability of their own subject changed relatively little. Ms. Miller still included “how you use it in daily life” in her definition of math during her final interview, and Ms. Smith still stated that science is “exploring the natural world. It’s asking questions, and figuring out why things happen the way they do.” It is not surprising that these beliefs did not appear to change, since the co-planning experience and the discussions with each other that the teachers had reinforced their beliefs and did not contradict them.

Regarding the subject that each did not teach, the teachers initially appeared to be much less confident in their explanations of their beliefs about the nature of the subject. Of mathematics Ms. Smith said, “Mathematics is the application of… I don’t know. Numbers.” She continued on to say that math is very broad and involves data collection, equations, formulas, functions, and “other things.” Ms. Miller’s beliefs about science were equally unsure. She explained that science is, “Well, I don’t know. Well, I know, but I don’t know how to word it. I guess, I don’t know what a correct answer would be. Study of life, I guess?”
While this lack of knowledge of each other’s subject seems like it could have limited the co-planning process, it actually seemed to have the opposite effect. Since the teachers had already been co-planning as a result of participating in the pilot study, they had already formed the social trust needed to ask each other to explain concepts as needed. Thus, as vocabulary and concepts came up which one teacher or the other did not understand, they often asked for clarification until they felt comfortable with the content.

By the end of the intervention, it was apparent that each teacher had learned more about the others’ subject, and while they were still tentative in their descriptions of the nature of the subject, they were more willing to give more examples. Ms. Miller said about science, “I don’t know officially, but the study of things. I know they do different parts of science, like earth science, and physical science, so I guess the way things work, and those type of things.” Ms. Smith made a similar statement about mathematics, “Math is using numbers, angles, or measurements to explain the world, or explain things that they come across. Explain how fast something moves, or explain the angle that the shadow is coming off of a tree.” In these later explanations, each teacher still declared that they were not the expert on the subject, but they gave grade-appropriate examples of how the subject applies to life and to the world, which aligns with their partner’s belief about their own subject. It appears through co-planning, each teacher not only further developed beliefs and knowledge about the opposite subject, but formed them in a way consistent with their own and their partner’s beliefs about the subject.

Participation in the intervention seemed to inform changes in both teachers’ knowledge and beliefs in specific aspects of each subject as well. For example, during one
co-planning session, Ms. Smith remarked that prior to this experience, “I was just like what are they talking about lines, and x’s and y’s. That [what we are doing now] makes sense to me.” As another example, Ms. Miller’s description of experiments during her final interview seemed to include more flexibility. “In math, things weren’t just written on a piece of paper and someone said here is the way it is. People had to prove it. And in science you have to do the same thing. People have to study and experiment and see what works.”

Ms. Miller and Ms. Smith’s beliefs about mathematics and science seemed to inform the co-planning process and the type of plans that they made. They also seemed to inform each other’s perception of the opposite subject, and through content-focused discussions, helped to influence each other’s beliefs in a positive way.

**Beliefs about teaching and learning.** Both Ms. Smith and Ms. Miller clearly and consistently communicated differences between their beliefs about teaching and learning, and those that they perceived from their administration. These differences ranged from use of resources for planning to collaboration and the actual content that they taught in their classes.

Regarding planning resources, the teachers expressed that the administration expected them to follow the county pacing guide for the timing and order of topics, and the state standards documents for the scope of topics that they teach in their classes. Ms. Miller and Ms. Smith seemed to value the use of the standards documents, and reported relying on them for information both before and after the intervention. In fact, as the intervention progressed, both teachers expressed that they began to look up concepts from each other’s standards documents as well. Ms. Smith said, “There have been one or two times that I actually looked up some math curriculum standards. Which I have never done before.” The teachers’ reliance
on state standards documents actually increased, not because of a blind desire to follow the
documents, but because of a true need to use the documents as a resource to understand
which concepts were relevant and timely for the students. This type of action demonstrates
Ms. Smith’s reliance on the state standards, not only for her own class, but also to include
concepts from the other class.

In contrast, the teachers reported that they did not use district pacing guides as they
were directed by their administration. Both teachers reported during initial interviews that
they often rearrange topics from the pacing guides based perceived on student needs. The
teachers reported that they preferred their own order for various reasons, rather than worrying
about student scores on district benchmark tests. The experience of interdisciplinary co-
planning seemed to strengthen this resolve. Speaking about her plans for the following year,
Ms. Miller said, “I started pulling the science standards. So then I know I can move - I
definitely will move and do all of my data with my linear stuff, instead of leaving it until the
end, so that would be a whole thing.”

Regarding collaboration, Ms. Miller and Ms. Smith both reported planning closely
and regularly with their same-subject colleague in determining the order and depth of topics
for their respective classes. However, both complained frequently about mandatory PLC
meetings during which they analyze school and district level standardized test data, for which
they saw no use. Both teachers commented at different times that it would be nice if they
could replace PLC meetings with ICT sessions, because they were more useful and
informative for their teaching. This demonstrates not only a sense of dissatisfaction with
administrative procedures, but the pragmatic nature of the teachers, who want to spend their time accomplishing tasks that seem useful to their ultimate goal of teaching students.

Regarding the actual content that they taught, obviously Ms. Miller and Ms. Smith both had permission from the administration to participate in interdisciplinary co-planning, with the assumption that they would be implementing interdisciplinary lessons in their classes. However, they often expressed dissatisfaction with their principal’s understanding of what it means to teach science and math in the classroom. For example, Ms. Smith commented during one co-planning session, “We were calculating how old these rocks are. That’s how old the earth is. And they’re - none of them have any idea. But anyway, so we were doing all that when we were solving it. And Mr. [Principal] was like, ‘she can’t teach math. She’s a science teacher.’ Stay in administration. Stay out of curriculum, please.” Even though she knew he meant his comment as a joke, she took it as an insult because of the time and effort that she had put in to creating interdisciplinary lessons.

Since both teachers expressed differences between their desire to educate students in the ways that they valued and understood and their administration’s desire to examine and raise test scores, they tended to categorize their duties as either a self-imposed part of good teaching or as one more administrator-imposed thing to do. Throughout the intervention, consistent with their reported beliefs about mathematics and science, both Ms. Miller and Ms. Smith consistently expressed that a major goal of teaching for each of them is to create opportunities for their students to experience and engage with concepts in their respective subjects. During one co-planning session, Ms. Smith said, “The children that have the most difficult time have the least amount of experience in life. Because if they’re - when we make
connections, a lot of the things that should make sense to them, that unless you talk to them and help them make the connections, it’s amazing how much developmental stuff happens in this age range.” This desire to help students make developmental connections, which seemed to grow over the course of the intervention as they noticed more connections, appears to be the driving force behind most of Ms. Smith and Ms. Miller’s decisions about the details of lesson planning.

Although both teachers strived to create learning experiences for their students, their preferred methods differed, and in particular for Ms. Miller, routines seemed to change along with their beliefs about teaching and learning over the course of the intervention. Initially, Ms. Miller followed a more traditional class routine, in which students come in and complete a warm-up, a “10 minute lesson,” and practice questions. Ms. Smith used a more student-centered routine in her science teaching, and expressed an interested in students seeing “the big picture.” Ms. Smith stated that her daily routine is “nothing typical,” meaning that the look of a lesson may change dramatically from one day to the next. She also believed that students appreciate this variety in her class. Ms. Smith further explained that she followed a 5E lesson format (engage, explore, explain, elaborate, evaluate), and that after an initial short recall or review, “it just depends on where we are in my 5E.”

Both Ms. Miller and Ms. Smith expressed a belief that a part of their responsibility in teaching is to create experiences for students that would help them connect their knowledge to the outside world. This seems to stem directly from each teacher’s understanding of their own subject, and what they believe their students should learn about the subject. For example, Ms. Smith said during her initial interview, “Some activities, it’s just to give them
exposure to a concept. Like, when we go outside, pointing things out to them, you’re giving them kind of some mental connections that they can kind of refer back to, you know, if we do something with microscopes, to show them things they can’t otherwise see in a textbook.”

Later, she added, “I love doing experiments because kids in science, they end up feeling like science - they tell me all the time, they’re like I get science. And I’m like you get it because you can apply it to something you’ve done, or an experience you’ve had.” Over time, Ms. Miller began to incorporate more activity in her lessons, possibly as a result of co-planning with Ms. Smith. During a co-planning session, she said, “Lately I’ve been doing a lot more group work.” She later said, “I add real-life problems that I think the kids enjoy. I try to do hands-on stuff,” and added that it is “not just computation, but I try to get them to see math in everyday life. So that’s what I try to teach them, that it’s not just pencil and paper and this test, but you can actually apply it to your life.” These examples provide evidence for the shifts in Ms. Miller’s beliefs about the nature of teaching and learning, that it can be a hands-on experience in order to create opportunities for students to experience academic concepts. This shift seems to have come directly from working closely with Ms. Smith, and from sharing in the learning experiences that she routinely provided for her students.

However, for both teachers, their new focus was on interdisciplinary connections. Ms. Smith reflected, “Recently, there’s been a lot more discussion with M, about well, that’s now on my mindset. Outside of just doing my regular planning, you know, that’s become a bit of a habit now to think how does that relate to math.” Ms. Miller related the excitement she felt about future co-planning with another science teacher during her final interview, “We’ve already started talking about - me and Ms. Roberts have already started talking about how
we’ve been doing projects that we could incorporate together, and even trying to see if we can get our schedule back to the way it used to be, so they will leave me and go to science, or leave science and go to math. So that when we don’t finish something, we can say take this part and take it to your science, or take this part and take it to your math class. So we’re thinking a lot about how it’s connected, and how we can make it work.”

Both teachers shared how they incorporated interdisciplinary connections in their classrooms on a regular basis, and reflected that their teaching was more effective because of it. As an example of the review that she has been doing in her class, Ms. Miller reflected:

We did functions the last couple of weeks, and I know one of them, it was a station where they had - I gave them the equation but I wrote it as a word problem, and it was like this bacteria is growing in this freezer, and the freezer is this temperature, so we kind of related and talked about different variables, so I kind of squeezed in what could affect the bacteria growing, and I was like, so that is what in math, the slope.

This connection was not something that was specifically discussed ahead of time during a co-planning session, but came out of Ms. Miller’s knowledge about the science topics that Ms. Smith’s classes were learning. This reflects a focus on interdisciplinary connections that extended beyond discussions during co-planning sessions and into many aspects of Ms. Miller’s lessons.

As another example, Ms. Miller said that when students struggle:

I come up with a different strategy sometimes, if possible. Maybe a different example, or model. Whatever the case may be. And now, I think of, how can I
connect it to science. I definitely use that as a way to reteach some things, or introduce it or make it relevant to them.

This reflects a difference in the way Ms. Miller approaches teaching, and by extension reviewing, in her classes from the beginning of the intervention when she said that she would simply reteach concepts or have videos available for review.

Ms. Miller now looks to connections to create experiences for her students. “I think the kids see a connection more.” She added, “Even though I think it’s more advanced for them to make that connection, they’re still willing to do that, and not just give me anything. So I think they’re putting a lot more effort into it. They were willing to venture out and try something different.” About particular projects, she said, “And the Gapminder thing. So like I said, even with the scatterplot project, they were like, we want to look at the Gapminder, so they were willing to venture out and try something different.” She stated, “I think they’re getting there. It’s small and slow, but most of them are.” During her final interview, she said:

I guess thinking about it from a science perspective, I could probably approach them understanding the why part more. So proving things, collecting data. I probably could do a lot more experiments. Or, more hands on stuff to make the connection better.

This reflects a major shift in thinking about what the act of teaching looks like in her class. As a result of co-planning with Ms. Smith, who relies on activities to provide experiences for her students, Ms. Miller was beginning to see experiments as a valuable part of teaching.

Several times during co-planning, either teacher expressed surprise about what students were capable of doing. Ms. Smith would say, “Our 8th grade math students are doing
this?” During a co-planning session, Ms. Miller remarked, “They already knew the correlation, I didn’t even really have to teach that. So now it’s just getting them to say here’s that line again, and now we got to find the equation of that line.” And, during her final interview, Ms. Smith said about a review that her students had just completed:

I’m like what kind of line did we draw on our cheat sheet, and they’re like hypotenuse. That kind of thing didn’t happen for me before this. But now it’s just because of the varying casual conversation that Ms. Miller and I just strike up now, we’re like, what are you doing, that sticks in my head and it allows for those kind of scenarios to happen more often.

The above examples demonstrate instances in which both Ms. Miller and Ms. Smith recognized the value of creating interdisciplinary for their students, and that when they allow students to think more deeply, the students often rise to the occasion.

The biggest worry about co-planning that both Ms. Miller and Ms. Smith had at the beginning of the intervention was about the time it would take, particularly with Ms. Miller teaching an extra class. During the last whole group session, Ms. Miller noted, “but I guess, we always talk about time. When am I going to have the time. But then we’re always thinking of it as everything is a time issue, because we’re just adding it on.” Ms. Smith also discussed the need to be intentional during the entire co-planning process, especially when the other subject is less comfortable for her. Regarding connections in English and Social Studies, she said, “So it’s easier, those two content areas just more naturally flow for somebody without a math background. So it just kind of happens. Whereas math had to be more deliberate for me.”
Both teachers alluded in their discussion of time to the mindset shift that seems to have occurred for them from treating co-planning and the inclusion of interdisciplinary connections as an extra thing to do to a part of their normal schedule. Ms. Miller found that now that it is a “part of what I do,” she is more likely not to neglect it because it is already structured in. “I find myself when I shifted thinking - ok, I’m not just adding. This is a part of it, then it comes easier. So, not thinking of it as just another thing like AM, or something else added, but make it a part of what you’re doing, then it becomes a little bit easier.” She repeated about her experience:

Not just thinking of it as something extra, but this is a part of what I do now. So that mindset has definitely changed. I think that’s the biggest part of it. When I went to Ms. Smith at first, it was like what can I do extra, but now this is what I’m going to do.

While Ms. Smith did not completely change her mindset, she made similar comments, that when connections are structured into the lesson, they get done, and when they are treated as something that is added on, it is too easy to push it out when time begins to get short. To overcome this, Ms. Smith advocated more time working together, especially over the summer, to create interdisciplinary lessons.

Overall, Ms. Miller and Ms. Smith’s beliefs about teaching and learning did not change regarding their commitment to providing quality learning experiences for their students, although it seemed that Ms. Miller changed her classroom routine to include more activity as a result of co-planning with Ms. Smith. In the use of resources and all other regards, the teachers seemed to value their ideas for teaching over administrative
expectations, and divided their work into things that are important for student learning and extra things that can be added on. For them, co-planning became a necessary part of what they do, and not an extra thing that has been added on.

**Beliefs about interdisciplinary connections.** Ms. Smith and Ms. Miller both viewed the link between mathematics and science as understanding relationships. When asked to define science during her initial interview, Ms. Miller stated, “to gather information and data, and to understand the relationships. So I guess math and science are connected in that way. Understanding relationships.” She added during a reflection that teaching math and science is similar because “The focus isn't just on getting them to grow on a particular set of skills. It is similar because we focus on how to get the students involved in the material and how to make them care about the skills that are being taught.”

Both teachers reported that before the pilot study, they had not intentionally created interdisciplinary lessons for students. Interdepartmental team planning was reserved for discussion about particular student needs or behavior, not academic or content planning. During her initial interview, Ms. Miller stated, “I think we all try to, you know, do cross curricular things. At least once or twice we were doing it last year.” She continued, “This year, [during the pilot study] I’m trying to figure out how to apply - even if it’s just an example that I give. I try to work it in. I’m not an expert, but I do try to fit it in.” By the final interview, Ms. Smith thought of the teams as more of a space where academic collaboration could take place. “I’m thinking about math a lot more. We tend to be like little mini college professors. We’re very much into just our content. But here, much more math oriented. You
know, at least aware.” She said, “The focus has widened, I guess. Broadened.” She actually went further to state her ideal:

I think in a good building that supports that kind of connectedness, I think that could be more purposeful. It could be part of the overall expectation, just everything - it’s not that, you have your science class, math class, social studies, but you almost want it to be that information is flowing between all four areas. You know, and so just because you’re learning math in here doesn’t mean that you’re not going to hear about it in there. It almost has to be a school atmosphere thing.

While Ms. Smith began the intervention expressing a value in creating interdisciplinary connections, this statement reveals that throughout the intervention, she attributed much more value to the connections that she made with her students, and that she wishes to expand these connections.

The teachers also showed growth in their understanding of what interdisciplinary connections exist, and how they could look for their students. During initial interviews, responses about possible connections echoes their recent pilot study experience, but were otherwise vague. For example, in answering a question about possible connections, Ms. Smith stated, “Lots of ways. A lot of the data that we collect in science requires some analysis. So whenever students collect data over a certain period of time, and then they graph their data, they can kind of see relationships.” During an early reflection, Ms. Miller stated that she recognized the difference between the interdisciplinary connections they were currently making, and what she considered interdisciplinary in the past:
From this experience I do not think I can say that I tried to make them interdisciplinary [in the past]. I mostly used other content to maybe introduce a topic or give an example, or provide some relevance for the topic. Now I think more in depth about the actual content that the students might be learning in other classes and try to make a connection.

Ms. Miller later reflected that “that this experience continues to open my eyes even wider about how the two contents are related. It is exciting to find ways to connect, like with congruence and similarity.” These statements provide evidence that Ms. Miller grew in her appreciation for what constitutes an interdisciplinary connection, and that she has learned to look for conceptual connections for her students above other connections that she may have made in the past that were more surface or cursory in nature.

In addition to her original ideas about analyzing data being the connection point between science and math, Ms. Smith later reflected on the usefulness of websites that they used such as Gapminder.org, which she used to connect science and math, “And then we went back and we researched it. We actually linked it to social studies, too.” During her final interview, she referred to two students within view to illustrate her point that science and math can connect through many vehicles. She said, “I’m thinking of these kids right now that are in the maker space. They’ve got to use tools. They’ve got to know how to measure things. Looking at angles.” During Ms. Miller’s final interview, she described another experience.

We did functions the last couple of weeks. I gave them the equation but I wrote it as a word problem, and it was like this bacteria is growing in this freezer, and the freezer is this temperature, so we kind of related and talked about different variables, so I
kind of squeezed in what could affect the bacteria growing. I said, so that is what in math, is the slope.

Experiences such as these demonstrate that Ms. Miller recognized and implemented connections with her students differently than she had in the past. She attributed her ability to draw these connections as she needed it to an understanding of what her students were learning in their science class, through regular interdisciplinary co-planning discussions.

Both teachers also saw a value for themselves as teachers, and for their students in making connections throughout the intervention. Ms. Miller said, “It helps me, I think, to be a better math teacher. It helps answer that question of when will I ever use this again.” She also commented, “I definitely think it’s successful, because the kids are able to communicate in both of our classes about what they learn.” Ms. Smith said, “I think it makes it a lot more relevant for kids.” She reflected:

I don’t know if they’re thinking about science more often, but they’re definitely thinking about math more often because I’m able to talk about it. And I’m only able to talk about it because I knew what Ms. Miller is doing in her class.

All of these statements provide examples the value that the teachers attributed students drawing conceptual connections. Specifically, Ms. Smith drew on her experiences to explain that her students were learning more of both subjects in her classes.

Ms. Miller reflected that “It is exciting to find ways they connect,” and Ms. Smith frequently expressed excitement about the connections that were revealed over the course of co-planning. She said, “See, I get goose bumps when I try to find little things that they can do. I just want to look at one and see if it is something they can do.” Throughout the
intervention, Ms. Smith looked to connections to help struggling students. She commented about connections during their discussion, “That’ll at least give them another connection in their brain to what this is, if they’re struggling with that.” Ms. Miller commented during her final interview about student understanding: “I think the kids see a connection more,” and about student engagement: “I think they pay a lot more attention.” She said, “even though I think it’s more advanced for them to make that connection, they’re still willing to do that, and not just give me anything. So I think they’re putting a lot more effort into it.” She was impressed that “they were willing to venture out and try something different.” She stated that not only was there value for students, but also, “to push us as teachers, because sometimes, we get comfortable doing just our own thing,” noting that it is common for students and teachers to become complacent, and that the introduction of exciting new connections helps both the student and teacher in this regard.

The focus of interdisciplinary connections also shifted from a reliance on big projects only to the inclusion of connections in many smaller ways. During her final interview, Ms. Miller noted that she realized while big projects are worthwhile, they are often cumbersome and do not get accomplished, but regular reinforcement can easily become a part of the daily routine. “So bringing up little things like that, it helps them remember.” As co-planning sessions progressed, Ms. Smith and Ms. Miller both found more frequent subtle ways to remind students about connections each day in their classrooms, as a supplement to the projects and activities that they were already doing. For example, in a later reflection, Ms. Smith wrote, “For incorporating the math content into science, often times I simply add an additional activity/lesson at the end of my science lesson.” As a more specific example, Ms.
Miller reflected, “This week I incorporated some examples of bacteria growing in equation form to get students to see the relevance of slope and y-intercept and how it is related to real life scenarios.” These examples provide evidence that the teachers began to incorporate smaller connections into their daily thinking, which enhanced the larger projects that they were able to complete with their classes.

Overall, both Ms. Miller and Ms. Smith began the intervention with a belief in the value of interdisciplinary co-planning, but vague ideas of how to connect the subjects. As the teachers continued discussion of content through interdisciplinary co-planning, they found many connections, which alerted them to the different kinds of connections that they could make. As they implemented these connections, they realized a greater value in making them, thus propelling their desire to make and implement more connections with their students, and increasing their knowledge of the types of connections over time.

**Summary for the Miller and Smith Case**

Ms. Miller and Ms. Smith were a case of busy teachers who changed their busy individual planning and teaching routines to incorporate co-planning. Part of their successful inclusion of weekly co-planning sessions may be because of the value that they attributed to interdisciplinary co-planning as a result of participating in the pilot study the semester prior to this intervention.

The teachers created several larger activities as well as smaller connections, which they implemented in their classes. They incorporated the co-planning process into their individual planning routines, and continued co-planning outside of regularly scheduled sessions. They came to co-planning sessions prepared with a timeline and potential activities
and topics that they were already planning to implement in their classes. They discussed content, activities, and students in an attempt to refine these plans. Their beliefs about the nature of mathematics and science, the nature of teaching and learning, and about interdisciplinary connections influenced and were influenced by their co-planning sessions. The largest shift in beliefs was in the area of teaching and learning, and thinking of interdisciplinary co-planning as a part of what we do every day instead of an extra thing that was added on to an already busy schedule.

Both Ms. Smith and Ms. Miller communicated that co-planning was overall successful and meaningful for them, and that they planned to continue to co-plan during the next school year. Ms. Smith said, “It opened up communication with us.” Because Ms. Smith was moving at the end of the school year, Ms. Miller was already looking to the other science teacher for collaboration the following year. “Ms. Roberts and I have already started talking about how we’ve been doing projects that we could incorporate together.” She added “I think we’ll know what we’re doing a little bit better.” Ms. Smith said, “Now, if you want me to talk about how I am going to do it next year, I’m teaching 6th grade science with a gifted inclusion group, and it’s mostly physics. And so 100% I’m going to be tracking down their math teachers and finding out what they’re learning in math in 6th grade.”

Jones and Williams: A Case of Resolving Misconceptions about Mathematics and Science

Often, teachers can have large misconceptions about each other’s subjects, even if they have a good understanding of their own subject. While all of the teachers that participated in this study exhibited some degree of discomfort with the opposite subject, Ms.
Williams exhibited a fear of mathematics to a much larger degree. Both teachers in this case mentioned throughout the intervention that they were beginning teachers with much less knowledge than their colleagues, but what they lacked in experience they seemed to make up for in eagerness to learn and to create opportunities for their students to learn. Over the course of co-planning with Mr. Jones, Ms. Williams’s fear softened, and she came to understand math as more of a useful tool than a torture device. In turn, Mr. Jones came to recognize science as an evolving method of discovery instead of a rigid set of facts and procedures. For Mr. Jones and Ms. Williams, by the end of the intervention, both teachers had grown in their understanding of both subjects through collaboration with each other.

**Background**

Mr. Jones was a first-year math teacher, and Ms. Williams was a second-year science teacher, both at ECHS. Mr. Jones taught Math 1 and Math 2 at ECHS. He double majored in mathematics and mathematics education, both student teaching and graduating in the neighboring county. Ms. Williams taught ninth grade Physical Science for the first time during the intervention. Prior to the current semester, she taught 3 semesters of Earth and Environmental Science, one at ECHS, and the previous two at another high school. Ms. Williams frequently mentioned that since this was her first time teaching Physical Science, and since Physical Science is more “math” and “skills based” than Earth and Environmental Science, she was not yet familiar or comfortable with the course content.

Math 1 and Math 2 are both taught as 90 minute, year-long courses at ECHS. While Math 1 is intended for 9th grade students and Math 2 is intended for 10th grade students, each of Mr. Jones’s classes had students who are in either higher or lower grades, depending
on their individual situations. During the intervention, Mr. Jones taught both sections of Math 1 that were offered at ECHS, and one of the two sections of Math 2. Physical Science is a 90-minute, semester-long course at ECHS that all 9th grade students are required to take during the spring semester. Ms. Williams taught all three sections of Physical Science offered at ECHS during the intervention. Mr. Jones and Ms. Williams estimated that about 80% of the students in Physical Science were also in Math 1 during the intervention, and thus focused on Math 1 during co-planning discussions.

ECHS was housed in two buildings because of its position on a community college campus. Mr. Jones and Ms. Williams were located in separate buildings, and had different planning periods, but they shared a daily common lunch time, which they used for their regularly weekly co-planning sessions. On days in which there was no co-planning session scheduled, both teachers still ate lunch in the same time and place, and reported that they mostly conversed with each other and the other teachers in the lunch room.

Although this intervention was Mr. Jones and Ms. Williams’s first time co-planning together, both teachers had previous experiences collaborating with other teachers. As a part of his student teaching, Mr. Jones co-taught and co-planned with his clinical teacher. Mr. Jones’s experience was different than the ICT experience because he worked with a mentor teacher of the same subject to teach one group of students. Ms. Williams co-taught a course entitled World Dynamics at her prior school. The World Dynamics course blended the history, English, and science into one comprehensive course for students. This experience, although interdisciplinary, was also different from the ICT experience because ICT experience in this study did not include a co-teaching aspect.
To present this case I will first share the nature of the content and activities that Mr. Jones and Ms. Williams planned and carried out in their classes. Next, I will report the findings with respect to the nature of the conversations that took place during the co-planning sessions that led to the planned connections and activities. Finally, I will present the findings with respect to the teachers’ beliefs – both how they influenced the co-planning process and how they shifted as a result of the experience.

Nature of the Co-planned Interdisciplinary Activities for Jones and Williams

To provide context for the findings related to the co-planning process, the findings related to the actual co-planned connections are first reported. In each of the co-planning sessions, Mr. Jones and Ms. Williams generally discussed several mathematics and science topics as well as possible activities and connections. Table 6 lists the math and science topics as well as large activities and connections that were discussed in order by co-planning session. For example, during the third co-planning session (CP3), 5 topics in mathematics were included in the discussion, and 3 topics in science. Connections were drawn between optics and angles, and between Ohm’s Law and literal equations. Time was spent discussing the connection between circuits in science and direct and indirect variation in mathematics, and the Ohm’s Law lab was developed.

Table 6. 
Jones and Williams co-planned topics and connections by planning session.

<table>
<thead>
<tr>
<th>Math topic</th>
<th>CP1</th>
<th>CP2</th>
<th>CP3</th>
<th>CP4</th>
<th>CP5</th>
<th>CP6</th>
<th>CP7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quadratic functions</td>
<td>reflected on project</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quadratic equations</td>
<td>upcoming topic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Table 6 Continued</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>exponential functions</td>
<td>past topic, M&amp;M lab</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>geometry (coordinate)</td>
<td>upcoming</td>
<td>current topic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>geometry (area/volume)</td>
<td>upcoming</td>
<td>connection with water</td>
<td>past topic</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>literal equations</td>
<td>planned w/ wavelength</td>
<td>mention past in science</td>
<td>reminder</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>trigonometric graphs</td>
<td>mention</td>
<td>connection</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>angles</td>
<td>mention past connection</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>direct and inverse variation</td>
<td>mention connection to electricity</td>
<td>reflect on connection in class</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>statistics (2 way tables)</td>
<td>upcoming topic</td>
<td>upcoming, current, past</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stats - permutations</td>
<td>connect to circuits</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stats – 1 var</td>
<td>current</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>stats – 2 var</td>
<td>upcoming</td>
<td>reflected</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>stats -sampling</td>
<td></td>
<td>past</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>piecewise</td>
<td>connection</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>slope</td>
<td>connection</td>
<td>review lab</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ratios</td>
<td>connection</td>
<td>connect</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Review topics</td>
<td>upcoming</td>
<td>upcoming</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>units</td>
<td></td>
<td>past topic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Science topic</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>kinetic energy</td>
<td>reflected</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>thermal and nuclear energy</td>
<td>upcoming topic</td>
<td>past topic, M&amp;M lab</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>waves</td>
<td>upcoming topic</td>
<td>planned</td>
<td>mention connection</td>
<td>current topic</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>electricity (Ohm's law)</td>
<td>upcoming topic</td>
<td>variation</td>
<td>past topic</td>
<td>past</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>circuits</td>
<td></td>
<td>connection</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>magnetism</td>
<td>upcoming</td>
<td>upcoming</td>
<td>past</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Over the course of the 7 co-planning sessions, Mr. Jones and Ms. Williams found many connections, which they planned and implemented with their classes. The teachers tended to discuss smaller ways to incorporate connections in their classes, such as examples
and short discussions within larger lessons. Five larger activities were also discussed, 4 of which were implemented over the course of the intervention. The teachers reported discussing and implementing these and other connections in their classes regularly because of an increased awareness of the students’ knowledge and abilities in each other’s class. The next two sections will focus first on each of the larger co-planned activities that were implemented by the teachers, and then, on the smaller connections that the teachers made throughout the intervention.

**Co-planned activities.** Mr. Jones and Ms. Williams discussed many connections between their subject areas. Although they often focused on smaller ways in which to draw connections, the teachers did discuss 5 larger activities, 4 of which they implemented in their classes. Three of the larger activities that were implemented were adapted from existing science activities. The fourth larger activity that was implemented was a plan to use the science reference tables to review equations in math class. A student worksheet was either created or modified for each of these four activities, which combined concepts from mathematics and science. The activities and labs that they teachers co-planned are described next. The complete activities that were implemented are included in Appendix P.

**The roller coaster project.** The roller coaster project was a pre-existing project that Ms. Williams had planned for her Physical Science class before the intervention began. In this project, students were instructed that they were part of a team of engineers designing a new roller coaster for Six Flags, and that they had to design and build a workable model of a roller coaster, which included several specific factors on which they would be graded. After the first large group meeting for this study, but before the first co-planning session, the
teachers noticed that Mr. Jones’s current topic, applications of quadratic functions in mathematics, overlapped in several ways with the concepts that students were learning through the roller coaster project, such as velocity and acceleration.

The teachers reported that both Mr. Jones and Ms. Williams discussed the project and answered content-related questions in their classes, and that Mr. Jones actually went into Ms. Williams’s science class during his planning period to talk to her students about the possible uses of quadratic equations in designing their roller coasters, and in solving problems involving velocity and acceleration. Students were provided with a “Calculations and Analysis” page to record and answer information about their roller coasters, and to use as a guide for the presentation of their actual roller coasters. As part of their presentations, the students had to answer questions about the velocity and acceleration of the roller coaster. Mr. Jones also helped Ms. Williams to evaluate the projects for that class, and interacted with students, asking them mathematical and scientific questions as they presented their projects.

Since the interdisciplinary reach of the project was established hastily (the project was already planned, and then the teachers added in the math content right before implementation), the teachers found through later reflection that they could have highlighted different aspects more in order for students to create further connections. They decided that when they had more foresight and time the following year, that they would revise this project before presenting it to students again. Regardless of future plans, the roller coaster lab still held a direct connection for students because the students needed to incorporate concepts that they learned from mathematics and science together to create and discuss their roller coasters. The activity was also timely because students were going to do the roller coaster
project anyway in science, and were currently learning about applications of quadratic
functions in mathematics, which was applied to the roller coasters that the students built.

The science reference tables project. In the science reference table review project,
groups of students in Mr. Jones’s math class used the reference tables from their Physical
Science class (which Mr. Jones provided) to complete various tasks. The reference tables are
a standard list of formulas that students receive in Physical Science to complete their
standardized end of course exam. The tasks included describing, manipulating and graphing
formulas, as well as using the formulas to write and answer contextual “real life” questions.
The student groups completed each task in the form of a slideshow, and then presented their
slides to the rest of the class. Mr. Jones also planned for time to discuss the various ways in
which students used the formulas during their presentations.

The science reference table project provided a concrete way for the teachers to
directly relate several of the concepts that they had been talking about throughout the
intervention. In particular, students were encouraged to think carefully about the meaning of
the science formulas to describe each of the variables in context, and to think about the
relationship between the variables for each task. Since the variables look different in the
different formulas, it provided an opportunity to discuss the differences and similarities in the
ways that scientists and mathematicians use notation.

Although the project was first suggested during the second co-planning session, it
was not implemented until the very end of the intervention, when the teachers were
reviewing for standardized tests in both classes. The timeliness of the concepts in this project
is largely irrelevant because it included a large number of topics from throughout the year as
review. However, the project could be considered timely because all science and math concepts in this project were from various times within each course that was being reviewed.

The Ohm’s Law virtual lab. The Ohm’s Law virtual lab was adapted from an activity that Ms. Williams had planned to implement in her science class. During the third co-planning session, Ms. Williams introduced Ohm’s Law \( V = IR \) and its variations (e.g., \( I = \frac{V}{R} \)) and descriptions (e.g., if voltage is held constant, current increases as resistance decreases) as separate pieces of related information. The connections between these pieces of information were discussed, as well as the use of literal equations and of direct and inverse variation to “translate” from one piece of information to another. The intent of the Ohm’s Law virtual lab worksheet was to make these connections clearer. In this lab, students manipulated sliders in an applet to determine the relationships between voltage, current, and resistance. They recorded the relationships in tabular and graphical form, and then used the relationships that they had explored to answer questions.

The Ohm’s Law virtual lab held a direct connection for students to apply the mathematical concepts of direct and inverse variation in order to investigate the relationship between voltage, current, and resistance. It was not as timely as the other activities, however, in that students in both Mr. Jones’s Math 1 and Math 2 classes learned about variation the previous semester.

The lightbulb lab. (This lab was discussed, but not implemented.) The idea of the lightbulb lab came from an activity that Ms. Williams planned to implement in her science class, in which students created circuits with batteries and wires to power light bulbs, and then to build flashlights. The lab was mentioned during the fourth co-planning session when
Ms. Williams described what her students were currently doing. She expressed frustration that all her bulbs were burning out because she had batteries with the wrong voltage. This led into a discussion of the types of circuits students could make with various numbers of light bulbs and batteries, as well as why the bulbs were burning out with the wrong voltage batteries. Ms. Williams planned to discuss both of these concepts with her students over the next few days, to revisit direct variation and Ohm’s Law in her classes during the following week. Mr. Jones wanted to extend the lab into his class and to develop a series of questions for students regarding series and parallel circuits, and the different combinations of light bulbs possible, to illustrate the basic counting principle in his class. Mr. Jones did not follow through to create these questions for students, however, when he realized that his students did not need to learn about combinations and permutations in mathematics until the following year.

Although there was a possibility for interesting connections using parameters from science to investigate counting principles in mathematics, the idea for this lab was abandoned once Mr. Jones realized that the mathematical concept that he was trying to connect was not required until the next math course. Thus, the lab offered the possibility for direct connections, but was not timely because the math concepts were not from the current course.

**The phase change lab.** Ms. Williams brought the phase change lab to the fifth co-planning session as a possible activity to do in her class to teach properties of matter. In this lab, students place a container of ice and water on a hot plate and measure and record the temperature each minute until after the water begins to boil. The students should notice the temperature is constant during the phase change times, and that it rises during the time when
the water is completely ice and when it is completely liquid. Ms. Williams and Mr. Jones discussed their students’ understanding about rate of change, particularly for constant functions. Ms. Williams adapted the questions in the lab to include questions regarding the rate of change of temperature as well as the y-intercept and equation of the line for each of the segments in the lab.

The phase change lab offered direct connections between phase change and temperature in science and rate of change and linear functions in mathematics. These topics were timely for Ms. Williams, as she was currently teaching phase change in her classes, but not for Mr. Jones, who had taught about linear functions and rate of change earlier in the course, and who was currently in a statistics unit with his students. However, since Mr. Jones commented that since he was wrapping up all new material and moving into review at that time, he would have several opportunities to refer to and make use of the phase change lab in his classes as well.

Each of the five activities that were discussed offered direct connections between math and science content that students were learning in each class, but the connections were offered in a variety of ways. Only one of the four activities that was implemented required students to collect and graph data (the phase change lab). Two of the activities (Ohm’s Law lab and the roller coaster project) involved graphing, but the mathematical focus of the activity was not the graphing itself. Three of the four activities implemented also made explicit connections between a science formula and formulas or equations in mathematics. Two of the four activities that were implemented required students to physically create (the roller coaster project) or measure (the phase change lab), while the other two activities
required students to use information that was provided on the computer (Ohm’s Law virtual lab) or on paper (the science reference tables project).

Of the activities that were implemented, only 1 (the roller coaster project) drew on connections between math and science topics that were currently being taught in each class. One other activity (the reference table project) could also be considered timely, since it was purposely a review of multiple topics that were taught throughout the year for both classes. One activity (the lightbulb lab) was discussed, but not implemented because Mr. Jones discovered that students did not need to learn those particular math concepts until the following course. The other two activities (Ohm’s Law virtual lab and the phase change lab) included current topics from science, but not from math, which limited the amount that Mr. Jones was willing to discuss each in his class.

Co-planned math and science connections. Most of the discussion that Mr. Jones and Ms. Williams had each session was about how they could implement smaller connections rather than larger projects in their classes. The number of topics and connections that the teachers discussed actually increased over the weeks, as the teachers became more comfortable discussing each other’s content. Table 6 (above) lists some of the connections that were discussed more at length during co-planning sessions. The focus of these conversations was not about how the project would look, or how to implement, as it often was with the activities, but what the content was, and confirming each other’s understanding of the actual connection being made.

Some of the connections that were discussed were directly related to larger activities. For example, as a part of the discussion of the relationship between voltage, current, and
resistance, the teachers discussed the similarities between electrical current and water flowing through pipes. They extended this conversation to discuss how students could use the volume of cylinders, which they learned in their math class, to find the actual volume of pipes, and relate that to the amount of electrical current in a wire. They also discussed how they would extend the discussion of the Ohm’s Law virtual lab to include application to the circuits and flashlights that they were building, such as that adding a light bulb to the circuit would cause all light bulbs on the circuit to glow dimmer because the increased resistance would lower the amount of current each bulb receives.

Other connections were discussed outside of the context of a larger activity. For example, Mr. Jones and Ms. Williams discussed sampling procedures in statistics from his math class and mixtures from her science class:

Williams: So using the biased – convenience [sample]. That would be a good example to use when talking about when you’re taking a sample from a solution versus a suspension or colloid.

Facilitator: What is a colloid, again?

Williams: That’s when – that’s like milk, where there’s – it’s different layers, but it’s still a…

Jones: So it is just that you can’t tell what the layers are?

Williams: Because some particles are intermediate in size. And there are smaller particles in a solution and larger particles in a suspension. Yeah, it’s in between.
Jones: Yeah. So if you had a colloid, and you took a convenience sample, and you took some milk off the top, and you did whatever you were going to do to find out about the

Williams: Cow or whatever. It’d be creamier on top.

Jones: So you’d say, wow, this is really creamy. But it’s because you didn’t take a sample of the whole thing. Because you took a biased sample, you didn’t really look at the whole thing.

Williams: So really, I’m just talking about biased and convenience.

Jones: Yeah. Well, how could you take a sample of the milk? You could take some from the top; you could take some from the middle; you could take some from the bottom. That would be stratified.

Williams: Oh, yeah.

In this connection, the teachers are using math and science concepts concurrently to explain the opposite subject or concept to each other. They use the idea of sampling in math to explain the difference between types of solutions, and they also use their understanding of different solutions to explain the difference in different statistical sampling procedures in mathematics. In her reflection following the lesson, Ms. Williams wrote:

In class, I didn't go into detail as much as I had planned, but I did mention sampling and how they just learned that in math. I compared taking random samples in a homogeneous solution to taking an unbiased, random sample and that in a solution, each sample should come back looking the exact same. I then said what if we just
took from the top of a suspension, would that give us an accurate picture of that mixture?

Often, connections such as these were able to be mentioned in both classes, since they worked well to provide context and service to each subject. For Mr. Jones and Ms. Williams, these smaller connections contributed greatly to the amount that the teachers could relate the content between their two classes for students.

Mr. Jones and Ms. Williams were able to successfully plan and implement both large interdisciplinary activities and smaller examples and discussion points between the math and science concepts from each of their classes. This is evidence that, despite their fears that they were beginning teachers and might not perform as well as other, more seasoned teachers, the ICT co-planning model worked for the two of them within the context of their school structure and belief system. To better understand the nature of the collaboration that took place which led to these activities, I next share findings related to the pair’s actual co-planning process as they engaged in the ICT model.

**The Co-planning Process for Jones and Williams**

Mr. Jones and Ms. Williams fit weekly co-planning sessions into their regular individual planning routines. Both before and after co-planning sessions, each teacher used state standards documents, textbooks, and other resources to plan at the yearly, unit, weekly, and daily levels. Although Mr. Jones used the textbook as his primary source for ordering topics and picking examples, and Ms. Williams tended to take into account the nature of the class and activities that she had available, they both reported blocking out units of time for
each topic, and then creating and refining lesson plans to fit within the predetermined allocations of time.

Co-planning seemed to fit in at the daily level of planning, but not at the most detailed level for Mr. Jones and Ms. Williams. Both teachers reported that being beginning teachers, they felt most comfortable creating very detailed written lesson plans, which Mr. Jones stored in notebooks and Ms. Williams stored electronically. These lesson plans were sometimes written out in advance, but often because of the reality and time constraints of planning to teach, were written up to the day prior to the lesson being taught. Mr. Jones tended to add notes from co-planning discussions into his lesson plans if they were already written, and to incorporate them as he was writing plans when the plans were not already written. Ms. Williams reported that it was too much for her to incorporate interdisciplinary connections into plans as she was writing them; that she needed to write the entire detailed science lesson plan and then consider when and where to add in connections to mathematics. This self-imposed requirement of writing the entire lesson plan before considering connections may have greatly restricted the amount and type of connections that Ms. Williams was able to implement successfully with her students.

Both Ms. Williams and Mr. Jones expressed concerns during the initial group meeting that they would be unable to co-plan, mostly because they are novice teachers and because of the time commitment. Mr. Jones said, “I just don’t want to mess anything up, on your end, because I didn’t participate, or answer one of the questions or something.” He added, “For me personally, it sounds awesome, and I really want to do it, and I want to give you the best that I can, I’m just worried that I might not be able to. Because I don’t know about you guys,
but in the next two weeks, I have one free afternoon, which I don’t mind committing to this, I’m just worried I’m not going to be able to commit enough time to it and I think you deserve better.” Ms. Williams said, “I’m happy to do it, but I’m in my second year teaching, and this is a new class that I’m teaching, so I don’t really know what I’m doing.”

Since Mr. Jones and Ms. Williams did not share a common planning period, and they were both involved in various activities that limited their ability to meet before or after school, their co-planning sessions were conducted during lunch, which was their only commonly shared time. The co-planning sessions for this case were short in length, averaging 30 minutes each during lunch, with one longer co-planning session (CP5) during a teacher workday. Since both teachers had classes both before and after lunch, and because they needed to find time to eat as well as co-plan, this time felt particularly rushed. The format of the co-planning sessions was similar to the proposed synopsis, overview, and discussion, but often it was time to leave before one teacher or the other felt confident in their understanding and application of the discussion that they had. Although Mr. Jones stated during his final interview that he did not feel rushed, when asked to rank factors that affect the success of co-planning sessions, the pair ranked time toward the top, implying that time was a factor for them. During her final interview, Ms. Williams said, “We were doing it during lunch, which is already rushed anyway. We were trying to eat, and also talk about incorporating a different subject into your lesson plan, which is difficult. So, it was very challenging, but I’m - I feel pretty good about what we did accomplish, but hopefully next year, we can actually incorporate some time. Some planning time either before school or after school, and not after lunch. It will be much better.”
On days that there was no regular co-planning session scheduled, the teachers still ate lunch together at the same time. When asked whether they “talk” during this time, their answers conflicted. Mr. Jones reported that they did regularly discuss connections, and Ms. Williams reported that they did not. This could possibly be because of a difference in the perceptions of the two teachers, that Mr. Jones considered what was probably more informal and brief conversations a part of planning, and that Ms. Williams did not. The differences in these perceptions will be further addressed, below, in the section regarding Mr. Jones and Ms. William’s beliefs.

During the co-planning sessions, the teachers mostly discussed math and science content, especially relating to student understanding and particular activities that were already planned in Ms. Williams’s science class. In addition, Ms. Williams’s self-efficacy was mentioned at some point during every co-planning session. Other concerns, such as specific plans for activities, and proposed time frames and other logistical concerns were inserted throughout co-planning sessions. Figure 10 lists the codes that were used to describe segments of conversation. The list on the left depicts the codes in order by type. Codes about content, logistical concerns, and activities/projects were broken down into several sub-categories. The list on the right depicts the codes in order by frequency during co-planning sessions. For example, the highlighted code, ICTP – CONT – discuss/clarify math content (coded for the ICT process, in the category of content, specifically about discussing/clarifying math content), occurred 40 times for this case throughout the intervention. On the left, it is categorized among the content codes. On the right, it can easily be seen that it is the 2nd most frequently occurring code for this teacher pair.
Figure 10. ICT process code occurrence for Jones and Williams case.

For Mr. Jones and Ms. Williams, most of their co-planning time was spent focused on discussing content, projects and activities, students, and self-efficacy. As such, these data will be further examined, and will be discussed in the remainder of this section. Other types of comments (e.g., references to EOC testing and other logistical concerns) by Mr. Jones and Ms. Williams occurred infrequently, and did not seem to impact planning sessions, so they will not be discussed, except as in reference to content, projects and activities, students, and efficacy.

**Discussing content and connections.** Regarding the content of the co-planning sessions, Mr. Jones and Ms. Williams generally approached several math and science topics

<table>
<thead>
<tr>
<th>Code</th>
<th>Frequency</th>
<th>Code</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICTP - BELF - efficacy</td>
<td>27</td>
<td>ICTP - CONT - math/science connection</td>
<td>43</td>
</tr>
<tr>
<td>ICTP - BELF - express excitement/value</td>
<td>18</td>
<td>ICTP - CONT - discuss/clarify math content</td>
<td>40</td>
</tr>
<tr>
<td>ICTP - BELF - rationale for decisions</td>
<td>6</td>
<td>ICTP - CONT - discuss/clarify science content</td>
<td>25</td>
</tr>
<tr>
<td>ICTP - CONT - discuss/clarify math content</td>
<td>40</td>
<td>ICTP - CONT - math/science connection</td>
<td>43</td>
</tr>
<tr>
<td>ICTP - CONT - discuss/clarify science content</td>
<td>25</td>
<td>ICTP - CONT - discuss/clarify science content</td>
<td>25</td>
</tr>
<tr>
<td>ICTP - CONT - name upcoming topic math</td>
<td>12</td>
<td>ICTP - CONT - express excitement/value</td>
<td>18</td>
</tr>
<tr>
<td>ICTP - CONT - name upcoming topic science</td>
<td>13</td>
<td>ICTP - CONT - 4 reflect on project/activity/lesson</td>
<td>15</td>
</tr>
<tr>
<td>ICTP - CONT - past topic in math</td>
<td>4</td>
<td>ICTP - CONT - name upcoming topic science</td>
<td>13</td>
</tr>
<tr>
<td>ICTP - CONT - past topic in science</td>
<td>5</td>
<td>ICTP - CONT - name upcoming topic math</td>
<td>12</td>
</tr>
<tr>
<td>ICTP - CONT - related knowledge</td>
<td>2</td>
<td>ICTP - LOG - timeline</td>
<td>12</td>
</tr>
<tr>
<td>ICTP - LOG - other</td>
<td>10</td>
<td>ICTP - PROJ - 2 possible project/activity</td>
<td>11</td>
</tr>
<tr>
<td>ICTP - LOG - responsibilities for connected project</td>
<td>1</td>
<td>ICTP - LOG - other</td>
<td>10</td>
</tr>
<tr>
<td>ICTP - LOG - timeline</td>
<td>12</td>
<td>ICTP - PROJ - 1 mention/describe existing project</td>
<td>9</td>
</tr>
<tr>
<td>ICTP - PROJ - 1 mention/describe existing project</td>
<td>9</td>
<td>ICTP - BELF - rationale for decisions</td>
<td>5</td>
</tr>
<tr>
<td>ICTP - PROJ - 2 possible project/activity</td>
<td>11</td>
<td>ICTP - CONT - past topic in science</td>
<td>5</td>
</tr>
<tr>
<td>ICTP - PROJ - 3 details for connected project/activity</td>
<td>30</td>
<td>ICTP - CONT - past topic in math</td>
<td>4</td>
</tr>
<tr>
<td>ICTP - PROJ - 4 reflect on project/activity/lesson</td>
<td>15</td>
<td>ICTP - CONT - related knowledge</td>
<td>2</td>
</tr>
<tr>
<td>ICTP - STUD - about students</td>
<td>29</td>
<td>ICTP - LOG - responsibilities for connected project</td>
<td>1</td>
</tr>
<tr>
<td>ICTP - TEST - mention EOG/testing</td>
<td>1</td>
<td>ICTP - TEST - mention EOG/testing</td>
<td>1</td>
</tr>
<tr>
<td><strong>TOTALS:</strong></td>
<td>324</td>
<td><strong>TOTALS:</strong></td>
<td>324</td>
</tr>
</tbody>
</table>
during each co-planning session. Math topics that were discussed include those that were upcoming as a part of the math class curriculum, and those that have already been taught, or were taught at a different level. Science topics that were discussed were generally topics that were upcoming in the Physical Science class, and rarely were topics discussed that were not current or upcoming in the science class.

The depth to which the teachers were willing and able to discuss content and connections changed over the length of the intervention. Not all math and science topics were described in depth, especially toward the beginning of the intervention. Both Mr. Jones and Ms. Williams seemed unwilling to describe a topic if they had already decided that they would not find a connection. For example, during one session Ms. Williams commented, “It doesn’t look like there is any math in magnetism.” During another, Mr. Jones said, “Unfortunately, I’m going into geometry next,” and Ms. Williams asked, “So… what? Do you see any connections?”

In many instances during the first half of co-planning sessions, an upcoming topic would be mentioned, but no detail was revealed. The facilitator would then ask the teachers to explain what they mean by the topic. The teachers would explain, and then be in a better position to speak about potential connections. Below is an excerpt from an early co-planning session during which the above described scenario took place:

Williams: We talked about thermal energy. We talked about - yesterday we talked about nuclear energy. Half life. So I did pull in math.
Jones: Yeah. The radioactive decay is another exponential function. So, she was able to incorporate that.

Facilitator: What do you do as far as radioactive decay with your kids?

Williams: Um…

Facilitator: Just tell them what it is, or…

Williams: Tell them what it is, go over the different - the beta, the alpha, the gamma. And then we did the…

Facilitator: Ok, so tell me what that means. I don’t know that.

Williams: So it’s just different ways an atom can release radiation when it does decay. So beta is when an electron - it’s basically when - say you have a carbon atom. And it kind of spits out electrons. And it can change to a different element. So it changes to nitrogen. So it underwent decay. Turning into a new element. And then there’s alpha, which is like they lose 2 protons and 2 neutrons.

Jones: It’s the different types of emissions they give off when they do these decays.

Williams: It’s the different type of penetration when you give off gamma

Facilitator: So it’s the different energies

Williams: Different energies, different masses. And so the M&M’s - they were just seeing. They started off with 100 either M&M’s or skittles. And they were supposed to shake it for the
half life. So, each one had a different half-life. 10 seconds or 20 seconds. So they had to shake it. And pour it out. They had to take out the decayed atoms that had the print side up. Either the M or S. So then they had a lesser amount. And they would shake that and do it again and keep doing it until they were gone. Until there was just 1 or none. And then they could see it in their data table and they had to graph it. They could see in their data table that for the first half life it decreased by approximately a half. And it decreased by approximately half again. Going to ¼ and then ⅛ so they could see, then that created the exponential curve.

Facilitator: So you could show them that that verbal description that you’re doing is really just this exponential equation.

Williams: And that’s what I did. I wrote out that problem on the board.

Facilitator: So do you do it like this? [drawing table]

Williams: And that’s exactly what their table looks like in their lab yesterday.

And then they had to graph it. They had to plot time versus amount.

In the excerpt above, it can be seen that the teachers were answering questions in short phrases, which were not helpful for drawing out connections. The facilitator kept prompting the teachers until Ms. Williams described the content more specifically.

In several other instances during the earlier co-planning sessions, upon asking Ms. Williams to clarify or explain, she would say that she did not know. For example, when
asked about the difference between watts and amps in electricity, Ms. Williams replied, “Don’t ask me. I haven’t taught myself yet.” For the sake of time, topics that could not be explained were usually tabled until the next planning session.

The third co-planning session seemed to mark the beginning of the changes that occurred in co-planning discussions for Mr. Jones and Ms. Williams. During this session, Ms. Williams left and brought her textbook back to use. The textbook helped greatly to give her confidence and to clarify concepts which she could explain, but was unwilling to commit to an explanation without the security of the book. This was also the first co-planning session in which Ms. Williams mentioned the value of taking notes in order to remember connections to bring back to her class. As the co-planning sessions continued, the teachers seemed to mention more topics, to be more willing to speak in depth about topics without being prompted, and to notice more connections between the topics.

Discussion of science content was often either in the context of a lab or project that students were expected to complete, or in terms of what students were to do in the class. For example, Ms. Williams answered a clarifying question above about representation of a concept by saying “and that’s exactly what their table looks like in their lab.” When explaining another concept during a different session, she said, “So, one problem is find speed is wavelength times frequency. And then they were given another problem where they were given Slinkies and they had to find the wavelength. And they did it.” One final example is when Ms. Williams described the upcoming topics of electricity and magnetism. She said, “It looks like electricity and magnets are tied together. I’m thinking of doing like a PBL, a project where they’re having to create an electromagnet, a flashlight. It’s going to be
like a survivor show.” In all of these examples, Ms. Williams seems to assume that the content and concepts that students are learning from each of these activities is obvious, and that the student procedures are the more important aspect to be clarified.

Discussion or clarification of mathematics content, in contrast, was not usually in the context of an existing project or activity. Rather, current and past topics in mathematics seemed to be discussed either 1) in context of student understanding, 2) purely as a mathematical example to explain a concept to Ms. Williams, or 3) in the context of the science concept that was also being discussed. Mathematical concepts described in terms of student understanding often seemed to be for the purpose of explaining what Mr. Jones does to alleviate certain student misconceptions, or to get students to understand the material better. For example, as a part of a discussion of student understanding of equations, Mr. Jones said:

Get them to understand the words in the problem and the numbers and how they relate. Stressing that really helps. Because I would always make them write out, instead of just the formula. Like what does s mean, s is - I call them let statements. Let s be, and for this it would be speed of the wave. And so that’s what I made them do for everything.

In this example, Mr. Jones discussed the content through the lens of student understanding to give Ms. Williams some ideas about how he conveys this particular bit of knowledge to his students. Although he considered student understanding in this quotation, it was still very teacher-centered, based on the amount of times he mentions himself during the quotation.
Other quotations that did not center around student understanding were generally about an upcoming topic that Mr. Jones was about to teach, or re-explaining a concept to Ms. Williams that she brought up from a previous session. For example, Mr. Jones described his next topic during one co-planning session:

The first thing I’m going to teach them is the fundamental counting principle. And so what that says is as long as you have independent events, all you have to do is multiply the events. For example, if I’m picking out an outfit, it doesn’t matter how the outfit colors work together, but I have 2 pairs of shoes, 3 shirts, and 4 pants. Well, by the fundamental counting principle, we view those objects as independent to each other. The amount of shoes I have, if I pick a pair of shoes, has no effect on the amount of shirts I have. So I do 2 times 3 times 4 and I get the total number of choices.

During a different session, he re-explained sampling vocabulary to Ms. Williams. “Random doesn’t mean there’s an equal likelihood, but it means a certain group is not favored. And then within those two, we have classifications. So for random, we have simple, random, stratified random, and then systematic.” Although Ms. Williams was attentive and interested during both of these examples, the clarification of each was not at her request. Rather, Mr. Jones was proactive in helping Ms. Williams understand specific concepts from his class.

Neither specific content in mathematics or science was generally discussed at a second co-planning session, unless it was to purposely reflect on a lesson or activity. For example, during one session, the concepts of literal equations and variation were discussed. The facilitator clarified, “So as far as math concepts, there is one concept when you have an
equation that has more than one letter, it’s called a literal equation, and when you solve for one or you solve for another, that’s what he’s talking about. And then the other math concept that he’s talking about is the variation, you know R is proportional to V. As R goes up, V goes up. So you got two different things there, really.” During the next session, Ms. Williams said, “I actually found an online simulation that I like with Ohm’s Law and it has the equation and it has the formula, and when you change things in the circuit, it actually - the R will get bigger, the V also gets bigger.”

Often a mathematics concept would be explained in terms of the science concept for which a connection was being made (as can be seen in the previous example). In another instance Ms. Williams mentioned optics. “We did just talk about optics. And the angle of incidence and the angle of reflection. And they kind of, some of them figured that out from, they said from your class. That the angles have to equal one another, that when they have a normal angle that is equal to 90 degrees, then they have to figure out the angle of incidence.”

During another session, direct variation was introduced. Mr. Jones said, “So if amps was held constant, as volts go up, power goes up. Same thing, right? Or if Volts was held constant, as amps goes up, power goes up. So, they’ll recognize it like this,” and Ms. Williams finished for him, “And inverse is just the other direction. Ok.” In each of the above examples, the science topic was thoroughly described, but using the math concept, so that really both content areas were being treated together.

**Discussing projects and activities.** Consistently, and usually once or twice per session, Ms. Williams would describe or mention an existing project or activity that her students were doing. This usually occurred during the portion of the discussion in which Ms.
Williams would tell about her past and upcoming content. As is described in the following section about the plans that were made, most sessions centered about connections that could be made, but not particular projects. Most of the quotations involving discussion of details for a particular project or activity occurred during the 5th and 6th co-planning sessions, in discussion of the Phase Change Lab. Toward the beginning of the intervention, Mr. Jones and Ms. Williams also spent time reflecting on the Roller Coaster Lab that they implemented before co-planning sessions began.

Quotations regarding specific projects were generally more focused than quotations involving other content. They involved more specific questions on the lab, and how students will perceive a particular question. For example for the phase change lab, Ms. Williams said, “All right, so this is what I’m going to do. So, when we go over #2, I’m going to ask the question, how fast is the temperature changing at that flat, horizontal portion. Hopefully they’ll say, it’s not changing. And I’m going to say ‘what’s the slope of that horizontal line,’ then? Because they should have made a graph, right?”

**Discussing students.** Most quotations involving students centered about their understanding. These were categorized into comments about what students do understand, what they will understand or prefer, or what they should understand or know.

Remarks regarding current student understanding were often very specific about a concept or part of a concept in mathematics, but vague about the actual student. For example, Mr. Jones said, “Well, they’re not going to like that. They just don’t like horizontal and vertical lines. I just don’t understand it. They’re going to recognize that it’s a horizontal line, and they will tell you where it is, but they will never give you the equation for it.” In this
example, Mr. Jones was specific about the topic, and the type of problem that students would face, but vague about what the students do or do not understand, and categorized them all as “they.” In fact, most quotations about student understanding were not about one specific student or group of students, but generalizing about all the students in their classes. For example, comments such as “how much they really don’t know,” “they knew it,” “they so don’t get it”, and “they don’t take units seriously” were common throughout co-planning sessions.

Particularly when talking about what students should know, Mr. Jones and Ms. Williams tended to talk about themselves. For example, Mr. Jones explained that students should understand units because he takes off credit if they don’t write them:

Since day 1, I have told them, if it is any kind of a word problem, or sentence structure, that they have to give me an answer in a full sentence, or they are getting no more than half credit. And so they know - I force them to make sure they know what units they are talking about, what statements they are talking about, the whole nine yards. Because they know if they don’t do that, they’re not getting full credit. So, I’ve made it a pretty important concept of units and that kind of thing.

The point of the comment is that Mr. Jones’s students need to understand units, and should, but the premise is because he the teacher told them to. Thus, this statement is really more about himself as a teacher than about his students.

During another session, Ms. Williams commented on student ability regarding labs, “These are assumptions I always make before we have labs, and then I’m like, dumbfounded most of the time. I’m like, really?” While these comments are regarding students and student
understanding, they are also phrased in such a way that the focus of the comment is on the teacher, not the student.

Some quotations clarify which students are in which classes, and asking what Math 1 students should know versus Math 2 students. For example, in the following excerpt, Mr. Jones and Ms. Williams are discussing whether her students will understand piecewise functions based on what class they are in.

Williams: Well, I have all your math 2 students.
Jones: Yeah.
Williams: You know. I’ll have several in each class. I have a mixture of Math 1 and Math 2 students. So the math 2 - have they already seen it? Piecewise?
Jones: Yeah, they all saw piecewise last semester, so they should remember it.

At the least, excerpts such as the one above, serve as a reminder that the teachers did not completely share the same group of students, and that they were successfully navigating other external factors, such as multiple classes, throughout the co-planning process.

**Discussing efficacy.** Ms. Williams made many comments over the course of the intervention about her own ability to know and teach her own course, and to make connections to mathematics. During the first few sessions, most quotations were about her feelings of discomfort with mathematics. In the first session, she commented, “See? That’s why I actually need to know more about math,” and later said, “I don’t know anything about this stuff.” During the second session, she said that it had been a tough week because, “this
week, I didn’t really know what I was doing.” Exchanges such as the following were common:

Jones: It just looks like math when you put that little x there.
Williams: See, when you do that I’m like “ooh”
Jones: Yeah, as soon as you put that x there,
Facilitator: It’s the same picture, there’s just a little x there.

After the third session, Ms. Williams expressed comfort for the first time. She wrote in a reflection, “I also looked up the definitions along with examples of direct/inverse variation and literal equations so I felt more comfortable explaining it in class. I added notes to my lesson plan.” During the fourth session, she remarked, “I could do that,” and during the fifth, “I feel comfortable doing that” about different connections. These changes in confidence, as mentioned above, allowed Ms. Williams more freedom to look more deeply into content and to recognize more connections because her fear was no longer stifling her ability to understand mathematical connections.

However, at that point she was not completely confident. She said about the labs she brought to the session, “And I haven’t had the time to really even go over these real well. So if you ask me a question, I probably won’t know.” When given the choice between the lower level and the higher level connection to make, she replied, “Yeah, I would rather just do math 1 stuff, anyway.” By the last co-planning session, though not completely comfortable, Ms. Williams seemed a lot more confident in her remarks about connections that she could bring to her classroom. Referring to one concept, she said, “so I guess I could bring that up, since
you’ve already done it,” and another, “yeah, I can definitely talk about that tomorrow as well.”

Overall, Mr. Jones and Ms. Williams each integrated co-planning into their individual planning routines, but would have liked more time to be able to discuss and plan connections. During sessions, they mostly discussed content, activities, and students, but Ms. Williams’s confidence was a large contributing factor to their discussions, and possibly because of this, explanation of math topics seemed to take on a different role than explanation of science topics. However, as Ms. Williams’s confidence increased over the course of the intervention, the teachers’ ability to engage in detailed discussion of content and to draw connections seemed to strengthen. In the next section, the teachers’ beliefs will be discussed, both how they influenced and how they were influenced by participating in the co-planning intervention.

Beliefs and the Co-planning Process for Jones and Williams

Both the co-planning process and the plans that Mr. Jones and Ms. Williams made were influenced by their beliefs about science and mathematics, about teaching and learning, and about interdisciplinary connections. In turn, some of these beliefs were greatly influenced by the discussions and planning that the teachers experienced as a result of participating in the co-planning intervention. The beliefs discussed in this section are based on the beliefs expressed by each teacher during individual interviews. Beliefs that were expressed during whole group sessions and co-planning sessions were also taken into account in order to verify and triangulate whenever possible. Beliefs in each of the three areas are discussed separately below.
Beliefs about math and science. Both Mr. Jones and Ms. Williams began the intervention with strong beliefs about the nature of their own subject. Ms. Williams held an inquiry view of science. She said, “Exploration and inquiry, is how I would sum up science. Knowledge and how the world works. Understanding how the world works.” She spoke of the discovery aspect of science through an activity that she described for her students:

What I’ve tried to have [students] do recently, is a couple of times having them design their own experiment. I really want them to discover things. Let them know it’s ok if they make a mistake or if they don’t do it right the first time. That’s the nature of science. You can make a mistake, and try it again in a different way.

She also spoke of the ability to have changes in theory. “It can be replicated by other scientists, and then it becomes a theory. But it doesn’t mean that that is the way, and that new information might come up and change that theory.” By the end of the intervention, it seemed that Ms. Williams’s beliefs about the nature of science did not change. She continued to express that science is “exploration and inquiry” and “understanding how the world works,” and that progress in science means “changes in theory.”

Mr. Jones held a more abstract view of mathematics. He stated that, “math is logical processes” and “steps with reasons.” He added, “It’s a flow chart for me,” and “If I’m willing to say this, I have a reason for it. And that’s how everything goes in math.” This view of math lead Mr. Jones to describe proof as the essence of mathematics, and problem solving as being able to answer a question as well as describe and defend the process that was used to come to the answer. Similarly to Ms. Williams, these beliefs about the nature of mathematics
did not seem to change for Mr. Jones over the course of the intervention. This excerpt from his final interview exemplifies his beliefs about mathematics:

Math is logical understanding and reasoning. It’s a way of conceptualizing anything.

Math - people most often say it’s just about the numbers. It’s not. We use numbers, but whenever we’re working out problems we’re using logical reasoning and steps.

It’s a process. Not just 2 + 2. It’s why do we do 2 + 2.

This example demonstrates Mr. Jones’s commitment to math as logical reasoning, and to defend mathematics as a way of thinking, and not a set of procedures to be memorized.

Both teachers also saw their respective subjects as exciting, and want others to share their vision. As early as the first co-planning session, Mr. Jones defended math, telling Ms. Williams that it is exciting. Both teachers spoke of influencing students to understand their point of view with enthusiasm. For example, Ms. Williams said, “And I love this activity I give them the very second day of earth and environmental science. And it’s called the nature of science.” She went on to describe an activity which demonstrates to students how theory can change as new information becomes available. The tendencies of both teachers to defend the nature of their respective subjects to each other and to students may have resulted in their continued efforts to recognize and describe connections between their subjects throughout the intervention.

Regarding the opposite subject, however, both teachers initially held seemingly immature beliefs. Mr. Jones seemed to use his understanding of math as an abstract endeavor to frame his beliefs about science being the application of mathematics. He said, “I see math and science as kind of siblings - brother and sister in a way. Math is kind of the reasoning
where science is the application.” He reiterated this several times during his initial interview. For example, he said, “so back to - again I kind of boil it down to the essence. So, science is kind of the application. So you see all these numbers in math, and you look at these formulas, and you can add 2 + 2, but when you take it to the real world, when you start to apply it, that’s where I see science as. How does it actually look? Can we model this mathematically in a science world? How does it look out there, not just on paper.” He made similar statements in reference to statistics, in particular data collection, and hands-on activities such as measurement, referring to them as science, not because they embodied discovery or inquiry in any way, but because they were the application of mathematics.

Ms. Williams began the intervention feeling very uncomfortable about math, coupled with a belief that math is procedural skill and memorization. When asked about what math is, she replied, “Analytical, right brain… precise, uh…” She said, “I’m not going to be as strong at these questions.” She would not commit to definitions for any aspects of mathematics when asked, such as her understanding of math problems, proof, and theorems. This view of mathematics seemed to be enhanced by the fact that Ms. Williams was teaching physical science for the first time. She said, “It’s a lot more math obviously in physical science. It’s a lot more skills based.” She continued, “I feel like half science teacher and half math teacher so far. Every topic we’ve covered has to do with an equation that goes along with it.” She said that regarding math concepts in her own class, “I give a lot of practice problems,” showing her tendency to teach students only basic math skills as necessary and to protect them from the frustration and confusion of more involved mathematical problems.
The dichotomy between Ms. Williams’s and Mr. Jones’s initial beliefs is illustrated in the following interchange during their first co-planning session regarding velocity and acceleration.

Jones: I did tell them in my class, I don’t want to say it was a video, it was 10 seconds long. It was more like a clip, or a recurring gif, honestly. It was just a car, and it had how far it traveled and the time it took. And I was asking them ‘how far did it get in this section’. So we kept comparing that rate of change to average speed. And so yeah, we talked a lot about that in my class, and so hopefully, it sounded like that used some of that in yours.

Williams: Yeah. We had talked about acceleration is the rate of change of speed. So I’ve been trying to - But they still kind of mix up concepts sometimes. They forget, especially how to do it [the equations].

In the exchange above, Mr. Jones described the way that he tried to elicit student understanding about speed and rate of change. At this point, Ms. Williams did not equate that description with a different kind of understanding, and seemed to think she was affirming his statement by agreeing that they talk about the same thing in her class. However, her statement reflected a view that conceptual understanding meant picking the correct equation.

Both Mr. Jones and Ms. Williams both seemed to change their beliefs about the other’s subject over the course of the intervention, with Ms. Williams’s beliefs changing the most dramatically. Ms. Williams stated her original position several times, especially during the first few co-planning sessions, “I just feel like I actually just memorized it because I
really didn’t understand it.” In reference to content that was being described during co-planning, she would say, “I don’t even think I knew this,” and “That’s why I need to learn more about math, so I can actually…” The understanding of mathematics instead of memorization became a regular topic of discussion during co-planning sessions. For example, during a co-planning session, in response to Ms. Williams commenting, “It just makes sense to you,” Mr. Jones stated, “well, not really, I made it work for me,” demonstrating his belief that understanding is a goal to achieve in mathematics, and is more sustainable than memorization.

Applications of math, particularly of using graphing to describe concepts from physical science, became a source of conversation about the utility of mathematics during several co-planning sessions. For example, Ms. Williams commented, “This just - I mean, it blows my mind. Because seeing stuff like that. I mean, yes, I learned this. But this never meant anything to me. Because it never went with anything in the real world.” During another session, during which direct variation was discussed, she said, “I learned these equations are the same as something like $y=kx$. I had never thought of equations in science in these terms before so it was a real a-ha moment.” Later, she reflected, “Even though I’ve always been told that what you learn in math is practical, I never really thought that. But, whenever we have our meetings, you guys always kind of blow my mind because the way you explain math, and how you apply it to science, is just like, oh, ok. I get it now. I get how this applies to real life. And my teachers in high school - in college - could never do that. I always saw it just as numbers not applicable to anything. It’s like, memorize this stupid test, get it over with, and that seems terrible to me to still think that. I guess I never really thought
about it. But just hearing you explain it. You know, like when you did the graphs, and you show how everything I’m talking about, how it applies to math.”

As time went on, Ms. Williams’s view of mathematics as something to understand and not just memorize increased, and with it her confidence. Toward the beginning of the intervention, she said, “When I see it like this, but I was never taught like this. So, math to me was very boring.” She reflected during a later co-planning session, “To me math is just difficult. Not only trying to understand, but then having to try and explain it, I just don’t feel confident - very confident doing it. So that’s been a struggle for me.” In another reflection, she discussed the connections that she had just made with her class, “I think it’s really cool, and I never thought I would say that about math.” By the last co-planning session, however, she began to show confidence in her ability to convey some mathematical concepts.

Regarding a particular connection to mathematics that she had discussed, she noted, “I can definitely talk about that tomorrow as well.” This change in confidence and appreciation for mathematics obviously helped Ms. Williams to co-plan more effectively, and to implement the connections that were discussed during co-planning sessions.

By the end of the intervention, both teachers seem to have shifted toward each other in their beliefs about the opposite subject. During her final interview, Ms. Williams said:

Now I do have a new appreciation for math, compared to what I had in the beginning of the semester. I always, I hate to say it, I always had a very negative view of math, because really I didn’t understand it, and I looked at it more as memorizing things. … But, when we were working with Mr. Jones, connecting what I was doing in science to math, I was amazed all of the sudden, the ways things were being explained to me.
I was like, wow, math really is useful, if you connect it to these real-world situations. If you connect math to what they’re doing in science, to me it makes it much more relevant, and I think it made it more relevant to the kids, because to me, I was never taught that way in school.

The above excerpt from Ms. Williams’s final interview summarizes the change that she experienced in her beliefs about mathematics. Mr. Jones did seem to have refined his beliefs about science, but not as dramatically as Ms. Williams. He still defined science as “real world math” during his final interview, and thought of theories in science in terms of proof in mathematics, saying “You are trying to understand why something works. And so, proving a theory means following step by step without a doubt, this is how this works.” However, his thoughts about experiments and labs did seem to change to include the changing nature of science. During his final interview, Mr. Jones said, “You have hypothesized something. The experiment or lab is testing that hypothesis, and the data you get from the lab will help you reach a conclusion and see if you need to test again, or see if you need to revise your hypothesis.” This demonstrates that Mr. Jones’s view has begun to shift toward science as an inquiry activity, and one in which hypotheses can evolve over time, more in line with Ms. Williams’s beliefs about the nature of science.

Both Mr. Jones and Ms. Williams were relatively unchanging in their beliefs about their own subjects over the course of the intervention, but the incompatibility in their beliefs about each other’s subjects lead to various discussions throughout co-planning sessions, and dramatic changes in beliefs about each other’s subjects by both teachers.
**Beliefs about teaching and learning.** Both Mr. Jones and Ms. Williams reported little change in their general beliefs about teaching and learning over the course of the intervention. Both teachers expressed a commitment to group work and active learning in their classes, and perhaps because they seemed to mostly agree about the use of group work, activities, and active learning, the teachers did not discuss these during co-planning, as they discussed the nature of math and science, described in the above section. Each teacher cited several reasons for their preferences for group work, including the ability to differentiate instruction, assess understanding, and manage student behavior. Both also reported similar classroom routines, including a warm-up, short “lesson,” group activity, and wrap-up. These beliefs did not seem to change over the course of the intervention.

Although both teachers reported similar teaching styles and use of group work, they reported much different planning styles. This actually seemed to create a conflict for their co-planning process. Ms. Williams stated that she preferred to plan thoroughly for each lesson, including time allotments, directions for herself and students, and an informal script to follow. Mr. Jones provided evidence that he planned more loosely, and while he still prepared the activities and discussions for each lesson, he did not seem to concentrate on the details to the extent of Ms. Williams. Ms. Williams’s commitment to more thorough planning seemed to provide her with more concrete entry points to incorporate connections to mathematics into her lessons than it did for Mr. Jones. However, she also mentioned that it limited the amount of time and effort that she devoted to incorporating connections because she spent much more time planning just for science.
The difference in how the two teachers approached planning also seemed to influence their perception of the amount of time they spent co-planning. When asked whether they spent time co-planning outside of regular sessions, they expressed contradictory answers. Mr. Jones reported that they did, while Ms. Williams reported that they did not. This may have been because they spent time reviewing or discussing connections or concepts, but not creating detailed lesson plans. In addition, Ms. Williams mentioned that she would have preferred if spent more time working on detailed lesson plans, and that this teacher pair planned to do so the following year.

Both teachers also reported a belief both before and after the intervention that it is their responsibility as teachers to align the content that they teach with state standards. In addition, Mr. Jones reported using the textbook with students more than Ms. Williams. However, by the end of the intervention, Ms. Williams reported using the textbook for Physical Science more than she had in the past. This may not have been directly a result of co-planning, however, as she noted that her textbook use was mostly as an aid to teach herself the concepts before planning lessons for students involving different resources.

Mr. Jones seemed to be conflicted in his commitment to teach exactly as his pacing guide and other standardized documents dictated and what he thought students needed for conceptual understanding. For example, during an early co-planning session, he expressed that the standards compelled him to teach the quadratic formula as a formula to memorize instead of completing the square. He said, “I don’t like teaching them to memorize this. I hate even teaching that way.” This and other similar statements reflect his belief that he must
adhere to the standards as they are put forth, and that adding to them for the sake of student understanding would not signify complete adherence.

This complete commitment to the standards also seemed to affect Mr. Jones’s willingness to implement lessons that he co-planned. Regarding the light bulb lab, he commented to the other math teacher, “I was going to try to stretch it a little more, and try to make something interesting out of it, but I ended up not having to do probability for math 1.” He made a similar statement regarding topics that he had already taught:

A lot of the things she’s doing I’ve already done, and I’m passed that. So, it’s either I re-hatch it and go back, or - you know - I’m supposed to keep moving forward, so the things I’m doing now have no correlation to what they’re doing in her class because there is a correlation with what they’ve already done.

Although Mr. Jones was open to discussing a variety of connections that did not directly align with his timeline, he was tentative to bring up “old material” in his class. The above statement demonstrates Mr. Jones’s conflicted notions of following his pacing guide and developing connections. At the end of the intervention, Mr. Jones reflected that in co-planning the following year, it would be useful to align topics before the semester began so that some of those connections would be more useful for his classes.

Ms. Williams’s inquiry view of science and her initial competing belief in mathematics as memorization seemed to influence her perception of what she should teach and how she should teach it in her class. Several times, she mentioned the difference in the nature of her Earth and Environmental Science class the prior semester and her Physical Science class during the current semester, which she attributed to the difference in content.
She expressed wanting students to understand that making mistakes is a part of discovery. She said, “I really want them to discover things. You know? Let them know it’s ok if they make a mistake or if they don’t do it right the first time. That’s the nature of science. You can make a mistake, and try it again in a different way.” However, she also said, “There’s obviously a lot more math in physical science, it’s a lot more skills based.” This led her to state that she focuses more on the repetition of quizzes and tests. “A lot of things to make sure they know how to do it.”

Ms. Williams’s competing views of teaching mathematics and science seemed to soften over the course of the intervention. During the first co-planning session, she said about students understanding a connection to mathematics, “they were really confused and overwhelmed, so that’s when I broke it to them, you don’t have to do this.” During an early reflection, she commented, “I do think students struggle with applying what they learn in math to real world problems in science on their own. I usually have to make the connection for them.” This reflects her desires to shield students from the difficulties she perceives that they might have with mathematics.

During a later reflection, Ms. Williams said, “When I showed an example on the board, more students remembered the concept, they just didn’t know what it was called. I didn’t use a graph to illustrate the concept because I didn't feel as comfortable explaining that to the students in a way I thought they could really understand.” She added, “I probably underestimated them. Reflecting on what Ms. Taylor said in our meeting about letting go and allowing the students to figure things out, I realize that some of them could have probably shown the class how the equation can be illustrated on a graph and explained it much better.”
than me!” Examples of other comments that Ms. Williams made in support of her new confidence in mathematics with her students include, “When I showed an example on the board, more students remembered the concept,” and, “They remembered and knew $m$ was slope. I then asked them what the other lines showed.” These comments demonstrate Ms. Williams’s shift away from trying to protect her students to having them think more mathematically.

During her final interview, Ms. Williams still reported an inquiry view of teaching science. She stated, “I think labs are essential. You can read all day about science and it really not sink in. But as soon as you start doing some hands on things, that’s I think what the kids remember. They can, when they’re taking a test on something, and they read about something, I know that I’ve had several of them say, I just thought back to that lab, and I pictured what we did in that lab, and it helped me to answer the question. I think in science we have to have labs. I think it would be a disservice to the kids if you don’t.” However, she experienced far less conflict with her willingness to expose her students to mathematical concepts. “Before this project, I would keep the math very basic, just what was required for my students to understand the science content. Since co-planning with a math teacher, I've definitely gone deeper into math concepts that I would have done normally.”

**Beliefs about interdisciplinary connections.** Mr. Jones and Ms. Williams both began the intervention with a belief that creating connections for students is important because in the “real world,” students will need to use their knowledge from different subjects in conjunction with each other. Ms. Williams noted that students are traditionally taught each subject “in their own little silos, and they’re not connected.” She added the following:
You know, when you get out into the real world, if you’re - don’t think because you’re a scientist that you don’t have to read and write. Don’t think because you’re a mathematician that you don’t have to have communication skills. Or just because you want to do something with English or History that you won’t have to use any other skills.

Mr. Jones mentioned connections being the key to students understanding the “big picture,” and said that is why “I don’t mind Common Core quite as much as some people, because they do work on the big picture, and I think that’s important. It makes it so much easier to believe it works, and to see how it works.” He added, “We try and separate them, but I don’t think there’s a 100 per cent separation of the two. Regardless of how you do it. They are connected. Period.” These comments demonstrate that both teachers regarded connections between math and science as important because connections offer students applications to the “real world.” These beliefs did not change over the course of the intervention, but did strengthen, along with increases in the teachers’ knowledge about possible connections.

Both teachers seemed to be open to creating connections, but had vague notions of ways in which to connect math and science for their students. During her initial interview, Ms. Williams said:

Physical science is so much math. When you’re doing a lot of learning equations and word problems, and graphing, and looking at data, applying data to create tables and graphs. And for example, you know, right now the project that we’re doing with roller coasters, I didn’t even think about it, but talking to the math teacher, the quadratic equation was figuring out how to construct the roller coaster and parabolas.
You could probably look at most anything in physical science and be able to connect it to math. Earth and environmental? Uh, that’s harder. Um, I’m trying to think of if I use math - I’m sure I do, in something.

Mr. Jones held the belief that math is “logical processes and reasoning,” and that science is the application, as described in his beliefs about the nature of mathematics and science. Regarding connections that he makes in his classes, he stated, “Whenever we’re doing anything and I can see any connection, especially with science, because I know it’s the easiest connection out of all of them. For example, they were doing conversions. That’s the math that we did at the beginning of the semester. It’s important to see units. We were talking about milliliters, and how we are measuring things. Those are all science topics.” Both of these comments reflect that the teachers valued connecting mathematics and science concepts, but did not have immediate examples of how to do so at the beginning of the intervention.

Both teachers also grew in the amount and types of connections that they recognized. During her final interview, Ms. Williams commented about the amount of connections they found. “I think successes were finding so many connections between our subjects. That was I think really neat, because there were a lot.” During his final interview, Mr. Jones gave more specific examples of the connections that he found between the two subjects, including the connections that he made with statistics, quadratic functions, and graphing. He stated, “I think I did change in some aspects, because it mostly changed my perspective. Before these two months, I mainly looked at the math perspective, because that’s what I had to teach, that’s what I had to get across. Occasionally I tried to throw one of the other disciplines in
there. But it wasn’t forced, it was just, if it fits, it fits. If it doesn’t, I’m not going to bother. But now, it feels like I’m more actively looking at, and for anything, like is there anything else I could do with that to help them learn better, because when you make the connections, they learn better. So it’s a simple thing that makes those connections for them - if you actively look for them. And that’s what I’ve been doing more, is trying to actively look for things, instead of just passively doing it.”

The teachers seemed to base much of their enthusiasm for building connections on the success of their students. Mr. Jones expressed surprise on several occasions during co-planning sessions that his students actually made the desired connection that he thought they would not understand. For example, during one co-planning session, he commented, “That’s incredible that they got that,” and during a reflection, “Students struggled with making the inference as first, but once I started talking about some of the conclusions they have made in science class from last semester and their labs, they began to see that what we are comparing in our data is the same type of data they would take.” Ms. Williams also stated, “Much of the time the kids remembering that yes, we did talk about that in math. They couldn’t always give me the right answer, but they did remember it.” She reflected about specific lessons, and said her students understood voltage better when they saw “a diagram of a circuit and manipulate the variables that way,” and regarding roller coasters, “they understood the concept behind it, and how it connected to what they were doing with their roller coasters.” These examples illustrate the teachers’ building sense of value for interdisciplinary connections as they recognized the successes that their students experienced.
By the end of the intervention, both teachers espoused a deeper value and commitment to co-planning discussions. Ms. Williams stated that talking to Mr. Jones about student learning was helpful. “It gave me a much better picture of what they were able to do, and what they had already learned.” Mr. Jones recognized that students were able to see “the relevance of what they were doing in math class, not just for knowledge they needed in their science class, but in real-world applications.” He added that interdisciplinary co-planning is “not something that should it be done or should it not be done. It’s really something that needs to be done.”

Overall, both Mr. Jones and Ms. Williams began the interview with a belief in the value of interdisciplinary connections for their students, but without ideas for how the content would actually connect. As the teachers continued discussion of content through co-planning, they found many connections, and they also found that an awareness of each other’s content could be greatly beneficial to their own teaching. By the end of the intervention, the teachers expressed a commitment to continuing to search for interdisciplinary connections for their students.

**Summary for the Jones and Williams Case**

Mr. Jones and Ms. Williams are a case of teachers who had dramatic changes in their beliefs about mathematics and science through co-planning. They were both novice teachers who participated fully in the interdisciplinary co-planning intervention. These teachers began the intervention with trepidation that they would not be able to perform as well as the experienced teachers, but overcame their fears as they learned more about the applications of mathematics and science, and as they continued to experience success in creating...
interdisciplinary experiences for their students. Regularly scheduled co-planning sessions evolved from facilitator-driven to teacher-driven as the teachers learned to discuss content with each other in a meaningful way, to find relevant connections to use in their classes. Although discussion of self-efficacy and confidence did not completely leave the conversations, it did transform from an “I can’t” attitude to an “I can” attitude over the course of the intervention.

Mr. Jones and Ms. Williams both seemed to learn about the nature of mathematics and science from in depth discussions with each other. Ms. Williams, in particular, transformed her thinking about mathematics from skill and memorization to application and understanding. Mr. Jones also seemed to change his beliefs about science, particularly that science is a process of inquiry and not simply a collection of facts. The changes in belief and attitude toward each other’s subjects ultimately helped Mr. Jones and Ms. Williams to create more positive interdisciplinary experiences for their students.

Both teachers communicated that there are aspects of the co-planning process that they would change for the next school year, such as the amount of available time to write lesson plans. However, they also expressed a commitment to continue co-planning because of the benefits that they experienced for their students and for themselves. Ms. Williams said, “I think successes were finding so many connections between our subjects. That was I think really neat, because there were a lot. And going beyond what I would normally incorporate as far as math into physical science, and taking it a step further, and much of the time the kids remembering that yes, we did talk about that in math.” Mr. Jones expressed a similar statement, “It’s a simple thing that makes those connections for them - if you actively look
for them. And that’s what I’ve been doing more, is trying to actively look for things, instead of just passively doing it.” These statements reflect the tremendous growth that both teachers experienced over the course of the intervention. At least in the case of Mr. Jones and Ms. Williams, regular co-planning discussions contributed to increases in the teachers’ confidence and knowledge in math and science, which enabled them to plan more effectively for their students.

**King and Taylor: A Case of Discovering Value in Interdisciplinary Expertise and Collaboration**

Teachers are able, and often encouraged, to navigate their careers having little academic discussion with other teachers from outside of their own content area. Mr. King and Ms. Taylor were both lateral entry teachers, meaning that they entered teaching after completing a degree in an area outside of education. Their experiences outside of the field of education provided both teachers with a deep understanding of their own content as well as many other areas of related knowledge.

Both Mr. King and Ms. Taylor had 5 years of experience teaching high school. This intervention, however, was the first experience for each of them to regularly discuss content with colleagues from outside of each of their departments. Although the teachers had seemingly different approaches to learning in the classroom, they found that they both valued the teaching of students to be “21st century thinkers,” and diligent problem solvers. Both teachers contributed a great understanding of content and creative ideas to make learning relevant and connected for their students. Their conversations were often thought-provoking, and carried from one session to the next. Ms. Taylor noted that this intervention helped her to
take good lessons and labs that she had implemented successfully in the past and to enhance them so that students were gaining a deeper and more connected level of learning. For both Mr. King and Ms. Taylor, by the end of the intervention, both teachers recognized the opportunities that interdisciplinary collaboration afforded each teacher to create opportunities to extend student thinking in ways that each teacher individually would not have done alone.

**Background**

At the time of the intervention, both Mr. King and Ms. Taylor had taught at ECHS for the last 5 years. During the intervention, Mr. King taught 2 sections of Math 2 and 1 section of Advanced Functions and Modeling (AFM), and Ms. Taylor taught 3 sections of Biology. All students at ECHS are required to take two semester-long science courses in 10th grade: Chemistry in the fall and Biology in the spring; both taught by Ms. Taylor. Biology is a 90 minute, semester-long course. Math 2 is a 90 minute, yearlong course at ECHS. It is intended to be a 10th grade class, but many students come to ECHS with credit for Math 1 from 8th grade, so they take their math classes ahead of schedule. Math 2 was primarily mixed between 9th and 10th grade students, and AFM was primarily mixed between 10th and 11th grade students. Consequently, Ms. Taylor taught all 10th grade students during the intervention, most of which were in one of Mr. King’s classes as well.

Prior to coming to ECHS five years ago, Ms. Taylor spent one semester at a different high school. Before becoming a teacher, she worked for four years in the health profession as a clinical laboratory scientist. Ms. Taylor stated a belief that her background in laboratory science helps to inform her teaching about the applications of chemistry and biology to her students. Mr. King has a varied educational background, which gave him a wealth of
knowledge in a variety of fields, which he often shared. He has degrees in mathematics, history, and divinity, and he was completing a degree in engineering at the time of the intervention.

Ms. Taylor expressed a commitment to continuing in the teaching profession, and at the time of the intervention, was also working on her national board certification, a process in which she videoed her teaching and wrote reflections to address a variety of different prompts. Mr. King’s plan was to leave ECHS at the end of the 2015-2016 school year to relocate and finish his degree in engineering. Before the end of the intervention, he did secure a job at another high school closer to his engineering classes, for the following school year.

Although Mr. King and Ms. Taylor shared what they described as a good professional relationship, they had never planned academic content together before. Mr. King had experience planning common subjects with members of his own department, but since Ms. Taylor was the only Biology teachers at ECHS, she did not plan academic content regularly with other members of her department, either. ECHS only had 6 full time teachers at the time of the intervention, but is housed in two buildings because it sits on a community college campus. Mr. King and Ms. Taylor were located in separate buildings, and had different planning periods. They decided to have their regularly scheduled co-planning sessions after school once per week in Mr. King’s room.

To present this case, I will first share the nature of the content and activities that Mr. King and Ms. Taylor planned and carried out in their classes. Next, I will report the findings with respect to the nature of the conversations that took place during the co-planning sessions.
that led to the planned connections and activities. Finally, I will present the findings with respect to the teachers’ beliefs – both how they influenced the co-planning process and how they shifted as a result of the experience.

**Nature of the Co-planned Interdisciplinary Activities for King and Taylor**

In this section, the findings related to the actual co-planned connections are first reported. Mr. King and Ms. Taylor generally approached several math and science topics during each co-planning session. Exceptions to this were during session 3 and after the second large group meeting, during each of which one particular lab was planned for almost the entire time. Table 7 lists the math and science topics as well as larger activities that were discussed in order by co-planning session. For example, during the second co-planning session (CP2), 5 topics in mathematics were included in the discussion, and 4 topics in science. Two potential activities were discussed with some detail.

**Table 7.**
*King and Taylor co-planned topics and connections by planning session.*

<table>
<thead>
<tr>
<th>Math topic</th>
<th>CP1</th>
<th>CP2</th>
<th>CP3</th>
<th>CP4</th>
<th>PLE2</th>
<th>CP5</th>
<th>CP6</th>
<th>CP7</th>
</tr>
</thead>
<tbody>
<tr>
<td>trig modeling</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>exponential &amp; logs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>graphing equations</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>transform graphs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>modeling</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>sequences</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>law of sines</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>statistics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Exceptions to this were during session 3 and after the second large group meeting, during each of which one particular lab was planned for almost the entire time. Table 7 lists the math and science topics as well as larger activities that were discussed in order by co-planning session. For example, during the second co-planning session (CP2), 5 topics in mathematics were included in the discussion, and 4 topics in science. Two potential activities were discussed with some detail.
Table 7 Continued

<table>
<thead>
<tr>
<th>Surface area and volume</th>
<th>Connect to cell cycle</th>
<th>Connection</th>
<th>Current topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probability combinations</td>
<td>upcoming connection with DNA</td>
<td>connect with DNA</td>
<td></td>
</tr>
<tr>
<td>Sampling</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Science topic**

<table>
<thead>
<tr>
<th>Evolution</th>
<th>Past topic</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Antimicrobial resistance/current topic past topic</td>
<td>current</td>
<td>past topic</td>
<td></td>
</tr>
<tr>
<td>Cell structure and function</td>
<td>upcoming topic</td>
<td>discuss potato lab</td>
<td>reflect on potato lab</td>
</tr>
<tr>
<td>Cellular size</td>
<td>Discuss current</td>
<td></td>
<td>Cell volume</td>
</tr>
<tr>
<td>Carrying capacity</td>
<td>mention project</td>
<td></td>
<td>Connect trig graph</td>
</tr>
<tr>
<td>pH</td>
<td>Connect log scale</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Macromolecules</td>
<td>Current</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enzymes</td>
<td>Upcoming</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chlorophyll</td>
<td>Leaf lab</td>
<td>Leaf lab</td>
<td></td>
</tr>
<tr>
<td>Experimental design</td>
<td>Potato lab</td>
<td>Leaf lab</td>
<td>Leaf lab</td>
</tr>
<tr>
<td>Cell cycle</td>
<td>Upcoming reminder</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equilibrium and cancer</td>
<td>Current connection</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sound waves</td>
<td>Connection</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Genetics</td>
<td>Connect to probability</td>
<td>Discuss probability examples</td>
<td>Mention</td>
</tr>
<tr>
<td>DNA</td>
<td>Upcoming</td>
<td></td>
<td>Discuss</td>
</tr>
<tr>
<td>Biotechnology</td>
<td>Connections</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Activity/Lab**

| pH paper for King   | pH paper in math decided against |         |             |
| Potato lab          | Discuss discuss Detail reflect  |         |             |
| Predator/prey       | Mention                      |         |             |
| Leaf lab            | Discussed described          |         | Sent info   |
| Volume and surface area | With cell cycle | Cellular respiration |
Over the course of the 7 co-planning sessions, Mr. King and Ms. Taylor discussed many connections, both between the content that they intended to teach, and to other related knowledge. The teachers discussed 5 larger activities or labs, 3 of which were implemented. The teachers reported that discussion of these activities and connections provided opportunities to enhance lessons that neither would have thought of alone without each other’s content expertise. The next two sections will focus first on each of the larger co-planned activities that were discussed by the teachers, and then, on the smaller connections that the teachers made throughout the intervention.

**Co-planned activities.** Mr. King and Ms. Taylor discussed many connections, both between their curricula and other related knowledge. Although they often split the discussion between larger activities and smaller connections, there were two occasions (CP3 and PLE2) in which the discussion revolved almost entirely about one activity. Overall, 5 larger activities were discussed, 3 of which were implemented. All of the larger activities that were implemented, as well as one activity that was not implemented, were adapted from existing science labs. A student worksheet was either created or modified for each of the 3 activities that were implemented, which provided directions and questions for the students with concepts from mathematics and science. The activities and labs that the teachers discussed during co-planning sessions are described next. The complete activities that were implemented are included in Appendix Q.

**The pH and logarithmic scale activity.** This activity (not implemented) was the first large activity discussed in detail by Mr. King and Ms. Taylor, and involved students measuring the pH of various substances, calculating the concentration of H+ and OH- ions in
each substance, and then plotting their findings on a graph. The purpose was to visually demonstrate to students the difference in counting by exponents and magnitudes compared to counting the actual concentration of ions so that they would gain a deeper appreciation for exponents and for logarithmic scales. This activity was discussed during the second and third sessions, when Mr. King was teaching about exponential and logarithmic functions in his AFM class, but it was eventually dropped and not implemented.

The pH activity seemed to hold a direct connection between mathematics and science, but not to the biology that Ms. Taylor was currently teaching. The discussion that the teachers had regarding pH was from when Ms. Taylor taught the topic in her Chemistry class in the fall. If this activity were implemented, students would have used the pH measurements and calculations from science in order to mathematically graph the pH scale and recognize it as a logarithmic scale. Furthermore, they would have had the opportunity to recognize that a difference in pH equates to a difference in the magnitude of the concentration of ions that are present in a substance. However, this was the only large activity that Mr. King and Ms. Taylor discussed that was not adapted from a pre-existing lab in science, which may be part of the reason why it was not implemented, since it would be more difficult to create the activity from scratch instead of adapting from an existing source.

*The predator/prey lab.* The predator/prey lab (not implemented) was mentioned during the first co-planning session as one of several labs that Ms. Taylor often implements with her class, as a connection with Mr. King finishing trigonometry in his Advanced Functions class. The project was brought back up toward the end of the semester, when Mr. King was approaching trigonometry in his Math 2 classes. The original lab, of which Ms.
Taylor was unsure of the origins, is implemented on a field such as a football field. Each student picks a card, which assigns different roles as either a deer, a resource, or a wolf. The students with the deer card then have to run across the field to find resources that they need and evade the student with the wolf card. Mr. King extended this activity to consider a model for population of deer and one for population of wolves. He related these models by discussing the series of transformations that would be necessary to do to one model to produce the other. Ms. Taylor shared an excel file with data from the previous year so that Mr. King could produce the models. Mr. King also considered finding the probability of survival for each deer, but decided against it because it would be complicated to accurately predict probabilities with so many variables.

This activity, if implemented, would have provided for students in Mr. King’s class a modeling situation for trigonometric graphs and their transformations. It would have also allowed students to track the predator/prey relationship more accurately, and to recognize the interdependence of species in the wild. Thus, it would have held direct connections between math and science, and toward the end of the semester, it would have been timely, since both classes were discussing content related to the lab.

The potato lab. Of the activities that were implemented, the first was the potato lab. Ms. Taylor had used this lab in the past, which came from a modeling curriculum that she commonly used. In contrast to other activities, this lab was discussed extensively over several co-planning sessions, and was almost the entire topic of discussion during one session (CP3).
In the original lab, students were supposed to submerge pieces of potato in a sucrose solution, and then measure the percent change in mass after one day. Mr. King and Ms. Taylor revised the lab to include an extension in which Ms. Taylor gave students a solution of unknown molarity. They also changed the directions from finding a line of best fit to an exponential curve. With these new revisions, Ms. Taylor was able to ask students to create an exponential regression equation to model the percent change in potatoes as a function of molarity of the solution. The students were to graph all of their data, including the values for their solutions of unknown molarity. Finally, they were to solve their regression equation to interpolate the molarity of the solutions. Mr. King produced a short video that Ms. Taylor showed in her class to help her explain how to find the regression equation and solve for the unknown. Related to this activity, Mr. King created an extra credit problem for his class to solve using similar data and a logarithmic curve.

Ms. Taylor was particularly pleased with the potato lab, because, she said, “I think that activity was meaningful, and an extension of what I wanted them to learn.” The students used mathematical techniques and concepts that they were currently learning in their AFM class in order to find information and answer questions regarding the tonicity of the sugar solutions with regards to the potato pieces. In addition, both concepts were timely in that the students were currently learning both the science and the math concepts that were in the activity.

*The leaf lab.* The leaf lab was the lab that Ms. Taylor brought up after the second whole group meeting (PLE2), and the teachers discussed implementation of the lab for an hour following this session. In the original lab, obtained by Ms. Taylor from an unknown
source, students were to force a solution of baking soda into sections of a spinach leaf, squeezing out empty space. This causes the leaf to become dense and sink. The leaves were then placed next to a light source, and as they performed photosynthesis, they began to float.

Ms. Taylor and Mr. King discussed ways to extend the lab to have students consider other variables in photosynthesis, such as distance to the light source, temperature, and light color. The original lab suggested graphing the number of leaves floating as a function of time. As part of the discussion about how students could extend the lab, Mr. King and Ms. Taylor discussed different ways in which the data could be graphed and different measures of central tendency that might be used to describe how long it took the leaves to float. Mr. King also mentioned extending the lab to include a situation in which students would look at each of the variables from the perspective of the owner of a greenhouse. Ms. Taylor did not make many revisions to the original worksheets that accompanied the lab, but she did write notes for herself of discussion points that she included during the class discussion of lab results. She reflected that the discussions with Mr. King influenced implementation of the lab in the class, and opened up discussions that she would have otherwise not had with her students. She discussed different types of graphs with her students, and was pleased with the graphs that students produced in their lab reports. In reflecting on this lab, however, Ms. Taylor mentioned that students need more practice with experimental design, and in reflection after the lab, brainstormed ways with Mr. King to create more of a focus on experimental design next year with her students.

Although there was potential for a variety of different connections through this lab, fewer connections were actually planned and implemented with this lab than the potato lab.
Although the students were working on a unit in statistics at the time of implementation of this lab in their science class, and some of the connections that were discussed were related to statistical graphing, direct connections to the content from the mathematics class were not explicitly mentioned. This makes the lab less timely than the other, although with more careful planning, it had the potential to easily span both subjects.

*The volume/surface area lab.* The volume and surface area activity was actually completed in Mr. King’s class after the intervention and final interviews, but it was discussed during the 5th and 6th co-planning sessions. The purpose of this activity was to demonstrate that cells of different shapes have a different surface area to volume ratio. In the activity, students slice potatoes into different shapes, and then soak them in iodine. They then calculate the surface area of the iodine-soaked potatoes, the entire volume, the volume of the portion of each piece that is saturated with iodine, and the ratio of saturated to unsaturated potato volume for each piece. The lesson in cellular biology is that cells with a higher surface area to volume ratio have more opportunity for diffusion through the cell membrane. In mathematics, aside from practicing how to find surface and volume for different shaped objects, Mr. King took the opportunity to connect the idea of surface area to volume ratio to cell division as well. By having students specifically compare two similarly shaped pieces of potato, one of which was double the diameter of the other, he was able to discuss that when a cell grows, the ratio of surface area is the square of the ratio of the size of the cell, and the ratio of volumes is the cube of the ratio of size of the cell, thus producing a need for cellular reproduction.
The volume/surface area lab offered a direct connection between the math and science concepts, as it used measurements and calculations obtained from the activity to connect the mathematical concepts of volume and surface area with the science principles of cellular diffusion and cellular reproduction. It was adapted from an unknown source, but largely rewritten to include all of the information that the teachers discussed. The lab was also timely in that the science class was working on cellular biology, and the math class was entering a geometry unit, which included volume and surface area.

Of the three larger activities that were implemented, 2 (the potato lab and the volume/surface area lab) offered direct connections between the science content and mathematics content that students were learning in their classes at the time of implementation. In the third (the leaf lab), connections to content that students were learning in both classes were drawn, but the written worksheet and directions that students received was not altered to reflect the changes in discussion. All three activities used graphing as a way to model scientific relationships, but these graphs were different among all three, demonstrating the difference in content in the mathematics class at each time in the intervention. In addition, in all three of the activities that were implemented, as well as the two activities that were not implemented, students completed physical activities, such as timing and measuring as an act of data collection.

**Co-planned math and science connections.** Several connections between current mathematics and science content were established during co-planning sessions, in addition to the larger activities, and connections to other related knowledge that was brought up as a part of many conversations. These connections were developed as either examples or possible
discussions for either Mr. King or Ms. Taylor to have with their classes that tie concepts together from mathematics and science. The number of these connections fluctuated from one session to the next, depending on the focus of the conversation during each session, but did not seem to increase or decrease overall over the course of the intervention.

As opposed to the larger activities implemented by this teacher pair, the connections that were discussed did not rely on students physically completing activities or collecting data. In several instances, these discussions made their way into both teachers’ classes, and may have been more cohesive than the larger activities for this teacher pair. For example, during the first session, the Scale of the Universe applet was discussed as a way to help students visualize the relative sizes of objects that differ by powers of 10. This was used to explain microscopic sizes in Ms. Taylor’s class, since she was beginning a unit on cellular biology, and to reinforce the concept of exponential growth in Mr. King’s class, since he was beginning a unit on exponential and logarithmic functions. As another example, during session 5, Mr. King and Ms. Taylor had a lengthy discussion about the similarities and differences among Punnett Squares and 2 way tables, and between theoretical and experimental probability. Both teachers used elements from this discussion with their students.

Mr. King and Ms. Taylor were able to successfully plan and implement both large interdisciplinary activities and smaller examples and discussion points between the math and science concepts from each of their classes. This is evidence that the ICT co-planning model worked for the two of them within the context of their school structure and belief system. To better understand the nature of the collaborations that took place which led to these activities,
I next share findings related to the pair’s actual co-planning process as they engaged in the ICT model.

**The Co-planning Process for King and Taylor**

Ms. Taylor had expressed concerns during the initial group meeting that she would not have the time to commit to co-planning. She said, “I’m just concerned that I might spread myself too thin and not give you quality work,” and added that she was already committed to a project with the English teacher, and working on her National Board certification. Ultimately, she decided to participate, because of the opportunity that she said they as teachers don’t take often enough. “I’m grateful to have a time, we need to do this, so that we do something that I feel, math and science departments, we try and do, but we don’t make that time to actually do it.”

Both Mr. King and Ms. Taylor seemed to easily fit co-planning sessions into their regular individual schedules. Since this teacher pair did not share a common planning period or lunch time, they co-planned after school one afternoon each week, generally on Tuesdays. These meetings often lasted about one hour, but on occasion went beyond 90 minutes. The teachers had ample time to discuss content and activities, explore possible connections, and reflect on lessons that they had co-planned. Although Ms. Taylor stated that she felt comfortable with the amount of time she spent co-planning, she commented during the second whole group session that co-planning time before the semester began would be helpful as well. During her final interview, she said, “I would say it would work really well if they were able to plan a couple of days before the semester started. Because then you don’t have a schedule to meet. I would say 3 or 4 days during, before you are actually teaching
your content. And then several days once a week for an hour.” This statement demonstrates that not only did she find the co-planning that they actually did valuable, by the end of the intervention, she was willing to increase the amount of time she spent.

Co-planning seemed to fit into the teachers’ planning routines at the daily level, but not at the most refined level of planning. Ms. Taylor stated that she enjoyed planning, and in particular, thinking about potential student misconceptions and how to alleviate them. She used state standards documents, textbooks, and other resources to write plans for herself at the yearly, unit, weekly, and daily levels. Ms. Taylor often brought materials that she had been thinking of implementing to co-planning sessions to discuss, and then refining them after co-planning, but before using them in her class. Although it was evident through discussion with Mr. King that he gave thought to planning, especially at the yearly and unit level this was mostly a mental occurrence for him, and he reported using his Smartboard slides as his daily lesson plans. Mr. King admitted by the end of the intervention that he would experience more success if he would take the time to create more detailed plans, but that was not a priority for him. This resulted in Mr. King often contributing to co-planning sessions, but not following through after the session to incorporate the connections that were discussed into his lessons.

During most co-planning sessions, the teachers completed multiple tasks, between reflecting on past topics and/or activities, discussing upcoming content, and planning future activities. In addition, during several sessions, they spent a majority of time on one particular focus. For example, during session 1, the focus was on establishing a variety of connections, but during session 3, the focus was on refining one particular activity. This teacher pair also had one extra unscheduled planning session, after the second group meeting, because
Ms. Taylor wanted to discuss connections for an upcoming lab. Thus, the number of topics and connections that Mr. King and Ms. Taylor discussed varied from one session to the next, but did not seem to overall increase or decrease over time.

The teachers seemed to alternate mostly between talking about content, activities, and students. Figure 1 lists the frequency of the codes that were applied to co-planning session conversations. The list on the left depicts the codes in order by type, including sub-codes. The list on the right depicts the codes in order by frequency of application. For example, highlighted code, ICTP-CONT-math/science connection (coded for the ICT process, in the category of content, specifically about discussing math and science connections) occurred 53 times. On the left, it is categorized among the content codes. On the right, it can easily be seen that it is most frequently occurring code for this teacher pair.

Figure 11. ICT process code occurrence for King and Taylor case
For Mr. King and Ms. Taylor, most of their co-planning time was spent focused on discussing content, projects and activities, and students. As such, these data will be further examined, and will be discussed in the remainder of this section. Other comments, such as those about beliefs or logistical responsibilities, were also made, occurred less frequently, and did not seem to affect co-planning sessions, so they will not be discussed, except as in reference to content, projects and activities, and students.

**Discussing content and connections.** Mr. King and Ms. Taylor discussed mostly current and upcoming topics in math and science, and mentioned past topics relatively few times. Generally, about 2 upcoming topics for each subject were mentioned during each co-planning session. Often, these marked the beginning of a new segment of conversation, and were followed by clarification of particular content. For example, the following exchange was toward the end of a session, but it marked a shift in conversation from the project that the teachers were discussing immediately before:

Taylor: I will be talking about genetics - I was trying to calculate how much….

In about 3 weeks. We’ll be talking about biodiversity.

King: Yeah, you’ll be doing probability then. Punnett squares.

Taylor: Oh yeah. I guess we’re not lining up that much right now.

King: They don’t have to be taught concurrently. We did combinatorics - permutations, combinations last week.

In this example, the focus shifted from the prior topic of discussion to Ms. Taylor’s upcoming content. Mr. King asked a clarifying question and offered the content that he had been teaching. After the above exchange, Mr. King and Ms. Taylor continued to discuss the
connections between Punnett Squares and combinatorics, specifically comparing and contrasting Punnett Squares and 2-way tables. This check for upcoming content was important throughout the co-planning process because it helped the teachers to focus on the connections that would be relevant to both curricula in the near future.

Mr. King and Ms. Taylor also often mentioned knowledge that was related to the topic of discussion, but not a part of either or their curricula. There were few occasions where the related knowledge seemed to be tangential to the co-planning discussion, but more often, they were brief, and there was a purpose for putting forth the knowledge. For example, Mr. King mentioned the concept of absolute hot during a discussion of exponents and conceptualizing large and small sizes:

I’ve learned recently the concept of absolute hot. I’ve heard of absolute cold before, like 0 Kelvin. There’s an absolute hot. I can’t even remember how many zeros it is. Like 15 trillion degrees or some absurdly hot number. So, I’ve seen a logarithmic scale of everything from absolute zero to absolute hot, and the reason that it is a reasonable size is because it is logarithmic. Otherwise it would just be… I mean 15 trillion degrees, it’s so far away. The difference is unfathomable. It’s literally unfathomable.

During another occasion when Ms. Taylor was explaining vocabulary for cell phases, the following exchange occurred:

King: All of these are Greek prefixes, did you know that?

Taylor: Oh no, I didn’t.
King: I can’t remember all my prefixes, but pro means before, you know that’s obviously the first phase. Meta is during. Ana is - I think it is against. And their prepositions can mean more than one thing, just like ours can. But telos is a noun, actually. Telos is the end goal of something.

Taylor: Oh, nice. I’ve heard it pronounced telo-phase. But I think most Americans pronounce it telophase.

King: Because of telephone, yeah. But telophase, telos - so like,

Taylor: I always wondered why they said telo. That’s why.

In both examples, the knowledge was related to one teacher’s curriculum, but not the other. In the first example, it was in relation to the logarithmic scale in mathematics, and although Ms. Taylor’s science class was learning about size relationships about cells, it did not relate to her content. In the second example, the discussion of Greek prefixes was related to the cell division that Ms. Taylor was teaching in her science class, but not to anything in Mr. King’s math class. These examples demonstrate the diverse amount of knowledge that both Mr. King and Ms. Taylor brought to co-planning discussions, ready to make connections, not just between each other’s curricula, but with any reasonably related knowledge.

Ms. Taylor offered related knowledge when discussing statistical analysis and standard deviation. “When I worked in the hospital, we would run our controls every day to make sure our data was valid. And we had names for it, like if it was 1 standard deviation - we wanted it within 2 standard deviations.” This, however, differed from the above examples because it described an experience that was loosely connected to both curricula, because the
topic of discussion in mathematics was standard deviations in statistics, and in science it was biotechnology.

In one final example of related knowledge, the economics teacher interrupted a co-planning session one time to ask how to best draw a graph on the computer for a worksheet. Mr. King asked more about the content and context she was using it for, which initiated a small conversation about independent and dependent variables as they relate to supply and demand curves. Although this was not part of the content that we were describing in math and science when the economics teacher walked in, it became an informative part of conversation for both Mr. King and Ms. Taylor. This example also demonstrates how Mr. King and Ms. Taylor approached the conversation with the economics teacher with an open mind. They thoughtfully discussed the concept that the teacher was trying to convey as well as answering the original question of how to produce a worksheet quickly and efficiently. This type of thoughtfulness may be attributed to their regular co-planning experience, in which they look for conceptual connections instead of simply looking for ways to teach their own content.

Most often, connections were either couched in or led to segments in which the teachers discussed or clarified content, or drew connections among their content. Depending on the session, sometimes more science content was discussed or clarified, and sometimes more math content was discussed or clarified. Discussion of both content areas took similar forms, sometimes in more abstract terms, and sometimes in the context of a lab or activity.
Often, excitement or awe about a particular concept was expressed through a description of the concept. In one example during a discussion of the logarithmic scale, Mr. King described his appreciation for large numbers:

It’s really a frustrating thing - our brains don’t think logarithmically. Sure, we can bring it down, but we can’t truly appreciate it. Even with that interactive. To really appreciate what 10 to the 9th meters is, you’d have to walk it. You know what I’m saying? Or get in an airplane and back away from it. I don’t even know, what is 10 to the 9th meters, that’s like to the sun? Or not quite, but you know it’s this literally astronomical distance.

In the above example, Mr. King expressed described his appreciation for large numbers in order to convey the point that large numbers are difficult for students as well as adults to think about in a realistic manner.

Often, a segment would serve several purposes. For example, in the following exchange, Mr. King is asking Ms. Taylor about independent assortment in order to describe 2 way tables that he teaches in his class, and both concepts are described so that both teachers had an understanding of how they are used in each class.

King: If these were completely independent of each other, what would you expect? What percentage of males would you expect to have blue eyes?

Taylor: If it was 25%, I would expect 25% of the males.

King: If you expect 25% of the males, then let’s look at the males. I have 2 out of 8 males have blue eyes, and that’s 25%. So, because these are
very close, and in this case, exactly the same, in this population, these are independent events. So what I do with my students.

Taylor: Ok, so if you have another one that said skin cancer - and whether

King: And whether you’re black or white. Yeah.

Taylor: Then there would be a relationship between being light skinned and having skin cancer.

King: Exactly. Then that would be - then you would have different percentages. So what I always try to do with the kids - I try to pick things that are not too sensitive topics. You know? We’ll compare - we always compare - we’ll pretty much compare males to females, and then what color they like. You know? Whether they’re a gamer or not. And we’ll pretty much test stereotypes in our classroom. And I always have a little conversation with them about

Taylor: They probably enjoy that because it’s something for them to relate to

Facilitator: So now how similar is that to what you do now as far as independent traits. Or, is that what you call it?

Taylor: We call it independent assortment, which is actually an oversimplification, but it works for our class. Basically the concept of independent assortment is that your traits are not necessarily going to be inherited together, so you could have some of the traits, like your mother, on your chromosomes, would be more - you know, you would
have different chromosomes from different parents that would give you different characteristics.

In the above excerpt, the teachers described probability in genetics in tandem with 2-way tables in statistics for the purpose of finding the relationship between the two. This type of segment was common when the teachers were working to establish conceptual connections outside of the discussion of any project or activity.

Many times, one of the teachers asked specific questions about content in order to describe or discuss particular connections. For example, during a discussion of pH, as it related to the logarithmic scale, Mr. King said:

What I was trying to get back to was thinking about the extremes, when you’re at the very lowest pH and the very highest pH you could be at, is that something that at this level you can wrap your mind around, you can just talk about your hydrogen ions, and you can say, at a very, very low pH, are we approaching something?

Ms. Taylor described the difference between pH and pOH. Mr. King then remarked, “Is it possible to have one group do pH and one group do pOH? And then just point out - hey, you just reversed your scales. Then that’s a reflection across the line x = 7.” In this example, Mr. King needed to ask specific questions about how pH worked before he could articulate his idea for connecting it to his content. Once his questions were clarified by Ms. Taylor, he was able to proceed. Questions and clarifications such as these were often relied on by Mr. King and Ms. Taylor in order to self-assess the feasibility of connections before they articulated them.
Many times, discussions combined content with the details of a project. In the following example, asymptotes were described in terms of the context of the lab, and also compared to the idea of carrying capacity in science.

King: Yeah. There’s some, theoretically, at least, there’s some line, some y value, some percent mass change that no matter how high the molarity in the sucrose is in the solution, the potato is just not going to get any lighter. Do you see what I’m saying? It’s not going to. And so there’s some theoretical limit to how much weight the potato is going to lose.

Taylor: Ok, so some y value that is no longer going to matter if I have a higher and higher concentration.

King: Right. There’s a theoretical limit to how… it’s kind of like a carrying capacity problem. Right? Like it doesn’t matter, right? Like, that’s how many rabbits this island will support before they start dying off.

It’s a limit.

Taylor: Yeah.

King: So that’s what an asymptote is.

In the above example, the context of the lab created a situation in which Mr. King could describe a mathematical concept clearly and efficiently, so that Ms. Taylor would be able to relay the same concept to her students. This became an important part of integrating mathematical concepts into Ms. Taylor’s pre-existing science labs because it provided her with specific ways to relate otherwise vague connections.
Both Mr. King and Ms. Taylor shared expertise in their own subject area that helped to determine connections between content. During one session, Mr. King and Ms. Taylor had already described their upcoming topics as angles in geometry and macromolecules in science. Mr. King joked about “the angle of depression to the macromolecule” because he was not seeing an immediate relevant connection. Ms. Taylor said, “Actually, we talked about saturated lipids versus unsaturated lipids. We talked about when we looked at a saturated lipid, the carbon chains have all single bonds.” She described the shape of each type of molecule, including the angles created by each of the bonds, and the reason why different types of fats are often found in solid or liquid states of matter. This lead into a conversation about the law of sines, which Mr. King had taught that day in class, and that it is important to check that the longest side is across from the largest angle. While it was not immediately apparent in this example that there was a connection between the content areas, it was Ms. Taylor’s expertise and commitment to explain the details of a concept that led to the teachers finding this connection.

Finally, regarding the discussion of content, Ms. Taylor began to ask for help regarding specific science concepts that are mathematical in nature. This type of asking her colleague for advice cuts across lines of science and mathematics in order to serve student understanding better. For example, in the segment below, Ms. Taylor asked for advice in explaining how to create genotypes for Punnett Squares.

Taylor: They don’t have a hard time filling in the results. They have a hard time filling in what we call the genotypes. The options - does that make sense?
King: They have a hard time, like when I ask them when you flip three coins. They have a hard time listing all possibilities.

Facilitator: Do you do tree diagrams?

King: Yeah, the tree diagram that you draw is generating the same list as the box there. So what we do is literally start with all the possibilities for the first one, and then draw a tree because what it does is it makes them visually make comparisons. So parent 1, gene A, could have this or this. And then parent 1, gene B, could be this - you know, big B or little b. And you do this for each gene.

Taylor: And they know to write big A, big B, big A, little b, little a - what is this called again?

King: Tree diagram.

In the above example, Ms. Taylor is not looking for a mathematical connection as much as an idea for how to get students to understand a concept in her own content. The given advice reflects math content, but is a more practical response for how a teacher with a different set of expertise might go about teaching the concept that Ms. Taylor explained from her own curriculum. As the intervention progressed, Ms. Taylor found value in this type of advice and asked questions such as these more often.

**Discussing projects and activities.** Quotations involving projects and activities were initially coded in four categories: mention/describe existing project, possible project/activity, details for connected project, and reflect on project/activity. Existing projects were mentioned at most sessions throughout the intervention. Some of these were peripheral,
either mentioning a project that was already planned to occur in the near future, or one that
had just passed. For example, when asked what she does with enzymes, Ms. Taylor replied,
“It depends. I’ve done a couple of different labs. Sometimes, we do more qualitative
observations. I do one lab where pineapple juice disrupts the process, basically, what makes
the jello solidify.” However, in two instances (the potato lab and the leaf lab), Ms. Taylor
brought an existing lab to the co-planning session, and the majority of the time was actually
spent determining connections and refining the lab so that it conveyed the connections that
the teachers discussed. When describing successes at the end of the intervention, Ms. Taylor
mentioned those two labs as her most successful connections throughout the project.

Both teachers frequently described concepts to each other in the context of an activity
or lab in order to gain more insight into the particular lab or the connections that they were
attempting to create. For example, in describing the potato lab, Ms. Taylor said:

I want them to understand that if the cell is increasing in mass, it’s in a state of
hypertonic. When it crosses the x axis, that’s isotonic because there’s no water
leaving the cell. And when it’s negative, it’s hypotonic because it’s losing mass.

Water is leaving the potato cell and entering the solution.

This type of description was more common for science content than math content, and was
useful to the teachers to give concrete examples for concepts that they wanted students to
understand through an activity.

Possible projects or extensions were often mentioned in reference to the lab that was
currently being discussed. For example, when discussing the potato lab (described in the
content section), Mr. King said:
What we could do with our students - I want to show them that if you change the window, the graph looks different. So, perhaps, you could just stretch the data out - make your molarities further out for one group than another, or cover a different range?

In the above excerpt, Mr. King wanted to extend the current project by using the data to demonstrate to students the difference in the look in the graph given different graphing windows. Although this particular idea was eventually discarded because of the impracticality of preparing solutions of the molarities that Mr. King wanted, this type of search for connections or extensions was typical of discussions regarding activities and projects by this teacher pair.

Details for upcoming labs included describing procedure for the lab, exploring data, explaining specific content involved in the lab, and reading through and extending questions on the lab.

For every lab or activity that was discussed, there was usually some type of conversation in which the procedure itself was described, and then other mention of what students should do or learn through the activity. For example, regarding the leaf lab, Mr. King asked questions such as “How big is the cup of water?” and “So it’s forcing it full - replacing the oxygen inside the leaf?” In discussion of the potato lab, Ms. Taylor described student specific procedures: “What will happen is they will collect their data and we will do a whiteboard meeting. They will basically have, what was their hypothesis, what their graphical data is, a pictorial representation, and what they conclude.” Procedures for calculating and manipulating data were also described. For example, Mr. King said, “So what
I am going to do is $y$ equals, and then do the vars. Stat, RegEq. It’s going to be 30 above it, we’re going to see it coming in above it, here we go. I’m just going to subtract 30 from that.” This type of comment was usually not to create a connection, but to make sure both teachers understood the activity, from which they would both build.

Specific data was explored, particularly for science labs. For example, comments were made about the potato lab such as “See how it is leveling off,” “so, it looks exponential,” “the data has a pretty good fit,” and “Our x’s go from 0 to 1.2, so I am going to go from 0 to 1.5.” Often, data was explored in the context in a concept that was previously discussed. Regarding the same lab, Mr. King described the data: “Because see how it is leveling off? There’s some natural barrier,” referring back to the previous conversation about asymptotes. The teachers were able to make progress, particularly using math skills to interpret science phenomena, by specifically analyzing data from the labs that they discussed.

Reflections about specific activities or labs often revolved around labs that Ms. Taylor implemented with her students. Mr. King did reflect on some of his lessons, but these were generally more of an aside or quick mention. For example, he described his extension of the potato lab to his class. He said, “I actually used Ms. Taylor’s data as an extra credit problem. It didn’t go over as well as I - it was optional, so some students were actually like, I just read my book.” This is representative of several examples that were briefly discussed by Mr. King, but no plans were made for further action, and the emphasis seemed to be on describing for the purpose of the study what interdisciplinary connection was made.

Ms. Taylor, in contrast, seemed to devote much time to reflection on her teaching. She often wrote notes to herself regarding specific questions within labs, and when planning
for labs, used notes from the previous year to help her make decisions. Many of her reflections revolved about student understanding. For example, she said, “That’s one thing I thought was really successful, is that the students were able to estimate. And to me it kind of gave them a practical application before you talk about the nitty gritty of mathematics.” She discussed the choice to use a video: “I think that helped them in the video. And they saw, they estimated that based on the percent mass change it should be close to .4 or .5 molarity. And, when they did their calculation, it was .498.” Ms. Taylor often wrote notes during co-planning sessions to keep with labs that she reflected over, and considered these helpful for planning the next year.

**Discussing students.** Comments involving students typically were made in reference to either student motivation or students understanding a particular lab or activity. Toward the beginning of the intervention, some comments were made about the amount of students that both teachers shared. For example, Mr. King said when a student interrupted the co-planning session with a question, “There you go. There’s at least one student that’s in AFM and Biology,” which opened a brief conversation of how many students both teachers have in common.

Mr. King made assumptions about student motivation. He said regarding the “unknown” element of the potato lab, “I think that every student’s going to – if I was a student I would not want to screw that thing up. That’s the one thing in the lab that I would want to get right.” Later, he reflected on his extra credit problem in terms of student motivation. “They didn’t bother. I think I spent 20 or 30 minutes writing it while they were testing, and I was like, I just finished writing it, and they were just like I’m just doing to keep
reading my book.” Ms. Taylor also commented on student motivation in terms of their work habits. “I just wish my students would be that excited. Some of them will be, but most of them are like, what’s the right answer.” These comments about motivation did not seem to change any of the actual plans that the teachers made, but they were made as more of an aside about how they thought students would react to various activities in their classes.

As seen above, many quotations involving content and activities consider student understanding. For example, in asking for advice, Ms. Taylor said, “They don’t have a hard time filling in results. They have a hard time filling in genotypes.” Procedures for labs generally described what students do. In consideration of specific lab questions, Ms. Taylor considered student responses: “So I could have a student who says we don’t need to do this because it crosses the x axis right here?” In reflection, she also considered student understanding when she said, “They actually got a negative logarithm, and I appreciate that they could just say that just because the calculator spit out a negative number doesn’t mean that’s possible.” These examples demonstrate an awareness that the teachers in this case had of students. The teachers did not express a focus on individual students, but more of a general awareness that the purpose of the labs or other activities were student understanding, and that without student understanding, the lab would be pointless.

Overall, although Ms. Taylor both planned and reflected much more than Mr. King, both teachers integrated co-planning sessions into their regular planning routines to meet once each week. The teachers did not talk to each other between sessions, but they expressed that they had enough time during sessions that they did not feel a need to talk between sessions. They discussed content, projects and activities, and students, and drew many
connections between content areas. Discussions of activities were sometimes peripheral, and sometimes very detailed, depending on the co-planning session. Discussions of students were fewer, but represented a backdrop of student understanding that must be accounted for and present in each connection and activity that was discussed. In the next section, the teachers’ beliefs will be discussed, both how they influenced and how they were influenced by participating in the co-planning intervention.

**Beliefs and the Co-planning Process for King and Taylor**

Both the co-planning process and the plans that Mr. King and Ms. Taylor made were influenced by their beliefs about science and mathematics, about teaching and learning, and about interdisciplinary connections. In turn, some of these beliefs were influenced by the discussions and planning that the teachers experienced as a result of participating in the co-planning intervention. The beliefs discussed in this section are based on the beliefs expressed by each teacher during individual interviews. Beliefs that were expressed during whole group sessions and co-planning sessions were also taken into account in order to verify and triangulate whenever possible. Beliefs in each area are discussed separately below.

**Beliefs about the nature of math and science.** Both Mr. King and Ms. Taylor seem to see the purpose of their own subjects as to investigate and understand the world around us. To Ms. Taylor, the investigation aspect seemed predominant in her definition of science. She stated that science is “a creative, innovative investigation of ideas, where you have a systematic method, or at least, you get closer to systematic as you investigate.” For Mr. King, the emphasis seemed to be on understanding. Mr. King said that math is “a way to interpret and quantify the world around us and the world that’s not around us, kind of. It
exists in abstraction [too].” He later said, “It’s incredibly important to be able to model things,” reaffirming his position that mathematics provides a way to understand a variety of situations through modeling.

Both teachers readily defined mathematics in terms of its utility for science. Mr. King said, “It’s known as the queen of the sciences. So it’s an interpretive tool for science. It’s how we do science. You couldn’t do empirical, quantitative observations without it. Science would be kind of speculative, I guess.” Ms. Taylor said that math is “the language of science.” She added, “If you don’t understand basic mathematical functions, you’re going to have trouble understanding anything in biology or chemistry.” These beliefs about mathematics being the language of science worked well for this teacher pair. Mr. King was teaching Advanced Functions and Modeling, which was a class designed to help students use math to model and interpret many types of contextual situations. Ms. Taylor’s Biology class provided a context for many math concepts, and Mr. King’s math class provided the “language” with which to describe biology concepts that Ms. Taylor wanted to enhance.

Mr. King and Ms. Taylor seemed to be relatively unchanging in the above aspects of their beliefs about the nature of mathematics and science, and provided similar statements at the beginning and end of the intervention, as well as throughout co-planning sessions. However, as is evidenced below, Mr. King and Ms. Taylor did not coincide as neatly in their views of what it means to “do science.” Ms. Taylor seemed to initially hold a more active view of science, including multiple trials and persistence. She stated:

I think science is really about having a creative question, finding a way to investigate that question, and coming up with the results. I think science is really, really creative,
even though we think of science as being set in stone for some reason. I guess to me, science is really meant to be an experience, and often an experience in failure. Mr. King defined science as “an attempt to understand the world around us through observation,” in which “we pose a hypothesis. We create a scenario to test our hypothesis. And that’s kind of the experiment. We’re creating the space for the observation to happen.” By the end of the intervention, Mr. King seemed to have acquired an appreciation for scientific inquiry. He reflected, “When I was in high school, we performed very few labs. Science was knowledge, not a process. Ms. Taylor takes a different approach, one which I think is better. I have been greatly encouraged by the ways in which the math which I teach can enhance the scientific process in her classroom.” While Mr. King continued to express a belief during his final interview that science is an attempt to know things, he seemed to amend his view. He added, “Science, more generally, maybe, is the process by which we obtain that knowledge. I mentioned the scientific process - just whereby you test things. You make hypotheses, and you see if they work.” This change in Mr. King’s attitude toward science seems to be influenced through co-planning by noticing the labs and other activities that Ms. Taylor implemented with her students, and recognizing the benefit that these activities have had on her students’ learning.

Ms. Taylor also mentioned her lack of knowledge with both the content of mathematics and use of the graphing calculator, but seemed open to learning as the intervention progressed. For example, at the beginning of the intervention, Ms. Taylor said, “I don’t think I could teach math.” However, she persevered. During a later co-planning session, she said, “My problem is that I kept trying to do a linear line. And I knew it wasn’t a
linear line, but I couldn’t remember how to solve if it’s an exponential.” She later reflected, “I struggled with using the graphing calculator to derive the exponential regression curve. However, I practiced going through the motions many times so that I could better anticipate what questions they might have.” These comments reflect that Ms. Taylor was open to learning how to use mathematics to benefit her labs and her students.

Seemingly contrary to her belief that science is about “multiple trials” and “creativity,” Ms. Taylor was often quickly dismissive of “bad data” during co-planning sessions and reflections. For example, instead of thinking about the process and data point, she made comments like, “And that is one of the disadvantages of me just doing one trial.” She did recognize this deficiency, “I just keep looking at it as that’s just a faulty point, and I wasn’t even trying to see where it came from.” Even when she was gathering data to preview a lab that she would implement in her class, she “took off last couple of data points because it didn't change anything.” She did not see the points as outlining the horizontal asymptote in the graph, only as data that is irrelevant because it was not different than the data before it. Co-planning discussions with Mr. King may have helped to alleviate some of Ms. Taylor’s focus on bad data, because the teachers would discuss the data and determine whether there are other underlying reasons for it before it was dismissed as “bad data.” Ms. Taylor did not appear to give up her tendency to blame “bad data,” but she was willing to discuss problems with data from a mathematical and contextual point of view, which may serve to soften her position over time through more co-planning.

**Beliefs about teaching and learning.** Both Ms. Taylor and Mr. King seem to have beliefs about teaching and learning that conflicted with their beliefs about the nature of
Ms. Taylor openly expressed this conflict. “I guess I’m always at odds between what I am responsible for making sure the students learn based on the NC state curriculum, and based on the standards and what I actually think science is.” She added that she does not want her students to only know “a list of terms in a textbook, which is kind of the way I think we’re encouraged to teach science.” For example, she discussed the use of reference sheets, which all students in Biology use for the standardized end of course exam. “I have no problem with students having reference sheets, because real scientists don’t have every formula memorized. But this [sheet] offends me because it’s like, you’re too stupid to rearrange a formula.” Because of this internal conflict, Ms. Taylor stated that she tries to balance what she tells students with what she encourages them to experience, and what is on the state standards documents with what she feels they need most of for college. She said, “I know they have to do lab reports and they have to do labs.” Ms. Taylor also believed that she has a responsibility to “not just to teach literally my subject, but I also teach them 21st century skills. How to use technology. How to find a good resource. How our content crosses over. Literacy skills. Math literacy skills.” Although she expressed the tension that she felt with these competing views, Ms. Taylor mostly planned and co-planned based on her perceptions of what students need, rather than her perceptions of pressure to “teach the test.”

Mr. King did not explicitly describe his conflicting beliefs about teaching mathematics, but he consistently described mathematics in different terms when discussing the subject itself or his beliefs about teaching students. Although Mr. King stated a belief about the nature of math as “a way to interpret and quantify the world around us,” his driving belief about teaching high school mathematics, and actually all high school curriculum is that
it is “about teaching them to think.” He reinforces this more abstract view of mathematics: “Teaching math is not about teaching things that they’re going to use in their jobs. Almost to the student, they’re not going to be using it. Maybe if they teach math. I often tell them, I’m teaching them how to think.” His statement, “A lot of times, I should be ashamed of this, I suppose, but when there’s a word problem, I’ll say, we can just get the numbers. In my defense, or in a critique of the textbook, sometimes they’re just hanging numbers out there,” demonstrates the conflict in his beliefs between the utility of mathematics and the purpose of teaching high school mathematics to his students.

Both Mr. King and Ms. Taylor seemed to structure their class routine and their personal planning routine and use of resources around their beliefs about teaching and learning. Mr. King stated that he used a fairly traditional daily routine of homework review, warm-up, lecture, and practice. Ms. Taylor’s daily teaching routine varied, but she said, “I try really hard to make the topics relevant and real works. I try to do a lot of experiments.” Ms. Taylor discussed project based learning and why active learning is important for her in her classroom. “I think just seeing the application. Just seeing when people actually use those formulas, or what would it look like when someone actually does this.”

Neither Mr. King nor Ms. Taylor seemed to have changed their beliefs about teaching greatly over the course of the intervention. Ms. Taylor planned and implemented several labs, demonstrating her commitment to student learning through experience. These included, the potato lab and the leaf lab, described above in the section about plans. Throughout the intervention, Mr. King seemed to demonstrate his conflicted beliefs about mathematics being about application, and the purpose of teaching mathematics for students to think abstractly.
However, he seemed to have found value in Ms. Taylor’s inquiry based approach to teaching. During a later reflection, Mr. King wrote:

   Before this project, I most valued learning that was driven by curiosity. I wanted students to feel a sense of accomplishment when, say, deriving the Law of Cosines. I'd say that my view has not changed, but I recognize that if students are motivated to discover by the scientific process, then this ideal is more likely to be achieved.

This comment, influenced by Mr. King’s observation of Ms. Taylor’s insistence on labs and other activities, demonstrates that Mr. King was beginning to notice the value of Ms. Taylor’s approach to teaching.

Mr. King and Ms. Taylor also discussed student ability several times over the course of the intervention. Ms. Taylor viewed her students as creative and intelligent, and this view has been enhanced over the course of the intervention. Mr. King seemed to oscillate between beliefs about the ability of his students. At during one co-planning session he said, “I think they might surprise you sometimes,” to which Ms. Taylor replied, “They did. They knew the math better than I did. I just had to open a door for them.” Ms. Taylor expressed growth in her belief in her students’ abilities. In reflection about the potato lab, which included large connections to mathematics, she said, “I think that I just had to tell myself that it was ok. That the kids could help me do it better than I could help the students do it. And be ok with not being in control, which is kind of uncomfortable.” She added, “I think I wrote in my reflection that that was a big success.” These statements demonstrate that even though Ms. Taylor held an inquiry view of teaching, the co-planning process still helped her to overcome
other, more traditional ideas of teaching, and to find value in an even more student centered approach.

Overall, both teachers held conflicted beliefs about teaching and learning, which led to apparent inconsistencies in their teaching. Mr. King thought of mathematics as application, but the teaching of math as abstract. Ms. Taylor thought of science as inquiry, but she felt external pressures to teach in a more traditional way. Ms. Taylor may have helped Mr. King to see the value in a more inquiry based approach, and Mr. King may have helped to push Ms. Taylor toward an even more student centered approach by providing the opportunity to grow her trust in her students’ abilities.

**Beliefs about interdisciplinary connections.** Mr. King and Ms. Taylor both expressed a consistent belief that the relationship between math and science is that “math is the language of science.” Mr. King said, “You can have qualitative experiments, but math is the language that makes science happen.” Ms. Taylor stayed in agreement, “You need mathematics in order to do science. If you don’t have math, you don’t have science.” Mr. King stated several times throughout and at the end of the intervention that he also uses science as “fodder” for teaching. “And, I’m ok using science, because I expect science teachers] to use math as well.”

While both teachers were unwavering in their belief that “math is the language of science,” aside from data collection, they initially had vague ideas of the types of connections they would find between science and math. Both Mr. King and Ms. Taylor seem to have formed their beliefs about the types of connections based on limited past experiences. Ms. Taylor mentioned that before the intervention, she had not worked with the math teacher, but
had done projects with the English teacher because they share exactly the same students. Mr. King said that his exploration of interdisciplinary connections was “tangential and not that often,” and discussed his prior experience with an instructional coach that tried to help him make connections to literacy that were forced and tenuous at best. At the beginning of the intervention, Mr. King stated, “I guess my greatest fear is that it would be the same connection every week,” referring to linear regression, which he had already taught and did not need to review.

Toward the end of the intervention, Mr. King said that he learned to pay closer attention to the data produced by his colleagues; that it is useful for a much wider variety of modeling functions than he had previously thought, citing the connections that they had drawn throughout the intervention as evidence. Ms. Taylor mentioned that it would have been easier to align content if she was teaching Chemistry instead of Biology, but, she added, “I think in a way, it’s more creative the way we get our content to line up in biology and AFM.”

Ms. Taylor went into the intervention with a concern in her own ability to draw connections. She said, “I wish I was better at the other subjects. I wish I knew more. I’m sure there are so many opportunities I’m missing, just because I’m not as well rounded as I should be.” As the intervention progressed, however, Ms. Taylor found value in the types of connections that the combined expertise of both teachers could develop, which she said she would “never think of on my own.” Regarding microscopes and scale, she said, “Yeah, I kind of mindlessly teach them every year, but yeah,” referring to the connections between relative size and exponents that the teachers realized. Regarding the potato lab, she said, “I
don’t think I ever would have come up with this, I mean there’s no way. I probably would have had my students get to what you saw in the lesson where we estimated.” These examples demonstrate the new confidence and value that Ms. Taylor placed in co-planning, and in relying on the expertise of another teacher.

Mr. King also found value in discussions with Ms. Taylor. He reflected, “When I plan alone, I am primarily concerned with demonstrating how. ICT gives me more of a why. I have always been aware of the necessity of math, but planning with a science teacher demonstrates that.” In a later reflection, he wrote, “I have grown most in my understanding of how my coworker teaches. When I was in high school, we performed very few labs. Science was knowledge, not a process. Mrs. Taylor takes a different approach, one which I think is better. I have been greatly encouraged by the ways in which the math which I teach can enhance the scientific process in my classroom.” These comments demonstrate the changes in Mr. King’s beliefs about his ability to use science in his own classroom, as well as his appreciation for the value of listening to his partner’s expertise throughout the co-planning process.

Throughout the intervention, Ms. Taylor was appreciative of the expertise that her partner offered in mathematics and general knowledge. Regarding the leaf lab, she said “The biggest success was just having the second perspective on the project.” Regarding the entire intervention, she stated, “Now I see the value in simply talking about what I am doing in my class. Then afterward asking for cross-curricular opportunities that are obvious to a different content expert. The ideas that Mr. King has shared with me have exceeded my expectations.” This shift was major for Ms. Taylor because she now values talking to the math teacher on an
ongoing basis, and not just when she has a question. She expressed that this also helped her shift from math as an extra to “how can we connect to math” becoming part of her regular thinking and planning. She added, “I do not know that this project has changed that opinion, but it has given me another avenue to accomplish this goal.” Mr. King offered a similar, but more general statement. “I think I’m much more – I think it’s worth talking to a science teacher if I have a question or if they do. I think communication between teachers across curricula is a good thing.”

Overall, Ms. Taylor and Mr. King did not dramatically change their beliefs about the nature of mathematics and science, and about the nature of teaching and learning. Their comments about their understanding of each subject and the purpose of teaching each changed little over the course of the intervention because they were more aligned with their co-planning experiences. However, both teachers entered the intervention slightly skeptical of the amount and depth of connections that they would be able to make between their classes. They experienced through the intervention a variety of connections, which they were able to implement in their classes, and moreover, they found the value of discussing their content with a colleague of a different subject expertise.

**Summary for the King and Taylor Case**

Mr. King and Ms. Taylor are a case of teachers who discovered value in academic discussions with interdepartmental colleagues. They were high school teachers with 5 years of experience, who participated fully in the interdisciplinary co-planning intervention. The teachers came to co-planning sessions prepared to discuss their upcoming content, draw connections, which fit in naturally as a part of their planning routines. They created several
larger activities as well as smaller connections, which they implemented in their classes, although Ms. Taylor seemed to be more successful at implementation than Mr. King because she planned for her classes more thoroughly than Mr. King.

During co-planning sessions, the teachers discussed content, activities, and students in an attempt to refine plans. They spent some sessions focused on one activity, and some sessions discussing a variety of connections between several topics. In addition, they discussed student understanding, and Ms. Taylor spent time reflecting on co-planned plans that she implemented in her classes.

Mr. King and Ms. Taylor seemed to be fairly stable in their beliefs about mathematics and science, and about teaching and learning, but they found ample room for growth in their beliefs about interdisciplinary connections, and in interdepartmental collaboration. They found value in each other’s expertise, and in asking for general as well as specific advice on a regular basis to enhance lessons and look for connections. Ms. Taylor commented during her final interview, “I think what we did was needed and it’s something that I want to continue to do,” demonstrating her desire to continue to co-plan the following school year.

**Chapter Summary**

In this chapter, each teacher pair was presented as a case. For each case, background information, the plans the teachers created, the co-planning process, and the influence of and on the teachers’ beliefs were thoroughly discussed.

In the case of Miller and Smith, both teachers were experienced 8th grade teachers. Both believed that teaching their respective subject involved having students experience relationships within the subject, but were less confident in their roll regarding the opposite
subject and interdisciplinary connections. They met weekly during their planning period, and also talked to each other in between meetings to share excitement or seek advice. They talked about content, activities, and students in a connected way, but focused mostly on the details of specific projects and activities. They created or adapted several larger activities and some smaller examples and discussion points, and found several types of interdisciplinary connections. By the end of the intervention, they stated that the largest change in beliefs for them was a mindset shift from making interdisciplinary connections an extra thing to add on to their already packed curriculum to “a part of what I do.” Both teachers also expressed excitement to continue co-planning the following year, even though that meant finding new partners because Ms. Smith was moving to another state.

In the case of Jones and Williams, both teachers were novice 9th grade teachers. Ms. Williams believed in inquiry science, but held a traditional fear of mathematics, which she thought of as memorization. Mr. Jones believed that math is proof and reason, and that science is the application of math. Both teachers agreed that interdisciplinary connections are important, but neither had a realistic understanding of how to create connections between content. The teachers did not share a planning period, so they met weekly during lunch, where they saw each other daily anyway. They talked about content, activities, and students, but focused mostly on content, especially mathematics content as it related to Ms. Williams’s science content. Another focus for this pair was Ms. Williams’s self-efficacy as it related to mathematics. They created or adapted a few larger projects and activities, and several smaller examples and discussion points, spanning several different types of interdisciplinary connections. By the end of the intervention, they stated that the largest change in beliefs for
them was a new understanding and appreciation of mathematics and science. In particular, Ms. Williams stated a great shift from skills-based to application-based in her approach toward mathematics with her students. Both teachers also expressed excitement to continue co-planning with each other the following year.

In the case of King and Taylor, both teachers were experienced 10th grade teachers. Both believed that mathematics is the “language of science,” but were less confident in predicting how they would find relationships between their particular content, and Ms. Taylor was wary of the time commitment involved. They met weekly after school, usually for more than an hour, but did not meet between regular co-planning sessions. They talked about content, activities, and students in a connected way, and split their focus between the details of specific activities and an in depth understanding of the relationships between different content. They created or adapted a few larger projects and activities, and many smaller examples and discussion points, spanning several different types of interdisciplinary connections. By the end of the intervention, they stated that the largest change in beliefs was a new understanding of the importance of interdepartmental collaboration. In particular, Ms. Taylor realized the value of asking her partner for feedback about enhancing activities instead of waiting until she had a particular question. By the end of the intervention, both teachers expressed that co-planning does take time together and individually to follow up on plans, but that it is “time well spent.” Ms. Taylor was eager to continue co-planning the following year, but Mr. King expressed that he was moving and did not know if it would be possible in his new situation.
In the next chapter, these three cases will be compared and discussed in terms of the relevant literature in order to answer the three research questions presented at the beginning of this paper, regarding the co-planning process, the plans that teachers made, and the influence of co-planning on their beliefs about math and science, teaching and learning, and interdisciplinary connections.
CHAPTER 5: DISCUSSION AND CONCLUSIONS

The benefits of interdisciplinary curricula have been proclaimed over the years (e.g., Furner & Kumar, 2007), but empirical studies have been isolated and few (e.g., Becker & Park, 2011) because of obstacles that exist in schools that have traditionally been difficult to overcome (e.g., Koirala & Bowman, 2003). The Interdisciplinary Co-planning Team (ICT) model was developed by myself as an attempt to overcome many of these obstacles through sustained regular collaborative planning time in a low-stress environment without making administrative changes.

This study used a qualitative embedded multiple-case intervention design in order to gather and examine data regarding the nature of teachers’ planning processes, plans, and beliefs during a 10 week intervention in which the ICT model was implemented. Each teacher pair was analyzed as a separate case, and then cross-case comparisons were made. Answers to the following research questions will be discussed in this chapter:

1. What is the nature of teachers’ planning processes when the ICT model is implemented?
2. What is the nature of teacher plans when using the ICT model?
3. In what ways does participation with the ICT model influence teachers’ expressed beliefs regarding a) the nature of mathematics and science; b) teaching and learning; and c) making interdisciplinary connections?

In addition, implications for teachers and teacher researchers, limitations to the current study, and possible areas for further research are presented in this chapter.
Answering the Research Questions

In this section, each of the research questions is explicitly addressed according to literature and the results presented in Chapter 4.

**Research Question 1: What is the nature of teachers’ planning processes when the ICT model is implemented?**

As demonstrated in the conceptual framework (Figure 5) of this study, the ICT co-planning process is embedded in each teacher’s individual planning process, which is in turn against a background of teacher factors and external factors. Some of the factors that seemed to play a part in creating variations in the co-planning process across cases were time and scheduling commitments, teachers’ prior experience and knowledge, and teachers’ personal routines and organization. For example, Ms. Miller and Ms. Smith had years of experience between then, and taught at a middle school, organized into teams and with a common planning period. The other four teachers taught at a high school with no common planning period, and ranged in experience from 1 to 5 years. Other factors existed which seemed to unify the co-planning process across cases, including the presence of the facilitator, content focus, and continuity from one session to the next. Woodbury and Gess-Newsome (2002) described many of these factors and concluded that disregard for these factors leads to “change without difference” (p. 778).

This section will discuss interdisciplinary co-planning as a part of individual teacher planning before turning to the nature of the co-planning discussions and the content of co-planning discussions in terms of the contributing factors involved in each case.
Co-planning as a part of individual planning. The teachers that participated in this study each attended 7 weekly co-planning meetings with a partner, which were facilitated by the researcher. The teachers were generally instructed to meet in pairs weekly to discuss upcoming content and connections between the two classes, and to use those discussions to create and implement interdisciplinary connections with their students.

As the semester was already in progress at the beginning of the intervention, each teacher had already developed his or her own individual planning routine, which varied in the preferred amount and specificity of their written plans. For example, Ms. Williams preferred to write all plans in detail, and annotated questions and comments that she did not want to forget with her students. Mr. Jones used a notebook to organize notes, worksheets, and other materials, such as those mentioned by Brown (1988). Ms. Smith wrote her plans on the board in “grocery list” fashion (McCutcheon, 1980), and Mr. King relied on slides prepared in advance to drive discussion with his students. Each teacher was pragmatic in their own approach, which they believed was the most efficient for them personally.

Regardless of the difference in the look of their written plans, all of the teachers in this study reported that they took into account state standards documents, time, student motivation and ability, and available resources in their discussion of upcoming plans, revealing some of the complexities of the planning process as highlighted by Davis (2014). The variety of resources that the teachers used, including websites, applets, and videos, are similar to the resources noted by other researchers (e.g., Mumba et al., 2007; Drake & Sherin, 2006).
However, the math teachers tended to rely more on the textbook and the science teachers tended to rely more on external documents and resources, leading to the most of the interdisciplinary activities from this intervention originating from science. In addition, Ms. Taylor, in particular, also found that she could bring labs to co-planning sessions to look for ways to enhance or extend them. This may carry implications for the consideration of collaboration among textbook publishers, as well as the importance of collaboration among teachers for the purpose of sharing resources, as encouraged by Swanson & Bianchini (2014). It may have also contributed to the math teachers’ appreciation of active learning and project based learning, encouraged by many authors (e.g., Krajcik et al., 2008; Peters-Burton et al., 2014) as a result of collaboration with their science partners.

According to Yinger (1978/1980), and other later researchers (e.g., Young, Reiser & Dick, 1998; Milner, 2001), teachers use different levels for planning, including yearly, term, unit, weekly, and daily planning levels. In their individual planning, the teachers in this study used different planning levels, as evidenced in their interviews and observations of co-planning sessions. For example, Ms. Smith kept a monthly calendar on a whiteboard in her classroom which outlined the content over the following few weeks. The other teachers in the study did not keep such a calendar on the board, but did keep them in notebooks, on the computer, or mentally, continually adjusting as needed. In this context, co-planning seemed to fit in comfortably at the daily level of planning. Daily planning is short-term and creative in nature, addressing student engagement and practical knowledge (Milner, 2001), and while the teachers attended weekly scheduled meetings, most discussions centered about the particular details of one lesson at a time. Because planning is an iterative process (Clark &
Peterson, 1986; Farrell, 2002; Yinger, 1978/1980), the teachers in this study often came to co-planning sessions with ideas regarding content and activities, and then left with ideas that they then fit into their daily plans, which they were still forming or revising.

The teachers’ schedules and norms of collaboration were already set at both schools by the beginning of the intervention as well. At ICMS, teachers were organized into teams, which generally discussed specific students and behavior, but not usually academic content or learning. Ms. Miller and Ms. Smith, who had the experience of participating in the pilot study the semester prior to the intervention, met for regular co-planning sessions during their 45 minute common planning period. They also continued co-planning outside of regular sessions, at lunch, during their planning period, or just passing in the hallway throughout each week, particularly to ask follow-up questions or to expand on an idea or connection from a regular session. Ms. Miller and Ms. Smith reported discussing academic connections outside of co-planning sessions during the pilot study as well, but that they had never done so before the pilot study, and that other teachers on their team did not discuss academic content as they were. Ms. Miller and Ms. Smith are the only team that reported speaking extensively between regularly scheduled sessions, which may be due to a number of factors, such as the supportive team environment at their school, their individual excitement about the connections they were making, or their participation in the pilot study.

At ECHS, which is a smaller school, teachers are not organized into teams, but the students in the classes for each teacher pair tended to overlap because of the classes that each teacher taught. The culture of ECHS was one of collaboration and teamwork, which was an expressed expectation of students as well as teachers. However, the structure of the school
environment complicated the free exchange between teachers. The math teachers were housed in a different building than the science teachers, and none of them shared a common planning period. Mr. Jones and Ms. Williams opted to plan during their 30 minute common lunch time, which they reported always felt rushed. Mr. King and Ms. Taylor opted to plan after school, during which they reported feeling that they had as much time as they wanted. In fact, these sessions often lasted anywhere from 60 to 90 minutes, and this teacher pair had the most opportunity to thoroughly discuss connections, which the other teams often tabled for future discussion. It could be concluded that Mr. King and Ms. Taylor did not feel a need to meet between co-planning sessions because they had ample time during the sessions, or that the structure of the school did not support them traveling to meet throughout the school day. However, since Mr. Jones and Ms. Williams shared a common lunch period, they would have had the opportunity to discuss connections between sessions. Since Ms. Williams and Mr. Jones did not agree about whether or not they spoke between sessions, it may be concluded that they did see each other regularly, and perhaps discuss connections, but not with the same focus as during regular sessions. As it can be seen, proximity of space and time may play an important role in teachers’ co-planning routines.

During the final whole group meeting, each teacher pair ranked the factors that they perceived to influence their ability to co-plan. Among the top ranking factors for all three cases was time to meet regularly, to interact between regularly scheduled meetings, and to turn discussions from co-planning meetings into usable lesson plans. In addition, Mr. Jones and Ms. Williams ranked length of co-planning meetings highly as well, which makes sense based on the shorter length of their co-planning sessions during this intervention. Ms.
Williams commented during her final interview that when she scheduled co-planning for the following year, it would be after school or during a planning period, and not during lunch.

Overall, each teacher pair established a co-planning routine, which allows teachers to focus less on the logistics of planning and more on the content and details (Sanchez & Valcarcel, 1999). The co-planning routine was established early in the intervention for each teacher pair, and was influenced by the instructions given to the teachers as well as other factors, such as the teachers’ individual planning, time, and available resources. The co-planning sessions included a discussion of content, activities, and students to varying degrees, which is discussed next.

**The nature of the co-planning discussions.** Throughout literature, planning is described as complex (e.g., Goc-Karp & Zakaraisek, 1987; Milner, 2001) and pragmatic (e.g., Davis, 2014), and both of these descriptors seem to fit the co-planning discussions observed during this study. Coding of the co-planning discussions for process followed an open coding process (Glaser & Holton, 2004; Walker & Myrick, 2006) to create initial categories. Codes were then refined into categories using the constant comparative method of analysis (Birks & Mills, 2011).

Figure 12 shows the number of codes for each case, ordered by total number of codes. The number of codes alone demonstrates the amount of factors that teachers consider in co-planning. In all cases, the discussion can be categorized into mostly content, projects, and students, although there was variation among the teacher pairs for each of those strands. In addition, in the case of Jones and Williams, there were many comments about Ms. Williams’s self-efficacy as it evolved over the course of the intervention. In the other two
cases, there were mentions of teacher efficacy from time to time, but there was not a regular focus on a teacher’s ability to do or teach as there was for Ms. Williams.

<table>
<thead>
<tr>
<th>Codes by case, sorted by total number of occurrences.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cases</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>ICTP - CONT - math/science connection</td>
</tr>
<tr>
<td>ICTP - CONT - discuss/clarify math content</td>
</tr>
<tr>
<td>ICTP - PROJ - 3 details for connected project/activity</td>
</tr>
<tr>
<td>ICTP - CONT - discuss/clarify science content</td>
</tr>
<tr>
<td>ICTP - STUD - about students</td>
</tr>
<tr>
<td>ICTP - PROJ - 4 reflect on project/activity/lesson</td>
</tr>
<tr>
<td>ICTP - CONT - name upcoming topic math</td>
</tr>
<tr>
<td>ICTP - LOG - timeline</td>
</tr>
<tr>
<td>ICTP - CONT - name upcoming topic science</td>
</tr>
<tr>
<td>ICTP - BELF - efficacy</td>
</tr>
<tr>
<td>ICTP - BELF - express excitement/value</td>
</tr>
<tr>
<td>ICTP - PROJ - 1 mention/describe existing project</td>
</tr>
<tr>
<td>ICTP - PROJ - 2 possible project/activity</td>
</tr>
<tr>
<td>ICTP - LOG - other</td>
</tr>
<tr>
<td>ICTP - LOG - responsibilities for connected project/activity</td>
</tr>
<tr>
<td>ICTP - BELF - rationale for decisions</td>
</tr>
<tr>
<td>ICTP - CONT - related knowledge</td>
</tr>
<tr>
<td>ICTP - TEST - mention EOG/testing</td>
</tr>
<tr>
<td>ICTP - CONT - past topic in math</td>
</tr>
<tr>
<td>ICTP - CONT - past topic in science</td>
</tr>
<tr>
<td>TOTALS:</td>
</tr>
</tbody>
</table>

In all cases, co-planning discussion did not seem to follow a linear pattern. It oscillated between discussion of future topics, clarification and explanation of specific content, exploration of particular activities, labs, and projects, and mention of students, beliefs, and logistical concerns throughout most sessions. However, while teachers often circled back to discuss topics, they did not over-talk each other as Engstrom (1998) had noticed in his studies of team planning. This is probably because with only two teachers on each team, the cultural rules of engagement and respect are different than they are for multiple teachers, so each teacher had more opportunity to listen and to be heard.
The teachers often made comments during co-planning that served more than one purpose. The network diagrams in Figures 13, 14, and 15 demonstrate the connectedness of co-planning discussions by each teacher pair. In each network diagram, the codes are grouped visually by category, and then connected by arrows to the marker for the quotation to which each is attached. Quotation markers are grouped so that it is apparent if they are coded by only one or more than one code. For example, in Figure 14, the network diagram for Jones and Williams, all instances of ICTP – CONT – name upcoming topic math in the top left are grouped to the left of that code. For the code ICTP – BELF – efficacy, most instances of use are grouped above that code, but there is one instance (59:17) in which that code and another code, ICTP – CONT – math/science connection were both used for a single quotation. Thus, the connectedness of a single network diagram demonstrates the amount of quotations that served multiple purposes, and thus the complexity of discussion within the co-planning discussions for each teacher pair.
Figure 13. Network diagram of codes and quotations for Miller and Smith case.
Figure 14. Network diagram of codes and quotations for Jones and Williams case.
Figure 15. Network diagram of codes and quotations for King and Taylor case.
In all three network diagrams, it can be seen that multiple connections were drawn between content areas. In the case of Miller and Smith, there is less of a focus on pure content connections and more focus on projects and activities as they relate to different content. Ms. Miller and Ms. Smith may have focused more on projects and larger activities to create connected learning experiences for their students because they teach middle school, and teachers of younger grades focus more on activities than content (Sullivan et al., 2012). It is also possible, since Ms. Miller and Ms. Smith reported meeting outside of regularly scheduled sessions, that their discussions were more content-focused during these times, balancing out the amount of content and activities that they discussed.

In the case of Jones and Williams, this seems to be reversed, as there was almost no connection made between projects and content, but many connections drawn between content areas. This could have been because of the length of the co-planning sessions in the case of Jones and Williams, as these teachers did not have the time to discuss activities in the detail as the other teachers did. It could have also been because, as novice teachers, Mr. Jones and Ms. Williams made fewer connections (Penso & Shoham, 2003), in part because of lack of confidence (Leinhardt, 1983) and content knowledge (Gallagher, 1991).

In the case of King and Taylor, numerous connections were made between content areas, and between projects and content. This may be a reflection, again, on the amount of time that they had to co-plan compared to the other teacher pairs. This network diagram contains a strong connection between two unlikely areas. It is apparent that Mr. King and Ms. Taylor made the most connections to clarifying science topics through mentioning activities or projects, and the most connections to clarifying math topics through working out the
details of such activities and projects. This may be a reflection of the amount of planning that Mr. King was willing to put into implementing science connections in his math class compared to the math connections that Ms. Taylor was willing to implement in her science classes.

Finally, my presence as facilitator at all co-planning meetings may have influenced the nature of co-planning discussions that were observed in this study, as a facilitator has the capability of redirecting or guiding the teachers, and of providing feedback about the teachers’ plans and teaching reflections as deemed appropriate. In particular, in the case of Jones and Williams, the teachers might not have been as productive without this type of guidance initially. During the first few sessions, I asked both Mr. Jones and Ms. Williams clarifying questions more often than the other teacher pairs, because they more often seemed unwilling or unable to commit an in depth explanation of topics that may have resulted in more connections being made. This helped to engage the teachers with their content at a deeper level, which was found to be a major factor in the co-planning process for all teachers, and will be discussed in further detail below. The larger importance of the facilitator in the case of Jones and Williams supports research that states that beginning teachers need more support (Horn, 2005; Mumba et al., 2007; Norman, 2011) because they do not think as deeply about their own content as more experienced teachers (Borko & Livingston, 1989), which influences the amount and variety of connections they tend to make (Borko et al., 1990; Penso & Shoham, 2003).

Contrary to conclusions made by Roskos that interdisciplinary planning may be too complex for novice teachers to attempt (Roskos & Neuman, 1995; Roskos, 1996), in the case
of Williams and Jones, the novice teachers made great strides in the substance and depth of their co-planning conversations over the course of the intervention. This may highlight instead the need for specialized supports and consideration of individual teacher factors in successfully implementing co-planning teams, such as was indicated by Luft & Roehrig (2007) and Woodbury & Gess-Newsome (2002) in regard to the need for similar professional development.

Next, I will discuss the nature of the major focus of the content of the co-planning discussions: subject content, projects and activities, and students.

The content of the co-planning discussions. Analysis of teacher quotations during co-planning sessions revealed that the majority of co-planning time was spent discussing content, activities, and students, which aligns with Lenz, Schumaker & Dashler’s (1991) conclusions that most planning time is spent on determining content, organizing activities, and predicting student motivation.

Discussing academic content. Regarding the discussion of academic content, in all cases, the teachers mentioned upcoming topics on average once or twice per session, but spent most of their time on the clarification and explanation of specific concepts. Topics were often carried over from one co-planning session to the next, particularly if they involved a larger activity, if one of the teachers still had questions regarding specific content, or if the teachers spent an extended amount of time reflecting on a particular lesson. This focus on content has been shown to enhance teacher knowledge and practice (Garet et al., 2001), and was the guiding principle of interdisciplinary co-planning. Across cases, however,
this discussion and clarification of academic content was coupled with different types of remarks and served different purposes.

In the case of Miller and Smith, mathematical and scientific concepts were often described in terms of the lab or activity that was being discussed. Concepts were explained mostly in terms of how to do a problem, or what students should be able to do for a particular problem “at this level.” As was discussed above, this may be because Ms. Miller and Ms. Smith teach middle school, in which teachers tend to have a more student centered focus than in high school (Sullivan et al., 2012).

In the case of Jones and Williams, this discussion was often either to explain a mathematical or scientific concept to each other, or to explain student understanding (i.e., “they will know that”), and apart from specific activities. Detailed questions were asked and clarified to determine what students should know or do. As novice teachers, this served to strengthen knowledge of their own and each other’s content, which is an important factor in effective professional development (Chawdhary et al., 2014). Discussion of math content was often intertwined with comments about Ms. Williams’s mathematical self-efficacy (e.g., “I can do that”), which was not seen in the other cases. Mentions of student ability seemed to correspond to Ms. Williams’s comments about her self-efficacy, and she seemed more confident in her students’ abilities as her confidence in her own abilities rose over the course of the intervention. This supports literature that teachers try to protect their students from thinking in ways that they consider difficult (Perkkila, 2001), but also provides evidence that through focused professional learning, teachers such as Ms. Williams can learn to appreciate concepts that she once feared, and transfer this appreciation to her students as well.
In the case of King and Taylor, concepts seemed to be discussed through a larger variety of contexts, including in the exploration of lab data and creation of particular questions, in predicting student responses and misconceptions, in relation to each other and other related knowledge, and in reflection about particular labs and activities. Specifically, Ms. Taylor was the only teacher of all three cases to regularly reflect as a part of future planning, and to discuss specific content after implementing a lesson in her classes. This process of reflection is known to be important to teacher growth (Desimone, 2009), and a habit of reflection should be encouraged throughout co-planning. In addition, in the case of King and Taylor, related knowledge was often used to further discuss math or science concepts, or to draw connections that either teacher thought interesting or relevant, perhaps because of the varied backgrounds that these two teachers shared. This use of related knowledge was not as apparent in either of the other cases.

Finally, math and science concepts were not discussed an equal amount between the three cases. In the case of Miller and Smith and the case of Jones and Williams, science concepts were discussed slightly more than half as often as math concepts. In the case of King and Taylor, the number of quotations involving the discussion/clarification of science concepts actually exceeded those for math concepts. In this case, both Mr. King and Ms. Taylor were very knowledgeable about their own subjects, and often asked each other for more specific explanations in either subject. This is in contrast to the case of Jones and Williams, in which Ms. Williams stated that she was not comfortable with mathematics, and also that this was her first time teaching Physical Science, and “I really don’t know my own content.” This limited the amount that Ms. Williams was able to discuss her content in
depth, because she had to rely on limited knowledge or the textbook explanation to make sense of some concepts. However, she was resourceful, and did actually leave one co-planning session to retrieve her textbook in order to be able to discuss concepts more fully. In the case of Miller and Smith, the difference seemed to be not in the knowledge of each of the teachers, but in the context of the conversation. Since a lot of the conversation was based in specific activities, often adapted from existing science labs, more of an emphasis may have been placed on seamlessly placing the math into the science lab, regardless of the class in which it was implemented, rather than the other way around. These differences may be expected in interdisciplinary co-planning, and may actually highlight the fact that the teachers are learning and growing in meaningful ways instead of simply attending another meeting or checking off another box.

**Discussing activities.** Regarding the discussion of projects, in all three cases, the science teacher often came to co-planning sessions with an idea of an activity or lab that they wanted to implement with students that they would share. In contrast, in all three cases, it was rare that the math teacher came in with a description of any big project or activity. One exception is the Pythagorean project, which originated as an existing math project. Again, there were variations among the cases in the discussion of projects, but mostly in the amount and depth of discussion, not the nature of the discussion.

In the case of Miller and Smith, large amounts of time were used across each session to expand on existing activities and labs. Some comments were about the connection or concept, as described above, and then other comments were about the logistical responsibilities of the project. For example, one or the other would say, “I will make that
worksheet for them,” or “do you want to write the instructions for that?” Ms. Miller and Ms. Smith also both stated that they frequently spent time together outside of regular co-planning sessions to ask each other details or work out particulars for a specific project or lab. In effect, the concrete focus of activities by Ms. Miller and Ms. Smith may have been a contributing factor in their willingness to work together between regular meetings. This type of discussion, concerning both the academic and procedural content of activities, offers insight into the complex internal dialog that teachers may have when individually planning (e.g., Lenz, Schumaker & Dashler, 1991).

In the case of King and Taylor, two sessions were completely focused on the details of an upcoming activity, but the other sessions did not contain the same sustained focus on activity. This difference from the constant focus on activity from the case of Miller and Smith, above, may be in part because Mr. King and Ms. Taylor did not continue to plan outside of regular sessions as Ms. Miller and Ms. Smith had. Aside from an occasional email, final details were often either deliberated during the co-planning session or not discussed at all. This may have led to the larger variations in the implementation reported by Mr. King and Ms. Taylor.

Initially, in the case of Jones and Williams, activities were often not the focus of the conversation. Projects and labs were often mentioned or described as part of upcoming content, and then put aside to discuss connections among content. For example, during one co-planning session, Ms. Williams mentioned a project in which her students would create a video of how they use an electromagnet to power different devices that they build for the purpose of learning about electricity and magnetism. She said, “It’s like a survivor show,
basically.” Then, Mr. Jones asked about the formula $V=IR$, and both teachers moved on to discuss the relationship between formulas in math and science, dropping any mention of the potential project from Ms. Williams’s class.

It is apparent that the collective participation at ECHS helped Mr. Jones and Ms. Williams to discuss projects in a more meaningful way over the course of the intervention. During the second whole group meeting, Ms. Taylor mentioned that she brought a lab in to discuss, and shared her enthusiasm at the interdisciplinary connections that she and Mr. King ended up creating from the lab. Shortly after, Ms. Williams brought the phase change lab to a co-planning session, expressing that she was using the idea from Ms. Taylor. Later, Ms. Williams expressed that she felt the most confident about this lab compared to other co-planning sessions in which connections were less tangible. Collective participation encourages teachers to leave the norms of isolation (Fisler & Firestone, 2006), and it provided a useful opportunity for the teachers at ECHS to share ideas. This type of collective participation may be valuable to future co-planning teams, and should be encouraged.

**Discussing students.** Across cases, the teachers discussed content, activities, and students, but of the three, students were the least discussed. This may be because of the content focused nature of interdisciplinary co-planning. Many comments about students were general in nature, about “my students,” as opposed to comments about a particular student. One notable exception was in the case of Miller and Smith, there were instances in which the teachers would break from the conversation about the project or connection that they were discussing in order to consider one individual student, and then return to the
previous conversation. This may again be because of the team structure at ICMS, where teachers were accustomed to discussing student needs regularly.

Although Ms. Miller and Ms. Smith seemed to consider individual students more, they also tended to cast them in a more negative light. During one session, Ms. Smith said, “Our students can’t do tricky. Our students can’t even do plain.” This type of general comment occurred at least once during each co-planning session. However, this attention to student understanding helped Ms. Miller and Ms. Smith to take particular considerations to make sure labs and activities were accessible to all students. Ms. Smith noted in her final interview:

If you’re setting up an experiment or a lab, it has to be age appropriate. And you have to consider a lot of things. If they are exploring something that requires them to use tools, you might have to do a lot of pre-teaching. Like, when we did something with the microscopes, I had to go through and pre-teach them how you use a microscope, and what measurement is under a microscope.

These considerations about student accessibility were not discussed in the other cases.

In the case of Jones and Williams, most comments about students centered about what student understanding, which includes what they do understand, will understand, or should know. As novice teachers, Mr. Jones and Ms. Williams tended to speak about students in terms of themselves (i.e., “I taught them…”), especially initially, whereas the other teachers tended to approach student understanding from more of the students’ point of view (i.e., “They are confused about…”). In contrast, Mr. King and Ms. Taylor seem to approach discussion of student understanding from the perspective of the student. For example, after a
lengthy description of the types of errors that students made during one lab, Ms. Taylor said, “They obviously didn’t understand it,” and then worked to troubleshoot how to help students better understand the concept. Novice teachers are known to focus on their own perspective above that of students (Levin, Hammer & Coffey, 2009). The movement of Mr. Jones and Ms. Williams from teacher centered to student centered talk, and the tendency of the other two teacher pairs to discuss students in terms of understanding during this intervention may imply that interdisciplinary co-planning helps teachers to learn to focus on student learning above the usual implementation of curricula.

Overall, the act of interdisciplinary co-planning was integrated into each teacher’s personal planning routines based on several factors, the most important of which seemed to be time. The focus of co-planning discussions varied from case to case, but in all cases, co-planning for the teachers in this study did not appear to be a simple focus on materials, activities, and assessments (Young, Reiser & Dick, 1998), but a cyclic process of considering combinations of content, activities, and students.

**Research Question 2: What is the nature of teacher plans developed through participation with the ICT model?**

In all three cases presented in chapter 4, multiple science and math topics were discussed, and multiple connections were drawn. In the case of Miller and Smith, 7 larger activities were discussed, 6 of which were implemented. In each of the other cases, 5 larger activities were discussed, 4 of which were implemented in the case of Jones and Williams, and 3 in the case of King and Taylor. In addition, across all three cases, many smaller connections were discussed and implemented in classes either as examples or class
discussions. These smaller connections were often an extension of a larger lesson that either teacher had already planned or described. The plans covered a range of connections, spanning algebra, geometry, and statistics in mathematics, and biology, physical science, and other topics in science. Table 8 summarizes the plans made by each teacher pair. Appendices O through Q contain worksheets and descriptions of activities that the teachers created.

Table 8. 
Larger and smaller activities and connections across cases

<table>
<thead>
<tr>
<th>Larger activities, labs, and projects</th>
<th>Miller and Smith</th>
<th>Jones and Williams</th>
<th>King and Taylor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1. Lab practicum *</td>
<td>1. Roller coaster project</td>
<td>1. pH and logarithmic scale *</td>
</tr>
<tr>
<td></td>
<td>2. Pythagorean theorem project</td>
<td>2. Science formula sheet</td>
<td>2. Potato lab</td>
</tr>
<tr>
<td></td>
<td>3. M&amp;M lab</td>
<td>3. Ohm’s Law virtual lab</td>
<td>3. predator/prey lab *</td>
</tr>
<tr>
<td></td>
<td>4. Bacteria growth activity</td>
<td>4. Light bulb lab *</td>
<td>4. Leaf lab</td>
</tr>
<tr>
<td></td>
<td>5. Microbe clock</td>
<td>5. Phase change lab</td>
<td>5. volume/surface area</td>
</tr>
<tr>
<td></td>
<td>6. Gapminder activity</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>7. Biotechnology job search</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Smaller connections                   | 1. Rock dating and scatterplots                      | 1. Velocity and acceleration and slope            | 1. Exponents & microscopic size,                  |
|                                       | 2. Paleoclimateology and trend lines                 | 2. Radioactive decay and exponential decay        | 2. Absolute hot and exponents                     |
|                                       | 3. Age of earth and scientific notation              | 3. Waves and graphic translations                 | 3. Types of graphs and in science                 |
|                                       | 4. Volume in science by immersion and in math by measurement | 4. Waves and coordinate midpoint and distance      | 4. Significant figures in science and math       |
|                                       | 5. Relationship between density and volume           | 5. Optics and geometric angles                    | 5. Graph asymptotes and tonicity in science       |
|                                       |                                                     | 7. Circuits and fundamental counting principle     | 7. Cell cycle and Greek prefixes                  |
|                                       |                                                     |                                                   | 8. Functions and cancer growth                    |
|                                       |                                                     |                                                   | 9. Sound waves and trig graphs                    |
Table 8 Continued

<table>
<thead>
<tr>
<th>Smaller connections</th>
<th>8. Ohm’s law and batteries and graphing direct variation</th>
<th>10. Predator/prey cycle and phase shift</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>9. 2 way tables and science data</td>
<td>11. Probability and genetics</td>
</tr>
<tr>
<td></td>
<td>10. Mixtures and sampling</td>
<td>12. 2 way tables and Punnett Squares</td>
</tr>
<tr>
<td></td>
<td>11. Mixtures and 2 way tables with probability</td>
<td>13. Tree diagrams and Punnett Squares</td>
</tr>
<tr>
<td></td>
<td></td>
<td>14. Trig graphs and ex vivo lung profusion</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15. Economics and variables</td>
</tr>
<tr>
<td></td>
<td></td>
<td>16. Independent assortment and probability</td>
</tr>
<tr>
<td></td>
<td></td>
<td>17. Biotechnology and standard deviation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>18. Protein synthesis and probability</td>
</tr>
</tbody>
</table>

Note: activities with * were not implemented

Sullivan et al., (2012) noted that teachers of younger grade levels may focus on activities more than those of higher grade levels. As evidenced in the network diagrams, and triangulated in the above table, Ms. Miller and Ms. Smith focused more than the other teacher pairs on larger activities, and implemented almost twice the number of larger activities as the others. This may have been because, as middle school teachers, they were more focused on activity, as seen in analysis of the co-planning process, while the high school teacher pairs were more focused on content.

Each of the larger projects and activities that was implemented was accompanied by a student worksheet of some kind. Depending on the activity, these worksheets contained directions, places to record data, specific questions regarding student data, or more general
questions regarding the concepts in the worksheet. Across all three cases, most of the larger projects and activities were adapted from an existing worksheet or lesson that was altered as a result of co-planning discussion. Consistent with findings from Mumba et al. (2007), the teachers in this study reported that they drew on a variety of resources, both for individual planning, and to bring potential activities to co-planning sessions.

A continuum (Figure 16) analogous with the one in Figure 1 (page 19) was drawn to consider the interdisciplinary nature of the plans that the teachers created. As the purpose of this study was to create interdisciplinary lessons, no plans were collected or discussed that fit into 1) did not incorporate science or 5) did not incorporate math. It should be noted that the teachers did create plans that excluded the other subject throughout the intervention, but these were not the plans that were discussed during co-planning times. Teachers reported that the amount of lessons that did not involve any connection to the other subject decreased over the course of the intervention, because they were more aware of connections and used a larger array of smaller connections that may or may not have even been mentioned during co-planning as the intervention progressed.

<table>
<thead>
<tr>
<th>Math</th>
<th>Science</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Did not incorporate science</td>
<td>5. Did not use math</td>
</tr>
<tr>
<td>2. Used science as context for understanding math</td>
<td></td>
</tr>
<tr>
<td>3. Used both subjects to understand each other</td>
<td>4. Use math as tool for understanding science</td>
</tr>
</tbody>
</table>

*Figure 16. Continuum of interdisciplinary activities.*
Table 9 lists the larger activities, their origin, whether each was implemented, and where they would fit on the above continuum as they were discussed by the teachers. Across all cases, of the four larger projects or activities that were discussed but not implemented, three were an original idea, meaning the teachers would have had to create a worksheet or lesson from scratch instead of adapting it from other sources. One obstacle to implementing these activities may be the amount of time that it would have taken the teachers to think through and develop instructions and questions for students to implement the activity effectively. While the teachers found value in the connections, they were also forced to be realistic about the amount of time that they could devote to planning a specific lesson, since planning does take time that teachers often do not have (Aydin, 2014) and teachers have busy schedules (Berlin & White, 2012).

Table 9.
Comparison of larger activities and their origins.

<table>
<thead>
<tr>
<th>Teacher pair</th>
<th>1.</th>
<th>2.</th>
<th>3.</th>
<th>4.</th>
<th>5.</th>
<th>6.</th>
<th>7.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miller &amp; Smith</td>
<td>Lab practicum</td>
<td>Original idea</td>
<td>No</td>
<td>3</td>
<td>1.</td>
<td>2.</td>
<td>3.</td>
</tr>
<tr>
<td></td>
<td>Pythagorean Theorem project</td>
<td>Adapted from math</td>
<td>Yes</td>
<td>2</td>
<td>4.</td>
<td>5.</td>
<td>6.</td>
</tr>
<tr>
<td></td>
<td>M&amp;M lab</td>
<td>Adapted from science</td>
<td>Yes</td>
<td>4</td>
<td>7.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bacteria growth activity</td>
<td>Original idea – from science</td>
<td>Yes</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Microbe clock activity</td>
<td>Original idea – from science</td>
<td>Yes</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gapminder activity</td>
<td>Original idea</td>
<td>Yes</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Biotechnology job search</td>
<td>Original idea</td>
<td>Yes</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jones &amp; Williams</td>
<td>Roller coaster project</td>
<td>Adapted from science</td>
<td>Yes</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Science reference tables</td>
<td>Original idea</td>
<td>Yes</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ohm’s Law virtual lab</td>
<td>Adapted from science</td>
<td>Yes</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Light bulb lab</td>
<td>Original idea</td>
<td>No</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Phase change lab</td>
<td>Adapted from science</td>
<td>Yes</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>King &amp; Taylor</td>
<td>pH and logarithmic scale</td>
<td>Original idea</td>
<td>No</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Potato lab</td>
<td>Adapted from science</td>
<td>Yes</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Predator/prey lab</td>
<td>Adapted from science</td>
<td>Yes</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Leaf lab</td>
<td>Adapted from science</td>
<td>Yes</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Volume/surface area</td>
<td>Adapted from science</td>
<td>Yes</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The two original ideas that were implemented as larger projects and activities were both from the Miller and Smith case, and occurred at the end of the year. Both of these relied on a website that was already in existence, but the teachers created the lesson and worksheet directly from co-planning discussions because they did not find a suitable worksheet to adapt. This consistent adaptation of available resources may imply that there is a current need for creation and distribution of interdisciplinary resources to math and science teachers. Ms. Smith suggested that for future implementation, the facilitator could create a shared folder or drive for teachers to deposit lessons that they create for their classes. This type of collaboration between co-planning teams might further facilitate the adaptation of more interdisciplinary lessons and activities.

Most of the adapted activities originated from science, regardless of whether they were implemented in the science or mathematics classroom. This may be because the mathematics teachers in this study tended to think about teaching more traditionally (e.g., Perkkila, 2001) than their science teacher partners, who favored more inquiry based learning (e.g., Krajcik et al., 2008). It may also stem from a reliance by the mathematics teachers on the textbook (e.g., Remillard, 2005) whereas the science teachers in this study generally did not prefer to use the textbook. Thus, particularly for the mathematics teachers, the plans that were created through this study may be more inquiry based and student centered than the plans they would have otherwise created.

Regarding the content of the larger activities, three variations seem to exist in the type of action expected from students. In the case of King and Taylor, all of the larger activities that were discussed, even those not implemented, centered about students gathering and
analyzing data from experiment or lab. In the case of Jones and Williams, 2 activities that were discussed, 1 of which was implemented (phase change lab), fit this description. In the case of Miller and Smith, 2 activities (M&M lab and Bacteria growth activity) fit this description as well. Another type of activity that was implemented could be described as gathering information from a teacher-provided website to draw conclusions appropriate to the content. This was the case for 3 activities for the case of Miller and Smith (Microbe clock, Gapminder activity, Biotechnology job search), and 1 in the case of Jones and Williams (Ohm’s law virtual lab). Finally, in the case of Miller and Smith (Pythagorean Theorem project) and in the case of Jones and Williams (Roller coaster project and Science formula sheet), projects were planned in which students were given instructions to create based on concepts that they had learned. This variation in activities implies that the teachers did not only find one type of connection, as they had initially feared, but they found a variety of connections throughout the intervention. This also helps to focus a potential collection of activities that would be helpful to teachers into the categories of physical data collection and analysis; virtual labs (websites); and projects.

The integration level of the larger activities seems to be mixed across cases between those that favor one subject over the other, and those that do not, with the largest percent of mixed activities in the case of King and Taylor, and the smallest in the case of Jones and Williams. This may be because of the teachers’ difference in experience levels and content knowledge, which influenced the amount and type of connections that they were comfortable making. Finally, although most of the ideas for activities came from science, the plans that did favor one subject over the other were evenly distributed among math and science. This
implies that the math teachers were willing to use science activities as a resource when they applied to the math that they were currently teaching.

Smaller connections that were discussed were generally not created in the form of a worksheet for students, but integrated into teacher plans as examples or smaller discussion points. This makes the smaller connections more difficult to track and verify, but according to teacher reflections and unstructured interviews, they spanned the topics that were discussed during the co-planning sessions. According to teacher reflections, these smaller connections also seemed to contribute to the teachers’ ability to focus students’ attention on connections consistently throughout the intervention, making the interdisciplinary experience more cohesive for students. Ms. Smith stated, “They’re definitely thinking about math more often because I’m able to talk about it. And I’m only able to talk about it because I knew what Ms. Miller is doing in her class.” This reveals the necessity for teachers to create and implement the smaller connections just as much as the larger activities. It also implies that overall, the plans that the teachers made shifted from the ends toward the center of the continuum described in Figure 16.

At the beginning of the intervention, one of the reservations that teachers had was that there was not going to be enough variety in the connections to make co-planning relevant or valuable. By the end of the intervention, the teachers proved themselves wrong, and readily admitted that they were able to plan a large variety of connections throughout the intervention. During the last whole group session, Ms. Williams’s comments were echoed by each teacher:
I actually can’t believe we did that much, which makes me feel better. Because I honestly wasn’t keeping track of it. And it’s really cool to see oh, wow, look at all the stuff we did talk about. So I feel like, more successful.

This demonstrates not only the teachers’ surprise with the amount of connections that they had successfully planned and implemented throughout the intervention, but also a shift in their beliefs about their ability to co-plan interdisciplinary lessons for their students. This, coupled with the above stated tendency to create more frequent smaller connections because of regular co-planning, implies that the teachers’ efforts to create and implement interdisciplinary experiences to use with their students was successful.

**Research Question 3: In what ways does participation with the ICT model influence teachers’ expressed beliefs regarding a) the nature of mathematics and science; b) teaching and learning; and c) making interdisciplinary connections?**

The results of this study show that all of the teachers that participated in the co-planning intervention began with conflicting beliefs in some area, which were partially resolved through interdisciplinary co-planning. This may be common among mathematics and science teachers, since beliefs are interrelated, but not necessarily logical (Chapman, 2002).

Some researchers conclude that teachers may hold conflicting beliefs without even being aware of the conflicts (e.g., Chen, 2008; Wallace & Kang, 2004), leading to inconsistencies in their actions (Pehkonen, 1999). This seems to be the case for some of the beliefs held by teachers in this study; for example, Mr. King held a belief that the purpose of mathematics is to provide a language to describe the natural world, but the purpose of
teaching math is to teach students to think abstractly, which created inconsistencies in his behavior. For example, Mr. King discussed concrete connections between mathematics and science because of his belief that mathematics describes the world, but then implemented more abstract lessons in his classes, coinciding with his belief that teaching high school is about teaching students to think logically and abstractly. If Mr. King was aware of these inconsistencies, he did not mention them.

Beliefs in this section are divided into the areas of beliefs about mathematics and science, beliefs about teaching and learning, and beliefs about interdisciplinary connections. Most of the teachers in this study changed their beliefs in multiple areas in subtle ways, as evidenced in the results reported in Chapter 4. In addition, all of the participating teachers experienced a great change in beliefs in at least one area. The remainder of this section will discuss the greatest changes in beliefs for each case in this study. Individual teacher factors as well as external factors informed the teachers’ initial beliefs as well as the changes in beliefs described in each sub-section, as would be expected (e.g., Philippou & Christou, 2002; Woodbury & Gess-Newsome, 2002), and will be examined in this section in their relationship to each set of beliefs.

Beliefs about science and mathematics. Many researchers regard teachers’ beliefs about mathematics on a continuum from authoritarian to problem solving (e.g., Handal, 2003), and about science from traditional to inquiry based (e.g., Luft & Roehrig, 2007). At the beginning of the intervention, Ms. Williams would have rated at the inquiry end of the scale for science, and at the authoritarian end for mathematics. She described science as a field that constantly changing, and in which inquiry and exploration are more important than
facts. She expressed this through discussion of labs and projects that would help her students to understand and appreciate the nature of science as she saw it. At the same time, Ms. Williams expressed her belief that mathematics is a set of unrelated and unforgiving rules, and avoided mathematical thinking if at all possible, in the same way that the teachers in Nadelson et al.’s (2012) study avoided topics that made them uncomfortable. She also evidenced a desire to protect students from the difficulties of mathematical thinking, such as was described by Perkkila (2001). Because of this, she only taught basic mathematical skills, such as filling in a formula, as it was immediately necessary in her science class.

Mr. Jones held an equally naive view of science. He viewed mathematics as “steps with reason” and “logical processes,” similar to some responses from mathematics educators at the university level (Mura, 1995). In verbalizing his idea of science, however, he described math as the reasoning whereas science is the application. This is similar to findings from Watanabe & Huntley (1998), in which mathematics instructors viewed science as in service to mathematics.

Over the course of the intervention, both teachers experienced the opportunity to discuss mathematical and scientific concepts with each other. Each teacher grew in understanding of the opposite subject, and as time went by, became noticeably more comfortable discussing the other’s content in depth. Mr. Jones left his rapid responses in favor of deeper thinking about scientific concepts and scientific methods. Ms. Williams gained confidence and appreciation for multiple aspects of mathematics, including the use of formulas, 2-variable equations, and graphing. By the middle of the intervention, she had stopped saying comments such as, “I don’t understand,” and “I wish I could do that,” and
began saying, “That makes sense,” and “I can explain that.” She reported that by the end of the intervention, she had moved dramatically in her teaching of mathematics from skills-based to intentionally application-based because she realized all of the application that mathematics holds for her students. Mr. Jones exhibited similar changes in thinking, to a lesser extent, about the nature of science. He learned about the exploratory nature of science from conversations with Ms. Williams, and held discussions with his students about exploration in science connecting with the mathematics content that he was teaching. By the end of the intervention, he described scientific experiments more in terms of testing and revising hypotheses than in one set procedure.

There may have been several contributing factors for the changes in beliefs about mathematics and science by Mr. Jones and Ms. Williams. One factor may be that, because they were both novice teachers, their beliefs about each subject were still forming. Beginning teachers often demonstrate inconsistencies in beliefs, and between beliefs and practice, mostly because of conflicting beliefs and internal and external pressures (Brickhouse, 1990). Over time, the most incongruous beliefs may change to alleviate inconsistencies that have come to surface (Middleton, 1999, Nathan et al., 2010).

A second contributing factor may be the vast differences in each other’s initial beliefs about science and mathematics, and the teachers’ need to reconcile these differences through co-planning discussion. (Note: as with the other cases, these teachers did not explicitly discuss the nature of mathematics or science during co-planning discussions, or any other time.) Teachers have a need to resolve internal conflict once it is recognized, (Cooney, Shealy & Arvold, 1998; Pehkonen, 1999). Unlike intermittent or narrow use of a new
curriculum with which the teacher may be uncomfortable (Remillard & Bryans, 2004), the teachers in the co-planning situation have a greater need to resolve their conflicting beliefs in order to work together to plan for their students.

A third contributing factor may be that through focused discussion of content, both teachers began to see value and application for both disciplines in areas that they had not previously seen. This is similar to the changes in feasibility that some teachers experience in working with new curricula (Berlin & White, 2012), as Ms. Williams experienced tremendous shifts in efficacy over the course of the intervention. Although researchers have found that it is usually easier to assimilate new beliefs than to accommodate existing beliefs (Pajares, 1992), beliefs may change based on powerful experiences (Nathan et al., 2002), and in this case, fundamental beliefs about mathematics and science seem to have shifted for Ms. Williams and Mr. Jones.

Beliefs about the nature of teaching and learning. Ernst’s framework is often used to consider teacher beliefs about teaching and learning on a 3-tiered continuum from transmission to Platonic to problem solving (Perkkila, 2001). Teacher beliefs about teaching and learning seem to be intertwined (Wallace & Kang, 2004), and more complex than views about the nature of mathematics and science (Bergman, 2014), and both internal and external factors should be taken into consideration in determining teacher beliefs and apparent inconsistencies in beliefs (e.g., Haney, Czerniak & Lumpe, 1996; Wallace & Kang, 2004).

Ms. Miller and Ms. Smith both tended toward an experiential view of learning (Handal, 2003; Perkkila, 2001), and specifically described their intent to provide rich experiences for their students to learn mathematical and scientific concepts. However, they
perceived an administrative emphasis on testing scores above other indicators of learning, which stifled their reported implementation of inquiry based lessons in their classes. Ms. Smith stated that if time began to get short, the inquiry was usually the first part of the lesson to be discarded. Similar actions were noticed by Wallace and Kang (2004) in their investigation of secondary science teacher beliefs about inquiry.

Initially (before the pilot study), interdisciplinary connections fell into the same category for Ms. Miller and Ms. Smith as inquiry learning experiences. When Ms. Miller and Ms. Smith began co-planning, Ms. Miller further stated that she had been looking for maybe one connection that she could add into her existing lessons for her students. However, by the end of the interview, both teachers shifted in their beliefs about creating opportunities for their students to experience interdisciplinary connections.

By the beginning of the intervention for the current study, Ms. Miller and Ms. Smith has renewed their commitment to regular co-planning, and to implementing interdisciplinary plans in their classes. Co-planning truly became an experience that Ms. Miller and Ms. Smith integrated into the rest of their individual planning. The teachers were able to collaborate about content, and their excitement about connections between content areas was contagious. They expanded on their discussions in between co-planning sessions, and interdisciplinary connections became a constant consideration in lesson planning. Conversations about students evolved from discussing behavior and compliance issues to discussing student understanding of mathematical and science concepts. Throughout the intervention, creating interdisciplinary experiences went from being an additional task that might be nice to a necessary part of their everyday teaching.
The teachers in this case created the synergy that comes with collaboration (Lewis et al., 2012) through their expressed enthusiasm for developing and implementing the connections that they found through co-planning discussions. Their ability to collaborate regularly and to share in detail shifted their focus from developing a single-subject lesson that can be added to, into developing cohesive lessons that are composed of direct ties to both content areas. In addition, this shift may have been aided by their focus on larger activities, which became the vehicle through which their students experienced both mathematics and science.

By the end of the intervention, Ms. Miller seemed solid in her belief that this has become a part of “what I do now,” that looking for connections has now become an integral part of her regular routine. Ms. Smith reflected that she consistently thought about connections between mathematics and science, but that implementation was sometimes difficult because of the increased time that it took to plan the lessons. She added that it would be useful to plan out interdisciplinary lessons in advance, so that they would be ready as it became time to use them.

Ms. Miller’s and Ms. Smith’s shift in beliefs related to teaching and learning exemplify one way that teachers may exhibit apparent inconsistencies in their espoused beliefs about teaching and learning (Barkatsas & Malone, 2005), in this case between their ideas of providing experiences to students, and of administrative expectations. Although their administration obviously did not change over the course of the intervention, the teachers’ perceptions of feasibility and importance of providing interdisciplinary experiences for their students did change. They seemed to evolve over the course of the intervention from looking
at integrated connections as another impossible topic to add to an already overloaded curriculum (e.g., Pearson et al., 2010) to a feasible and valuable part of everyday learning, similarly to the teachers in Nadelson et al.’s (2012) study.

The team structure at ICMS may have helped Ms. Miller and Ms. Smith to develop the social trust needed (Borko et al., 2008) to make the shift in beliefs from interdisciplinary connections as an additional part to an integrated part of their lesson plans. These two teachers were comfortable asking content related questions during and in between co-planning sessions, and it was apparent that their ongoing mental planning dialog (Milner, 2001) included interdisciplinary connections as a top priority.

**Beliefs about interdisciplinary connections.** Similar to the teachers who were interviewed by Başkan, Alev, and Karal (2010), the teachers in this study all began the intervention with vague notions that interdisciplinary connections would be useful, but they did not have ideas about how to go about integrating curricula or drawing connections for students. During his initial interview, Mr. King expressed concern that there would not be connections that he could use with his class, or that it would all be the same connection (linear regression), which would not be useful for his upper level mathematics class.

As with the other teachers in this study, Mr. King and Ms. Taylor found a variety of interdisciplinary connections that were applicable to both classes. Mr. King reflected that he learned to pay much closer attention to the data produced by his colleagues because it is useful for a wider variety of modeling examples than he had previously thought. Mr. King also noted that even though he did not implement all of the connections that he discussed because he did not spend the necessary time to plan, when he did implement interdisciplinary
connections with his students, they were more engaged. This also seemed to help reconcile some of the conflict in his beliefs between the study of mathematics and the teaching of mathematics. He realized the importance of demonstrating to students that math is not simply “a bag of tricks,” and that it serves a real and important purpose in the context of other disciplines, similarly to the teachers in the study by Ross and Hogaboam-Gray (1998). These changes in beliefs echo changes in perceptions by teachers of other interdisciplinary projects (e.g., Berlin & White, 2012; Nathan et al., 2010), and can be attributed to the notion that beliefs can be changed or reconciled through intentional learning experiences (Phillip, 2007).

Ms. Taylor was impressed by the amount and variety of connections that the pair found, and noted that she was able to implement these connections as a natural extension of the concepts that she intended to teach. She found that the connections allowed her to go further into the science content than she could have before, particularly with the labs that she had adapted based on co-planning discussions. This aligns with the benefits to students by situating learning in context which were discussed by other researchers (e.g., Ivanitskaya et al., 2002; Koirala & Bowman, 2003).

In addition, Ms. Taylor realized the value of interdepartmental collaboration in order to enhance her plans in science. She stated that before the intervention, she would have only asked her partner teacher for help when there was a specific question, such as how to create a graph using particular software. After the intervention, however, she saw much more value in asking for general feedback to enhance or extend a lesson or lab. Ms. Taylor described the value of collaborating with a teacher who has a different area of expertise than her own, not
only to troubleshoot problems, but to be creative and to build new ways for students to experience learning. She stated:

Now I’m like, maybe I just need to go talk to my other content experts and get an idea like, maybe something really small I can do that will show students that it’s not just math, science, English, history, but that there truly is a link between the different subjects, and that we might teach our own content, but that doesn’t mean that they’re different, or that they don’t have the same overriding principles between the subjects.

This is similar to the collaboration that Froyd and Ohland (2005) found to be essential to successful implementation of integrated curricula, and that other researchers have concluded leads to a richer repertoire of teaching and learning approaches (e.g., Herbel-Eisenmann et al., 2011). This shift in beliefs about interdisciplinary collaboration may have been more pronounced for Ms. Taylor and Mr. King because of their previous lack of experience with regular collaboration, particularly with faculty outside of their own department. These teachers did not feel like they were starting over, but simply that they were taking something they already had and making it better.

**Discussion**

The purpose of this study was to describe the nature of co-planning for middle and high school teachers when they participate with the Interdisciplinary Co-planning Team (ICT) model. Regarding the co-planning process, each teacher pair incorporated co-planning into their weekly schedules, according to factors unique to that pair. Co-planning discussions revolved around academic content, activities, and students in an intertwined way. The emphasis of co-planning discussions for each teacher pair reflected the personal and
situational factors for each teacher pair, including the grade level and school, teaching experience, and other commitments that each teacher held.

Regarding the plans that the teachers created, there were variations in the number of larger activities and smaller connections, but all participating teachers made and implemented both types of plans throughout the intervention. Larger activities were accompanied by a worksheet. Smaller connections were reportedly made increasingly often as the intervention progressed. In addition, the plans reflected a variety of connections, and the teachers’ pragmatic nature to adapt, rather than create from scratch, when possible.

Each teacher pair began with conflicted beliefs in multiple areas, leading to apparent inconsistencies between behavior and beliefs. Participating in co-planning sessions seems to have served to soften these conflicts in their beliefs. In the case of Jones and Williams, the greatest shift was in their personal beliefs about mathematics and science. In the case of Miller and Smith, the greatest shift was in their beliefs about the incorporation of interdisciplinary connections and student experiences into their planning and teaching routines. In the case of King and Taylor, the greatest shift was in their beliefs about the value of interdisciplinary collaboration, both in the types of connections that they were able to make, and in the type of expertise that they were able to offer each other.

Each teacher that participated in this study did so with no prior experience co-planning for math and science (with the exception of Miller and Smith, who participated in the pilot study). The teachers held a variety of backgrounds, including their personal experiences and teaching experiences. Although they all held concerns at the beginning of the intervention, mostly about their personal abilities and knowledge, by the end they were
pleasantly surprised with the amount and depth of connections that they were able to plan for their students. This was mostly achieved through facilitated weekly co-planning meetings, during which the teachers discussed concepts from each subject in order to find connections and to create plans for their students to experience the connections they found.

In addition to creating and sustaining a co-planning routine and plans to implement with students, the teachers in this study each increased their knowledge about each other’s content area, and were increasingly able to recognize and appreciate connections across the disciplines.

In Figure 17, each participating teacher is placed on the math/science continuum. The arrows represent movement in expressed beliefs and in planned activities from the beginning to the end of the study. At the beginning of the study, all of the teachers in this study would have fallen at the ends of the continuum, either teaching 1) math for math’s sake, or 5) science for science’s sake, respectively. Although each teacher thought slightly differently about their own subjects, each expressed an effort to have their students see their discipline as they do, and were only concerned with their own discipline. Throughout the intervention, many interdisciplinary plans were made, which spanned 2) science-driven math, 3) math and science in concert, and 4) math-driven science. In particular, Ms. Miller and Ms. Smith created several activities in which they attempted to use science and math in concert, for example with their Gapminder project.
By the end of the intervention, the teachers expressed greater appreciation for each other’s subjects, and a commitment to continue to teach 2) science-driven math and 4) math-driven science, respectively. For example, Mr. King commented during his final interview, “I recognize that if students are motivated to discover by the scientific process, then this ideal [of them understanding math] is more likely to be achieved.” While this is not the complete integration that some authors (e.g. Drake, 2007; Moore, 1903; Vars, 2001) may have hoped for, it does align with Common Core (CCSS-M, 2010) and NexGen Standards (NGSS, 2013) to provide more relevant context and connections in both math and science.

Next, I will note the limitations of this study, before discussing the implications of the study and for interdisciplinary co-planning for teachers, teacher leaders, and for future researchers.
Limitations of the Study

Like all research, this study has some limitations. First, a small convenience sample of teachers was used (6 teachers) at a small number of locations (1 middle school; 1 high school) over a relatively short time span (10 weeks). Given the novelty of the ICT model and that this study increased the participant group from 2 to 6 teachers from the pilot study, it was beyond the scope of the current study to include more teachers or locations, or to increase the time span. Therefore, results and discussion are limited to the scope of the study, and not generalizable to the larger teacher population.

Second, role management was particularly important in this study, given that the researcher developed the ICT model, and that the researcher also conducted the professional development necessary to implement the model with teachers. Though there is no complete safeguard against researcher bias, the observation and interview protocols served to mitigate the amount of bias incurred in data collection and analysis. In addition, care was taken to separate the participants’ voice from the researcher’s when applicable in order to understand the nature of teacher planning and beliefs, and not the researcher’s.

Finally, this study did not attend to actual teaching practices or the effects of the ICT model on the participating teachers’ students. Therefore, though it may be concluded that the ICT model had great effects on the participating teachers’ planning and beliefs, the effect on students cannot be concluded, except through theorizing using existing literature.

Implications

The Interdisciplinary Co-planning Team (ICT) model was created to help teachers to provide an interdisciplinary experience for students while fitting into the current structure of
schools. In this study, the ICT model was implemented with teachers across several grade levels in order to describe the co-planning process and the plans that the teachers created. The intervention was considered successful in that the teachers met weekly for the duration of the intervention, and that they created and implemented a variety of plans in their classes which included connections between their content areas. The teachers were also enthusiastic to continue co-planning the next school year, after the intervention had ended. This section describes implications from this study for teachers, for teacher leaders, and for future research.

**Implications for Teachers**

The results of this study indicate that teachers from a variety of backgrounds directly benefit from participating in interdisciplinary co-planning teams in several ways, including access to resources, increased knowledge and appreciation for specific content and connections, and increased appreciation and understanding of interdisciplinary collaboration. Teachers in this study also expressed benefits resulting from perceived increases in their students’ understanding and engagement.

Regarding access to resources, both teachers in each pair expressed that they found value in discovering the resources that their partner teacher used regularly. Particularly for the mathematics teachers, who tended to use the textbook more than their science colleagues, this provided an increase in activities which they reported to implement with their classes. For the science teachers, the mathematics teachers provided an extra intellectual resource, because they could quickly and easily explain mathematical concepts which were useful to the science teachers. The teachers were also more apt to share physical resources, such as lab
equipment and measuring devices. This implies that the ICT model created new and powerful ways for the teachers to share both intellectual and physical resources, a valuable asset to continued professional growth.

Regarding the teachers’ knowledge and appreciation for specific content and connections, one design feature of the ICT model is that teachers engage in in-depth discussion of content, which was realized in discussion of the co-planning process. Thus, it should not be surprising that teachers develop knowledge of specific content and connections, both for their own subject and for their partner’s. In addition, each of the teachers in the study began with little appreciation for the purpose and application of their partner’s subject, particularly as it applied to their own. Over the course of the intervention, the math teachers expressed increased understanding about scientific inquiry as it could be applied to their content, and the science teachers expressed a comparable increase in understanding about the application of mathematical concepts to their content.

By the end of the intervention, the teachers all echoed a sentiment of surprise in the nature and amount of connections that they were able to realize throughout the intervention. This implies that participation with the ICT model may be an effective way for teachers to develop professionally in their own understanding of both specific subject matter and the connections between subjects. The teachers became more knowledgeable about what students know in each class, which made them better able to draw appropriate connections for students at various times during their teaching. In particular, Ms. Williams reflected on her new knowledge. She said, “It gave me a much better picture of what they were able to do, and what they had already learned.” It is known that teachers often do not follow through
with change to the curriculum because of a lack of content and related knowledge (e.g., Başkan, Alev, & Karal, 2010), and the ICT model seems to provide a method for teachers to gain the necessary knowledge to feel successful in continuing to look for and create interdisciplinary lessons for their classes.

The increase in knowledge and appreciation for each other’s content was particularly noticeable in the case of Jones and Williams, the novice teachers. As less experienced teachers, Mr. Jones and Ms. Williams each expressed more inconsistencies in their understanding of math and science, and more doubt about their ability to create interdisciplinary connections. Participation with the ICT model seemed to not only increase knowledge and understanding in this case, but also the confidence and self-efficacy that the teachers needed in order to follow through with the plans that they discussed. Thus, the in depth content discussion that is a part of co-planning may be a particularly useful form of development for newer teachers to develop knowledge and confidence.

Another benefit of participation with the ICT model for teachers in this study was an increase in appreciation for interdisciplinary collaboration. At ECHS, which housed Jones, Williams, King, and Taylor, teachers were not in the habit of communicating regularly between departments. At ICMS, which housed Miller and Smith, grade level teachers were organized into teams, which regularly discussed students and behaviors, but not content. In all cases, the teachers found value in discussing content with a teacher from outside of their own department because of the insights that their partner would regularly offer. The teachers noted that these insights added rigor and relevance to the plans that they implemented, and
planned to continue co-planning after the end of the intervention, indicating that they found value in these discussions.

According to the results of this study, it seems that the opportunity to combine in depth discussion of content with a close professional relationship in which both teachers are mutually experts in their own content provided other benefits to teachers as well. First, scheduling regular meetings between partners proved to be much easier than scheduling with larger groups. The teachers also expressed a greater sense of accountability to a single partner than if they were planning interdisciplinary activities alone or with a larger team. They seemed to feel more comfortable asking for clarification or a further explanation of concepts because they were having a one on one conversation instead of worrying if they were holding a larger group from moving forward, which may imply that the partner approach encouraged increased social trust during the intervention. Since implementing interdisciplinary connections often requires a cultural shift in thinking (Koirala & Bowman, 2003), the opportunity to develop insights with a partner may provide a way for teachers to develop this shift gradually and in a supportive environment.

Finally, the teachers’ perceptions of their students’ increase in understanding and engagement seemed to play a part in the teachers’ attitudes toward the entire interdisciplinary co-planning experience. The teachers reported back to co-planning meetings about the attitudes of their students, and seemed to have a renewed interest in their students’ perceptions of the content and the activities, leading to more student-centered planning and an increased excitement level among the teachers during co-planning. Most of the larger activities that the teachers in this study planned were student centered, and discussion of
these activities often involved discussion of student understanding and accessibility, which helps with hands-on, minds-on learning (e.g., Furner & Kumar, 2007). Especially in the case of the middle school teachers, Miller and Smith, seems to have not only changed their outlook on interdisciplinary connections, but on their daily teaching. This ability of the teachers to notice and share positive feedback from their students may increase the teachers’ current and future efforts at interdisciplinary co-planning as well as creating and maintaining a variety of student-centered plans to be implemented in the classroom.

**Implications for Teacher Leaders**

Teacher leaders, including department heads, instructional coaches, administrators, and teacher educators, may be interested in introducing teachers to interdisciplinary co-planning for many of the teacher benefits discussed above. In this study, teachers from a variety of backgrounds seem to have been positively impacted through the co-planning intervention, and expressed an interest in continuing to co-plan after the intervention ended. Their increases in knowledge and appreciation for each other’s subjects may provide a reason to expand ICT co-planning to more teacher pairs in these and other schools.

One teacher suggested that ICT co-planning in her school should replace existing PLCs (small group meetings within departments), which focus mainly on standardized testing scores. This provides evidence that the teachers that participated in this study were less concerned with tracking student exam scores, and more concerned with creating useful activities and lessons for student learning. While ICT co-planning may not replace intra-departmental meetings and collaboration, it may provide a valuable supplement and allow teachers opportunities to collaborate in ways that they may not otherwise experience.
Teacher educators may consider discussions with pre-service and in-service teachers which include the benefits of different types of planning so that teachers are more aware of the different opportunities that they can take to collaborate with colleagues.

Administrators may consider whether the structure of the time and space within their school building encourages interdepartmental collaboration, particularly, grade level collaboration. At ICMS, Ms. Miller and Ms. Smith shared a common planning period, and their classrooms were within a short distance of each other. They saw each other regularly in passing, and often continued co-planning between regularly scheduled meetings. At ECHS, the teachers did not share a planning period, and they were not close in proximity. While these factors did not stop them from successfully co-planning and implementing interdisciplinary lessons, they may have been further encouraged through more thoughtful administrative planning.

The use of a facilitator, though not a part of the original ICT model, seems to have been an important part of the intervention, and is recommended, particularly for teams of newer teachers. For example, in the case of Jones and Williams, the first year teachers in this study, both teachers were eager to collaborate, but seemed quick to dismiss discussion of content if they saw no immediate connections, particularly toward the beginning of the intervention. Contrary to claims by Roskos that implementation of interdisciplinary curricula may be too complex for novice teachers to attempt (Roskos & Neuman, 1995; Roskos, 1996), the participation of the facilitator seemed to provide an easier access point to finding interdisciplinary connections without overwhelming teachers. The function of the facilitator at these earlier meetings became to ask, “What does that mean,” “what is that,” and other
questions that lead the teachers to discuss content further and find connections that they could use in their classes.

The use of a facilitator also may have provided additional accountability in the initial establishment of a routine for even the more experienced teachers. Ms. Taylor commented:

I think the best thing about it was the accountability. We knew that you were coming. We knew that we were going to meet. And I think this could very easily become a project that you think is a great idea that you want to do, but if you don’t have that accountability in there, it may not happen.

Administrators and teacher leaders may consider encouraging a more experienced teacher to facilitate or participate in co-planning sessions, particularly for novice teachers as a form of accountability and professional development. Teachers may also gain insight about co-planning from discussing affordances and possible troubleshooting with other ICTs, as the teachers in this study did during the whole group sessions. Scheduling larger group sessions periodically for collective participation may provide teachers with additional leadership opportunities as well as increased accountability in co-planning.

Finally, teacher leaders may consider the written and electronic resources that are available to teachers who are trying to co-plan interdisciplinary activities and lessons. While many resources may be adapted to include both math and science, as has been shown in this study, few are readily available to use by both teachers. Part of the success on ICT co-planning in this study is the increase in teacher creativity in planning lessons across disciplines, and teachers should be encouraged to continue to create and share these lessons.
In addition, teacher leaders can continue to collaborate to create, adapt, and share additional resources for teachers that are not limited to one academic subject.

**Implications for Researchers**

The benefits of interdisciplinary co-planning for teachers that are described above may be a partial list, which may be expanded as further research about interdisciplinary co-planning is conducted. The three limitations of this study that are listed above are a result of decisions made in the design of this study because of the novelty of the ICT model. Confrey et al. (2004) proposed that “no single methodology by itself” can be sufficient to determine a curricular program’s effectiveness (p. 191), and that various stages of study are necessary. Although this statement was regarding mathematics curricula, it can be extended to include teacher interaction with the ICT model. The first stage of study, the pilot study, was conducted immediately prior to the intervention for the purpose of establishing the possibility of co-planning between secondary science and mathematics teachers. The second stage of study, reflected in this paper, was a multiple (3) case study, designed to describe the nature of teacher co-planning and plans with use of the ICT model, and their resulting changes in beliefs.

Subsequent studies should further extend the scale of study regarding the ICT model. For example, it is possible to scale up in many ways, including the number of teachers, the number of sites, the subject areas of the teachers, and the time span. Different facilitators may also be trained, and the effects of implementation of the ICT model by different facilitators may be studied. The ICT model was designed to include teachers of all subjects.
and secondary grade levels, and teachers of other subjects and grade levels may be included in subsequent research.

Finally, the ultimate goal of any change in education is a positive impact on student learning, the actual implementation of interdisciplinary plans, as well as the effects on participants’ students in all of these cases may be studied. Parallels to Remillard’s (2005) enacted and intended curriculum may be made in studying the implementation of plans that teachers co-plan. Student engagement, motivation, understanding, and achievement may be measured in comparative studies in order to further understanding of the effects of both interdisciplinary studies and the ICT model on students.

Conclusions

The Interdisciplinary Co-planning Team (ICT) model was developed to encourage teachers to collaborate regularly to develop and implement interdisciplinary learning experiences for their students. This study has demonstrated that the unique dynamic of interdisciplinary co-planning pairs creates an environment conducive to sustained interdisciplinary collaboration. Regular co-planning with one partner teacher encourages external accountability and structure for interdisciplinary planning, while affording opportunities for teachers to increase social trust and self-efficacy in a less stressful environment than collaboration in larger groups. Thus, participation in co-planning pairs creates further opportunities for teacher growth as teachers of various backgrounds and experience levels are empowered to ask questions and to contribute to co-planning discussions in meaningful ways, and participation should not be limited to particular teachers.
This study has further demonstrated that participation in interdisciplinary co-planning teams pushes teachers away from thinking about their own subject as a silo, resulting in an expressed commitment to teaching math and science content as necessarily connected. Participation in co-planning discussions encourages teachers to share their individual expertise, which enhances their understanding of both their own content and that of their partner teacher. This enhanced knowledge and perspective encourages teachers to develop the confidence and self-efficacy necessary to continue to pursue and implement interdisciplinary connections with their students, effecting lasting change within the classroom.
REFERENCES


Ball, D. L. (2002). What do we believe about teacher learning and how can we learn with and from our beliefs?. In D.S. Mewbern, et al. (Eds.), *Proceedings of the Annual Meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education*. Columbus. 3-19.


Cetner, M. (2016). *The implementation of an interdisciplinary co-planning team model among mathematics and science teachers*. Unpublished manuscript, Department of Science, Technology, Engineering and Mathematics Education, NC State University, Raleigh, NC.


North Carolina Department of Public Instruction. (NCDPI, 2013a). NC school report cards:
2012-2013 school year, Beaufort Co Early College High. Retrieved from

North Carolina Department of Public Instruction. (NCDPI, 2013b). NC school report cards:
2012-2013 school year, C M Eppes Middle. Retrieved from


Vinner, S. (1999). Beliefs we live by and quite often are even not aware of – their possible impact on teaching and learning mathematics. In E. Pehkonen & G. Torner (Eds.), *Mathematical Beliefs and Their Impacts on Teaching and Learning*, (pp. 146-152). Oberwolbach.


APPENDICES
Appendix A

ICT Pilot Study Summary for Pilot Study
Michelle Cetner Brown

Overview: The purpose of this study is to implement a framework for Interdisciplinary Coplanning Teams (ICTs) with classroom teachers to describe how ICTs support teachers’ planning and teaching practices. A pilot study will be conducted with on pair of teachers (1 math, 1 science) in Fall 2015, possibly followed by a larger study in Spring 2016 (3-4 math/science teacher pairs).

Why Interdisciplinary? The Common Core State Standards (CCSS) and the Next Generation Science Standards (NGSS) both emphasize problem solving and critical thinking, which are greatly enhanced by a commitment to drawing connections between subject disciplines. Students who are exposed to integrative approaches also demonstrate greater interest, motivation, and achievement (Becker & Park, 2011).

What are ICTs? Interdisciplinary Coplanning Teams are pairs of teachers from different disciplines who meet regularly to discuss content and create lessons to use in their classes which emphasize connections between the disciplines. The following model describes the ICT routine for each teacher.

![The ICT Model Diagram](image-url)
What are the potential benefits to students?
- Deeper understanding of content (Berlin & White, 2012)
- Increased problem solving and communication skills (Moore & Smith, 2014)
- Increased interest and engagement (Morrison et al., 2015)
- Increased retention of concepts (Neulight et al., 2007)
- Improved test scores (Becker & Park, 2011)

What are the potential benefits to teachers?
- Increased focus on student learning instead of teaching (Czerniak et al., 1999)
- Increased focus on concepts and processes over memorizing facts (Vars, 2001)
- Increased pedagogical and content knowledge (Boyle et al., 2010)
- Teachers develop shared language (Owen, 2005)
- Collaboration creates enthusiasm and builds community (Borko et al., 2008)
- Increased reflection (Silver & Suh, 2014)

How will the ICTs be implemented, and what type of commitment is needed for the pilot study?
- Fall 2015: I will work closely with 2 teachers to help them learn to coplan for 4 weeks.
- The teachers should expect an introductory meeting (1 hour), and at least one coplanning meeting per week (1 hour each, 4 hours total).
- They will implement plans that they create during the meetings with their classes.
- They will be asked to keep a brief journal of their experiences.

What data will be collected?
- Observations of coplanning meetings and several teaching episodes, which include audio-recording and field notes.
- Teacher journals about the experience of coplanning (if teachers wish to keep them, I can copy and return them)
- A copy of any artifacts created during coplanning (lesson plans, worksheets, etc)
- NO STUDENT DATA or student work will be collected.
Appendix B

Principal script for recruiting teachers for interdisciplinary planning teams.

“I have given permission for a study to be conducted, which teams two teachers together to plan interdisciplinary lessons. The researcher is asking for a math teacher and a science teacher to volunteer to participate. The following overview should help to answer most questions.”

(Principal hands out overview and gives time for teachers to read through it). Principal points out section that details what teachers can expect.

“I want you to know that your participation in this study is completely voluntary. There will be no change in your duties or evaluation whether or not you decide to participate. The researcher is only looking for two volunteers, so if more than two people volunteer, I will pick two depending on your schedules and the student groups you teach.”
Appendix C

**Interdisciplinary Co-planning Study Overview for Dissertation Study**
Michelle Cetner Brown

**Overview:** The purpose of this study is to implement a model for Interdisciplinary Co-planning Teams (ICTs) with classroom teachers to describe how ICTs support teachers' planning and teaching practices. Participating teachers will be expected to participate in regularly scheduled co-planning sessions and to implement co-planned lessons in their classes.

**Why Interdisciplinary?** The Common Core State Standards (CCSS) and the Next Generation Science Standards (NGSS) both emphasize problem solving and critical thinking, which are greatly enhanced by a commitment to drawing connections between subject disciplines. Students who are exposed to integrative approaches also demonstrate greater interest, motivation, and achievement (Becker & Park, 2011).

**What are ICTs?** Interdisciplinary Coplanning Teams are pairs of teachers from different disciplines who meet regularly to discuss content and create lessons to use in their classes which emphasize connections between the disciplines. The following model describes the ICT routine for each teacher.
What are the potential benefits to students?
- Deeper understanding of content (Berlin & White, 2012)
- Increased problem solving and communication skills (Moore & Smith, 2014)
- Increased interest and engagement (Morrison et al., 2015)
- Increased retention of concepts (Neulight et al., 2007)
- Improved test scores (Becker & Park, 2011)

What are the potential benefits to teachers?
- Increased focus on student learning instead of teaching (Czerniak et al., 1999)
- Increased focus on concepts and processes over memorizing facts (Vars, 2001)
- Increased pedagogical and content knowledge (Boyle et al., 2010)
- Teachers develop shared language (Owen, 2005)
- Collaboration creates enthusiasm and builds community (Borko et al., 2008)
- Increased reflection (Silver & Suh, 2014)

How will the ICTs be implemented, and what type of commitment is needed?
- Teacher-participants will attend three whole-group professional learning sessions. The first will be during the first week to introduce the concept of ICTs; the second will be after 4 weeks to debrief and troubleshoot; and the third will be at the end of 8 weeks to debrief and conclude the study.
- Participants will also attend weekly interdisciplinary co-planning sessions with a partner, facilitated by the researcher.
- Participants will be asked to keep a journal which answers specific prompts about the co-planning experience.

What data will be collected?
- Individual teacher interviews at the beginning and end of the study.
- Observations of co-planning sessions and several teaching episodes, which include audio-recording and field notes.
- Teacher journals about the experience of co-planning (if teachers wish to keep them, I can copy and return them)
- A copy of any artifacts created during co-planning (lesson plans, worksheets, etc)
- NO STUDENT DATA or student work will be collected.
Appendix D

INFORMED CONSENT FORM for RESEARCH

North Carolina State University
Title: Implementation of a Model for Teacher Interdisciplinary Coplanning Teams
Principle Investigators: Dr. Allison McCulloch and Michelle Cetner Brown

What are some general things you should know about research studies?
You are being asked to take part in a research study. Your participation in this study is voluntary. You have the right to be a part of this study, to choose not to participate or to stop participating at any time without penalty. The purpose of research studies is to gain a better understanding of a certain topic or issue. You are not guaranteed any personal benefits from being in a study. Research studies also may pose risks to those that participate. In this consent form you will find specific details about the research in which you are being asked to participate. If you do not understand something in this form it is your right to ask the researcher for clarification or more information. A copy of this consent form will be provided to you. If at any time you have questions about your participation, do not hesitate to contact the researcher named above.

What is the purpose of this study?
The goals of this study are to better understand the planning strategies and personal beliefs held by experienced mathematics and science teachers in interdisciplinary co-planning teams (ICTs).

What will happen if you take part in the study?
If you agree to participate in this study, you will be asked to participate in several activities:

- Participate in pre- and post- interviews describing your beliefs about mathematics and science.
- Participate in training sessions to learn about the benefits and implementation of the ICT model. These sessions may be video or audio recorded.
- Participate in at least 6 ICT sessions with your partner. These sessions may be video or audio recorded.
- Use plans that you create in your classrooms. The researcher may ask to observe and audio-record your teaching for purposes of reflection and feedback. The researcher may also ask for a copy of any plans or accompanying artifacts that you create in the co-planning process.
- Record journal reflections on the planning process and your use of your plans.
Risks: There are no physical or emotional risks associated with participation in this study.

Benefits: The teachers that participate in this study will gain familiarity with a new form of planning that they can use even after the completion of the study. Students may gain a deeper understanding of content and increased interest, engagement and retention of concepts.

Confidentiality: The information in the study records will be kept confidential to the full extent allowed by law. Data will be stored securely. Pseudonyms will be used in oral or written reports to avoid linking you to the study.

What if you are a NCSU student? Participation in this study is not a course requirement and your participation or lack thereof, will not affect your class standing or grades at NC State.

What if you have questions about this study? If you have questions at any time about the study or the procedures, you may contact Michelle Cetner Brown at Poe 502 Campus Box 7801 NCSU Raleigh, NC 27695, or (252) 945-8938.

What if you have questions about your rights as a research participant? If you feel you have not been treated according to the descriptions in this form, or your rights as a participant in research have been violated during the course of this project, you may contact Deb Paxton, Regulatory Compliance Administrator, Box 7514, NCSU Campus (919/515-4514).

Consent To Participate “I have read and understand the above information. I have received a copy of this form. I agree to participate in this study with the understanding that I may choose not to participate or to stop participating at any time without penalty or loss of benefits to which I am otherwise entitled.”

Participant’s printed name__________________________ Date_________

Participant’s Signature____________________________ Date_________

Investigator’s printed name________________________ Date _________

Investigator’s signature____________________________ Date _________
Appendix E

Plan for First Group Professional Development Session

Duration: 1 hour

- Opening (10 minutes):
  - Use a powerpoint to describe the ICT model and the study.
  - Explain teachers’ part in this study and obtain signed Informed Consent forms.
  - Refer to Co-planning overview (Appendix B) for details that will be included.

- Bromothymol Blue Activity (30 minutes)
  - 5 minutes: Describe the activity and how it was co-planned. Add that data was collected in science class, then graphed and discussed in math class.
  - 20 minutes: Have teachers complete activity in their interdisciplinary teams (See Appendix E for activity)
  - 10 minutes: Provide time for teacher feedback. Emphasize connections that are made between the science and mathematics content, and ask how other connections may be made.

- Co-planning time (15 minutes)
  - Have teachers get with interdisciplinary partner and generate a list of possibilities for interdisciplinary lessons.
  - Have partner pairs share out and ask teachers to spend time refining one of their ideas as a potential interdisciplinary plan for the upcoming week.

- Wrap-up and debrief (5 minutes)
  - Make sure to leave time to schedule future meeting dates.
Appendix F

Interdisciplinary Activity - Bromothymol Blue

Exercise & Cellular Respiration

Purpose:
The purpose of this lab activity is to analyze the affect of exercise on cellular respiration.

Background:
I. Purpose.
- To observe the effects of exercise on cellular respiration.
- To identify the role of carbon dioxide production, breathing rate, and heart rate in determining
  the rate of cellular respiration.

II. Background Information.
Cellular respiration (see chemical reaction below) is a chemical reaction that occurs in your cells
to create energy; when you are exercising your muscle cells are creating ATP to contract. Cellular
respiration requires oxygen (which is breathed in) and creates carbon dioxide (which is breathed out).

\[ C_6H_{12}O_6 + 6 \text{O}_2 \rightarrow 6 \text{CO}_2 + 6 \text{H}_2\text{O} + 36 \text{ATP (energy)} \]

This lab will address how exercise (increased muscle activity) affects the rate of cellular
respiration. You will measure 3 different indicators of cellular respiration: breathing rate, heart rate,
and carbon dioxide production. You will measure these indicators at rest (with no exercise) and after 1
and 2 minutes of exercise. Breathing rate is measured in breaths per minute, heart rate in beats per
minute, and carbon dioxide in the time it takes bromthymol blue to change color.

Carbon dioxide production can be measured by breathing through a straw into a solution of
bromthymol blue (BTB). BTB is an acid indicator, when it reacts with acid it turns from blue to
yellow. When carbon dioxide reacts with water, a weak acid (carbonic acid) is formed (see chemical
reaction below). The more carbon dioxide you breathe into the BTB solution, the faster it will change
color to yellow.

\[ 6 \text{CO}_2 + 6 \text{H}_2\text{O} \rightarrow 6 \text{HCO}_3^- + 6 \text{H}^+ \]

Materials:
Beaker/Test tube/cup
bromothymol blue solution (BTB)
straw
stop watch

Pre-Lab: Use your background information AND your Cellular Respiration notes to answer the following
pre-lab questions.

1. What is the equation for cellular respiration? Label which items are the reactants and the
   products.
2. In what part of the cell does cellular respiration occur?
3. Write a prediction/hypothesis of how exercise will affect your body's production of carbon dioxide
   (i.e. do you think your body will produce more or less carbon dioxide as you exercise). Make sure you
   EXPLAIN WHY you feel that way.
Procedure:

PART A: Resting (no exercise)

Measuring Carbon Dioxide Production:
1. Use a graduated cylinder to measure out 20 mL of tap water and pour it into a small beaker.
2. Use a dropper to add 8 drops of bromthymol blue to make a BTB solution.
3. Using a straw, exhale into the BTB solution. (CAUTION: Do not inhale the solution!)
4. Time how long it takes for the blue solution to turn yellow. Record the time in Table 1.
5. Wash out the beaker repeat steps 1-4 twice more.
6. Average the results of the 3 trials. Record this in Table 1.

Measuring Breathing Rate:
1. Count the number of breaths (1 breath = inhale + exhale) you take in 1 minute. Record this in Table 2.
2. Repeat this 2 more times.
3. Average the 3 trials to get your average breathing rate. Record this in Table 2.

Measuring Heart Rate:
1. While you calculate your breathing rate, have your partner take your pulse.
2. Count the number of beats in 30 seconds and multiply that number by 2. Record this in Table 3.
3. Repeat this 2 more times.
4. Average the 3 trials to get your average heart rate. Record this in Table 3.

PART B: Increased Muscle Activity (Exercise)
1. Exercise for exactly 1 minute by doing jumping jacks.
2. While you are exercising, your partner should get the BTB solution ready as in Part A.
3. After 1 minute of exercise, immediately exhale through the straw into the BTB solution. Time how long it takes for the BTB to turn yellow. Record this in Table 1.
4. Then quickly calculate your breathing and heart rates as you did before. You only need to do this once.
5. Record these values in Tables 2 & 3. Remake your BTB solution.
6. Exercise as you did before, but for 2 continuous minutes.
7. Immediately exhale through the straw into the BTB solution. Time how long it takes for the BTB to turn yellow. Record this in Table 1.
8. Then quickly calculate your breathing and heart rates as you did before. You only need to do this once.
9. Record these values in Tables 2 & 3.
10. If there is time, repeat the entire procedure for your lab partner. Record data from 2 OR 3 other subjects in the class to get more data depending on if you partner was able to go or not.
### Results:

#### Table 1. Carbon Dioxide Production (time it takes BTB to change color)

<table>
<thead>
<tr>
<th></th>
<th>Student 1</th>
<th>Student 2</th>
<th>Student 3</th>
<th>Student 4</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>RESTING</td>
<td>Trial 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Trial 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Trial 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EXERCISE</td>
<td>1 minute</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 minutes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Table 2. Breathing Rate (breaths/minute)

<table>
<thead>
<tr>
<th></th>
<th>Student 1</th>
<th>Student 2</th>
<th>Student 3</th>
<th>Student 4</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>RESTING</td>
<td>Trial 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Trial 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Trial 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EXERCISE</td>
<td>1 minute</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 minutes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Table 3. Heart Rate (beats/minute)

<table>
<thead>
<tr>
<th></th>
<th>Student 1</th>
<th>Student 2</th>
<th>Student 3</th>
<th>Student 4</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>RESTING</td>
<td>Trial 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Trial 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Trial 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EXERCISE</td>
<td>1 minute</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 minutes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Analysis & Conclusions: Answer the questions below using your BACKGROUND information in the lab, as well as your lab data. ANSWER THE QUESTIONS IN COMPLETE SENTENCES.

1. How did exercise affect the time needed for the solution to change color? Explain why the color change occurred (How does BTB work?)

2. What can you conclude about the effect of exercise on the amount of carbon dioxide that is present in your exhaled breath? Why is this so?

3. What can you conclude about the effect of exercise on breathing rate? Why is this so?

4. What can you conclude about the effect of exercise on heart rate? Why is this so? What do your muscles need during exercise that the blood brings?

5. State whether your hypothesis was correct or incorrect and why. In doing so, discuss what you think is going on in the muscles of the body as muscle activity is increased. Address the need to get oxygen to the muscles and get rid of carbon dioxide, as well as how the muscles cells get the energy needed to continue contracting.
Appendix G

Outline for Co-planning Sessions

Duration: scheduled to be 1 hour each

- Researcher/facilitator asks each teacher to provide a synopsis of what they have done in their class over the last week.
  - Researcher asks teachers for any affordances and/or limitations in lessons that they co-planned within the last week.

- Teachers overview their plans for the upcoming week.
  - Teachers ask each other for clarification if necessary.
  - Facilitator may ask probing questions, such as “What do you mean when you say you are working on ____.”

- Teachers note commonalities in subject matter, or ways in which they can tie into each others’ subject matter in their own class.
  - Researcher may make suggestions if teachers do not come with ideas, or ask for clarification if it is apparent that one teacher is not understanding what the other is saying.

- Teachers discuss ways that they can approach commonalities or connections with their students, and come up with activities, examples, and discussion points that they will use in their lessons for the upcoming week.
  - Facilitator may make suggestions or ask clarifying questions based on the amount of guidance that it seems teachers need.

- Teachers wrap up by determining if additional tasks need to be completed or additional meeting time is necessary in order to teach the planned lesson or before the next co-planning session.
Appendix H

Journal Prompts

These need to serve the purpose of describing the nature of teacher plans when using the ICT model as well as use for teacher feedback for growth.

Teachers should make 7 journal entries (one per co-planning session). This list serves as a guideline for journal prompts. The prompts are subject to change as teacher needs are discovered throughout the intervention.

Week 1:

1. Did you implement anything in your class this week that you co-planned? If so, describe it. What did you do? What did students do? What did you struggle or have success with, and what did your students struggle or have success with?
2. Reflect on a lesson you have taught in the past that you have attempted to make interdisciplinary. Describe the lesson. In what ways did you attempt to make it interdisciplinary? What were some of the struggles you faced? What were some of the successes you had?

Week 2:

1. How is what you are doing with your partner similar or different from what you have done in the past?
2. Did you implement anything in your class this week that you co-planned? If so, describe it. What did you do? What did students do? What parts of the lesson do you struggle or have success with, and what do your students struggle or have success with?

Week 3:

1. Did you do anything (anything can be as small as an example or as big as a whole lesson) in your class this week that you discussed during co-planning? If so, describe it in detail. What did you do? What did students do? What parts did you struggle or have success with, and what do your students struggle or have success with?
2. Besides our weekly meeting, what else have you done to prepare or plan to teach what you have co-planned? Did you talk to your partner outside of our sessions? Did you seek advice from anyone else? Did you use any resources? Did you write anything down?

Week 4:

1. How is co-planning different or similar to the planning you do alone or with department members? Describe the differences in the subject matter that we discuss, the ways in which we discuss it, and anything else that comes to mind.
2. Did you implement any lessons in your class this week that you co-planned? If so, describe it. What did you do? What did students do? What parts of the lesson do you
struggle or have success with, and what do your students struggle or have success with?

Week 5:
1. ECHS: Reflect on our last whole group meeting (yes, it has been that long since you wrote a reflection). Was anything in particular said that you strongly agree or disagree with? Is there anything else that you thought of after the fact that you wish you had said?
2. ICMS: Reflect on the logistics of coplanning. Why do you think your group is being successful and the other group at your school is not. (Be honest. I do not share these.)
3. Did you implement anything in your class since your last reflection that you co-planned, or that was interdisciplinary? If so, describe it. What did you do? What did students do? What parts did you struggle or have success with, and what did your students struggle or have success with?

Week 6:
1. Describe “normal” ways in which you implement interdisciplinary content in your class. Is it through labs? Examples? Class discussion? Etc? How is this similar or different to ways you have introduced your students to interdisciplinary content in the past (before this project)?
2. Did you implement any lessons in your class this week that you co-planned? If so, describe it. What did you do? What did students do? What parts of the lesson do you struggle or have success with, and what do your students struggle or have success with?

Week 7:
1. Reflect on the co-planning project. In what ways have you grown or learned through the co-planning project? What aspects of student learning did you value the most before we began this project, and is that the same or different now? If you continue to work with your partner, what will do continue to do, and what will you do differently? Why?
2. Did you implement any lessons in your class this week that you co-planned? If so, describe it. What did you do? What did students do? What parts of the lesson do you struggle or have success with, and what do your students struggle or have success with?
Appendix I

Plan for PLE2: Second Whole Group Meeting
PLE # 2 - discussion about how ICT experience is going: troubleshooting, reflection, sharing successes and obstacles

1. How is it (coplanning) going? Tell me what you think of the experience so far.
   a. I am hoping this is a good icebreaker, and will begin a general conversation about their experiences.

2. I know from your reflections that this is different from planning together that you have done before because it is more sustained and more collaborative. How has working ICT coplanning into your schedule been? How useful has your time doing this been so far? Suggestions for improvement?
   a. I am hoping that they will also discuss planning they have been doing outside of regular sessions as well in answering this question. If they don’t go there, I will probably ask about this directly.

3. What things have you coplanned and then implemented? Is there anything you coplanned and then did not do? Why?
   a. I feel like they talk more about what they are going to do than actually do it, and I want to see if they have any obstacles/reasons for that, and if they have any troubleshooting techniques to share about that.
   b. I think they do more when they get more specific, and want to see if that comes out.

4. What specific successes have you had? What have you done that you are particularly proud of?
   a. I am hoping that the groups will talk about 1) the roller coaster project, and 2) the potato lab (and what made these projects particularly interesting).
   b. I am also hoping that they will talk about daily successes and examples that they have done in class, etc, specifically that most of what they have done has not been in the form of big projects. If they do not go there, I will ask this directly as well.
   c. They may also bring up personal learning. They have commented a lot about that.

5. I know when we interviewed in the beginning, most of you felt tension about introducing concepts from the other content, and I know Tabitha and Katherine in particular have really stepped outside their comfort zones in introducing math to their students. How is that going?
   a. I am looking for obstacles and success with content, as well as beliefs changing in efficacy since initial interviews.

6. Do you have any other thoughts or suggestions?
   a. Open for anything else.
Appendix J

Plan for PLE3: Third Whole Group Meeting
I plan to have teachers talk with their partner for 5-10 minutes on each prompt, and then share out and discuss as a whole group.

Activity: Here (next page) is a partial list of the topics you discussed in all of your co-planning meetings.
   1. Identify which ones your and your partner discussed, and add to the list as necessary.

   2. Of the topics you discussed, which made it to implementation in your classes? Categorize them as
      a. Activities/labs/projects
      b. Examples
      c. Discussion points

   3. Of the topics you discussed, which did not make it to implementation in your classes? Categorize them as
      d. Topic I already taught - will think about for next year.
      e. Topic I will teach - will keep in mind for this year.
      f. I gained personal insights and may incorporate in other ways that are not currently clear.
      g. Irrelevant and I will probably never use it.

   4. Which do you feel you had the most success with in creating connections for your students? Why

   5. Which do you feel you had the least success with? Why?
### List of topics (ICMS)
- Scientific notation
- Linear equations
- Cellular respiration
- Independent and dependent variables
- Gapminder
- Earth history
- Triangles, shapes, angles, transformations
- Pythagorean Theorem
- 2 Way tables
- Scatterplots
- Histograms
- Quadratic formula
- Volume of circular objects
- Similarity, congruence
- Bacteria
- Radioactive decay
- Exponential growth
- Geologic history
- Fossils
- Morphology
- Disease
- Biotechnology
- Slope

### List of topics (ECHS)
- Potential and kinetic energy
- Quadratic functions
- Velocity and acceleration
- Waves, Optics, sound
- Graphs
- Rate of change, slope, equation of line
- Evolution
- Cellular biology, Cell structure and function
- Hypotopic, isotonic, hypertonic
- Quadrilaterals
- Trigonometry, trig graphs
- Exponents and logarithms
- Relative size
- Half life, Radioactive decay
- Electricity, series and parallel circuits
- Magnetism
- Distance, midpoint, area, volume
- pH, pOH
- Ohm’s Law, Power
- Direct and inverse variation
- Literal equations, formulas
- Permutations and combinations
- 2 way tables
- Marcomolecules, Enzymes
- Transformations
- Domain
- Triangle inequalities
- Modeling
- Central tendancy/ variation
- Regression lines
- States of matter, Phase change
- Atomic structure
- Cell cycle, Cancer
- Population curves
- Mixtures, solutions, colloids
- DNA, RNA, Protein synthesis
- Probability, Dependent and independent events
- volume/ surface area
- Sampling procedures
- Genetics, Punnit Squares
- Normal distribution
Factors that contribute to successful co-planning

With your partner, arrange the following in order to most important to least important to your success co-planning (I think I will have them cut out and in a baggie and have them arrange on the table)

Time to meet regularly (coplanning meetings)
Proximity of space (being near each other during the day)
Length of coplanning meetings
Time to meet/interact between regularly scheduled meetings
Time to turn discussions from coplanning meetings into lessons you can use in your class
Availability of resources
Knowledge of each other's subject concepts
Knowledge of your own subject concepts
Knowledge of each other's SCOS/ standards
Knowledge of your own SCOS/ standards
Confidence in students' abilities to understand connections
Students' overall ability
Natural alignment of curricula
Amount of time available to teach concepts to students
Preparation of each teacher upon entering coplanning meetings
Specific content (does some content lend itself to connections better than other content?)
Ability to work with a particular partner
Your own ability to work with others
Amount of experience you have working with others
Amount of experience you have thinking about interdisciplinary connections
Amount of experience you have working with this particular partner
Amount of experience you have teaching a particular class
Other
Other

What advice would you give to future teachers coplanning? What advice would you give to facilitators, admin, etc?
Appendix K

Planning Observation Protocol

Observer______________________________ School Name_____________________
Observation date________________________ Time/period_____________________
Teachers_______________________________ Classes/subjects__________________

Topics discussed:

Curriculum materials used:

Lesson structure planned:

In planning, teachers mostly focused on (can check more than 1)
- practicing basic skills
- practicing vocabulary
- developing math concepts
- developing science concepts
- connections between math and science
- problem solving
- other_____________________________

Comments/ examples:

Summary:

<table>
<thead>
<tr>
<th>What happened</th>
<th>Who initiated</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
1. **Mathematics and Science Content**  
*Scale: 0 = not observed, 1 = minimal, 2 = to some extent, 3 = very descriptive of observation*

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th>Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a</td>
<td>Teachers discuss mathematics and science content and standards.</td>
<td>(0) (1) (2) (3)</td>
</tr>
<tr>
<td>1b</td>
<td>Teachers discuss mathematics and science concepts in depth.</td>
<td>(0) (1) (2) (3)</td>
</tr>
<tr>
<td>1c</td>
<td>Math and science content information was accurate.</td>
<td>(0) (1) (2) (3)</td>
</tr>
<tr>
<td>1d</td>
<td>Teachers discuss mathematics and scientific practices.</td>
<td>(0) (1) (2) (3)</td>
</tr>
<tr>
<td>1e</td>
<td>Teachers used accurate and appropriate mathematics and science vocabulary.</td>
<td>(0) (1) (2) (3)</td>
</tr>
<tr>
<td>1f</td>
<td>Teachers discussed connections between mathematics and science concepts.</td>
<td>(0) (1) (2) (3)</td>
</tr>
<tr>
<td>1g</td>
<td>Teachers discussed connections between mathematics/science concepts and other disciplines.</td>
<td>(0) (1) (2) (3)</td>
</tr>
<tr>
<td>1h</td>
<td>Teachers discussed how students would use previous knowledge or approach concepts.</td>
<td>(0) (1) (2) (3)</td>
</tr>
<tr>
<td>1i</td>
<td>Teachers discussed how students would make meaningful connections between mathematics and science concepts and practices.</td>
<td>(0) (1) (2) (3)</td>
</tr>
<tr>
<td>1j</td>
<td>Teachers discussed how students would make connections between mathematics/science concepts and real-world problems.</td>
<td>(0) (1) (2) (3)</td>
</tr>
<tr>
<td>1k</td>
<td>Teachers discussed specific activities, examples, and discussion points that they will use with students.</td>
<td>(0) (1) (2) (3)</td>
</tr>
</tbody>
</table>

2. **Attitudes About Interdisciplinary Teaching**  
*Scale: 0 = not observed, 1 = minimal, 2 = to some extent, 3 = very descriptive of observation*

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th>Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>2a</td>
<td>Teachers were receptive to learn each other’s content and practices.</td>
<td>(0) (1) (2) (3)</td>
</tr>
<tr>
<td>2b</td>
<td>Teachers voiced a desire to find deep connections between each other’s content and practices.</td>
<td>(0) (1) (2) (3)</td>
</tr>
<tr>
<td>2c</td>
<td>Teachers voiced excitement about students learning connections between mathematics and science.</td>
<td>(0) (1) (2) (3)</td>
</tr>
<tr>
<td>2e</td>
<td>Teachers expressed value in using interdisciplinary connections.</td>
<td>(0) (1) (2) (3)</td>
</tr>
<tr>
<td>2f</td>
<td>Teachers voiced concern about taking extra time to teach connections between content and practices and covering all of the standards for testing.</td>
<td>(0) (1) (2) (3)</td>
</tr>
<tr>
<td>2g</td>
<td>Teachers voiced concern about student ability to learn connections between the mathematical and scientific concepts.</td>
<td>(0) (1) (2) (3)</td>
</tr>
</tbody>
</table>

Record comments and specific examples below:

**Fieldnotes will be taken on Livescribe notebook paper**
Appendix L

Pre-intervention interview protocol

Teacher Pseudonym: ____________________ Date: ________________

(Parts that are written in bold or in parenthesis are for organization only, and will not be read/shared with participants)

Part 1: The purpose of this part of the interview is to learn what you think about mathematics and science.

Beliefs about teaching, learning, and students in math/science (These questions are a combination of adapted questions from Evans, 2003; and Luft & Roehrig, 2007)

Describe a typical day in your ideal (science or math) class.

(look for: what is teacher doing and what are students doing; whole class vs small group; who is doing the talking, asking questions, explaining, comparison to colleague’s classes)

How do you decide what to teach and what not to teach?

(look for: planning procedures, following textbook or other curriculum, begin with objectives or standards, focus on activities, depth of understanding)

How do you plan for instruction?

(look for: levels of planning, process, types of instruction, when and how planning occurs)

Do you do different types of planning?

(look for: focus on different things e.g., content, activities; compare to planning with department members, other colleagues)

What resources do you use, either in teaching or in planning for teaching?

(look for: electronic and material resources, for planning and for teaching, teacher guides, other teachers, notebook)

How do you know when your students learned something?

(look for: understanding vs repetition, when to move on to a new topic in your classroom, behavioral responses vs constructivist responses, transfer, tests, formal vs informal, answer vs thinking, multiple correct answers, justification, communication)

What do you do when students struggle?
Beliefs about the nature of mathematics (Adapted questions from Evans, 2003 survey questions)

In your view, what is math?
  (Look-for: difference between math and other disciplines, concrete vs abstract, isolated or real life)
What does it mean to solve a “problem” in math?
  (Look for: description of math problem, set of procedures vs problem solving view, showing work, length of problem, one answer vs multiple answers)
What is a theorem in math? What does it mean to prove something?
What does a person have to do in order to be good at math at school?
  (Look for: conceptual understanding, repetition and practice, visualizing vs symbols)

Beliefs about the nature of science (VNOS – Lederman et al., 2002)

What, in your view, is science?
  (Look for: difference between science and other disciplines)
What does it mean to conduct an “experiment” or “lab” in science?
  (Look for: procedure vs imagination, confirmation vs expanding knowledge, purpose/value)
What is a “theory” in science? What does it mean to prove something?
  (Look for: static vs. changing, cultural vs universal)
What does a person have to do in order to be good at science at school?
  (Look for: conceptual understanding vs repetition and practice, vocabulary and dates vs scientific principles)

Beliefs about interdisciplinary connections between mathematics and science (Adapted from McGinnis et al., 1997; and #7 is from Watanabe & Huntley, 1998)

In what ways are math and science connected?
  (Look for: science as context or application for math, math in service of science, specific terms, surface features, problem solving, real life or relevance, similar practices)
In what ways do your plans for instruction include connections in math and science?
  (Look for: topics in isolation, specific content connections, use of activity, problem solving, ability to create examples, desire to expand on situations as they naturally occur, efficacy)
In what ways do your plans for instruction include connections between math or science and other subject areas?
Part 2: The purpose of this part of the interview is to obtain an understanding of your experiences with the ICT model, not to evaluate your competence as a teacher or the practices that you individually use.

ICT Expectations: (The purpose of this set of questions is to find out about the sustainability of the ICT model.)

Describe how you expect interdisciplinary co-planning to fit or not fit into your regular schedule.

(What do plans consist of, how ICT implementation changes plans)

What successes and obstacles do you expect to have with your co-planning team?

What concerns do you have about interdisciplinary co-planning and about your students learning interdisciplinary content?

Social Trust/collaboration:

Describe some ways that you work with your colleagues currently.

Describe a time that things really worked well and when they did not.

Tell me about your professional relationship with (your partner). Have you ever worked specifically with (your partner)? In what way? How did that work?

Instructional Plans: (The purpose of this set of questions is to supplement artifacts and reflective journals about teacher plans. I am only asking this for the teacher pair that has already worked together)

Describe some of the lessons you planned, both together and separately since this project began, and how they went in your class.

Describe how you planned to create connections for student in your class.

In what other ways has your planning or teaching changed or remained the same over the course of this project, that we did not already discuss?
Appendix M

Post- intervention interview protocol

Teacher Pseudonym: ____________________ Date: ________________

(Parts that are written in bold or in parenthesis are for organization only, and will not be read/shared with participants)

Part 1: The purpose of this part of the interview is to see what you think about mathematics and science.

Beliefs about teaching, learning, and students in math/science (These questions are a combination of adapted questions from Evans, 2003; and Luft & Roehrig, 2007)

Describe a typical day in your ideal (science or math) class.

(Look for: what is teacher doing and what are students doing; whole class vs small group; who is doing the talking, asking questions, explaining, comparison to colleague’s classes)

How do you decide what to teach and what not to teach?

(Look for: planning procedures, following textbook or other curriculum, begin with objectives or standards, focus on activities, depth of understanding)

How do you plan for instruction?

(Look for: levels of planning, process, types of instruction, when and how planning occurs)

Do you do different types of planning?

(Look for: focus on different things e.g., content, activities; compare to planning with department members, other colleagues)

What resources do you use, either in teaching or in planning for teaching?

(Look for: electronic and material resources, for planning and for teaching, teacher guides, other teachers, notebook)

How do you know when your students learned something?

(Look for: understanding vs repetition, when to move on to a new topic in your classroom, behavioral responses vs constructivist responses, transfer, tests, formal vs informal, answer vs thinking, multiple correct answers, justification, communication)

What do you do when students struggle?
Beliefs about the nature of mathematics (Adapted questions from Evans, 2003 survey questions)

In your view, what is math?
   (Look-for: difference between math and other disciplines, concrete vs abstract, isolated or real life)
What does it mean to solve a “problem” in math?
   (Look for: description of math problem, set of procedures vs problem solving view, showing work, length of problem, one answer vs multiple answers)
What is a theorem in math? What does it mean to prove something?
What does a person have to do in order to be good at math at school?
   (Look for: conceptual understanding, repetition and practice, visualizing vs symbols)

Beliefs about the nature of science (VNOS – Lederman et al., 2002)

What, in your view, is science?
   (Look for: difference between science and other disciplines)
What does it mean to conduct an “experiment” or “lab” in science?
   (Look for: procedure vs imagination, confirmation vs expanding knowledge, purpose/value)
What is a “theory” in science? What does it mean to prove something?
   (Look for: static vs. changing, cultural vs universal)
What does a person have to do in order to be good at science at school?
   (Look for: conceptual understanding vs repetition and practice, vocabulary and dates vs scientific principles)

Beliefs about interdisciplinary connections between mathematics and science (Adapted from McGinnis et al., 1997; and #7 is from Watanabe & Huntley, 1998)

In what ways are math and science connected?
   (Look for: science as context or application for math, math in service of science, specific terms, surface features, problem solving, real life or relevance, similar practices)
In what ways do your plans for instruction include connections in math and science?
   (Look for: topics in isolation, specific content connections, use of activity, problem solving, ability to create examples, desire to expand on situations as they naturally occur, efficacy)
In what ways do your plans for instruction include connections between math or science and other subject areas?
Part 2: The purpose of this part of the interview is to obtain an understanding of your experiences with the ICT model, not to evaluate your competence as a teacher or the practices that you individually use.

ICT Expectations: (The purpose of this set of questions is to find out about the sustainability of the ICT model.)

Describe how interdisciplinary co-planning to fit or did not fit into your regular schedule.
   (Look for: planning process, planning during scheduled sessions and between them, locating resources, value of co-planning)
What successes and obstacles did you have with your co-planning team?
   (Look for: success and obstacles pertaining to scheduling, finding connections, content, implementation with students)
What successes and obstacles did you have with interdisciplinary co-planning and about your students learning interdisciplinary content?
   (Look for: Differences in concerns between beginning and end, how they were addressed, what concerns remain)

Social Trust/ collaboration:

Describe some ways that you work with your colleagues currently.
   (Look for within department, across departments, process)
Describe a time that things really worked well and when they did not.
Tell me about your professional relationship with (your partner). Have you ever worked specifically with (your partner)? In what way? How did that work?

Instructional Plans: (The purpose of this set of questions is to supplement artifacts and reflective journals about teacher plans. I am only asking this for the teacher pair that has already worked together)

Describe some of the lessons you planned, both together and separately since this project began, and how they went in your class.
   (Look for: what do plans consist of, how ICT implementation changes plans)
Describe how you planned to create connections for students in your class.
   (Look for: types of connections, level of connections, use of activity, thoughts on implementation)
In what other ways has your planning or teaching changed or remained the same over the course of this project, that we did not already discuss?
What advice do you have for a future teacher that may consider co-planning?
### Appendix N

**Codebook for Interdisciplinary Co-Planning Intervention**

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAC - belief about collaborating</td>
<td>Statements made by any teacher about their beliefs about collaboration, or leading to an understanding of their beliefs about collaboration</td>
</tr>
<tr>
<td>BAL - beliefs about learning (and students)</td>
<td>Statements made by any teacher about their beliefs about learning, or leading to an understanding of their beliefs about learning</td>
</tr>
<tr>
<td>BAP - beliefs about planning</td>
<td>Statements made by any teacher about their beliefs about planning, or leading to an understanding of their beliefs about planning</td>
</tr>
<tr>
<td>BAT - beliefs about teaching</td>
<td>Statements made by any teacher about their beliefs about teaching, or leading to an understanding of their beliefs about teaching</td>
</tr>
<tr>
<td>BIC - beliefs about interdisciplinary connections</td>
<td>Statements made by any teacher about their beliefs about interdisciplinary connections, or leading to an understanding of their beliefs about interdisciplinary connections</td>
</tr>
<tr>
<td>BINOM - belief in nature of math</td>
<td>Statements made by any teacher about their beliefs about the nature of mathematics, or leading to an understanding of their beliefs about the nature of mathematics</td>
</tr>
<tr>
<td>BINOS - belief in nature of science</td>
<td>Statements made by any teacher about their beliefs about the nature of science, or leading to an understanding of their beliefs about the nature of science</td>
</tr>
<tr>
<td>Jones Early</td>
<td>Statements made by Mr. Jones during the first whole group meeting (PLE1), initial interviews, and the first 3 co-planning sessions (CP1, CP2, and CP3), especially referring to personal beliefs or justifications</td>
</tr>
<tr>
<td>Jones late</td>
<td>Statements made by Mr. Jones during the last whole group meeting (PLE3), final interviews, and the last 2 co-planning sessions (CP6 and CP7), especially referring to personal beliefs or justifications</td>
</tr>
<tr>
<td>Jones mid</td>
<td>Statements made by Mr. Jones during the second whole group meeting (PLE2) and the 4th and 5th co-</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>----------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>King early</td>
<td>Statements made by Mr. King during the first whole group meeting (PLE1), initial interviews, and the first 3 co-planning sessions (CP1, CP2, and CP3), especially referring to personal beliefs or justifications</td>
</tr>
<tr>
<td>King late</td>
<td>Statements made by Mr. King during the last whole group meeting (PLE3), final interviews, and the last 2 co-planning sessions (CP6 and CP7), especially referring to personal beliefs or justifications</td>
</tr>
<tr>
<td>King mid</td>
<td>Statements made by Mr. King during the second whole group meeting (PLE2) and the 4th and 5th co-planning sessions (CP4 and CP5), especially referring to personal beliefs or justifications</td>
</tr>
<tr>
<td>Miller early</td>
<td>Statements made by Ms. Miller during the first whole group meeting (PLE1), initial interviews, and the first 4 co-planning sessions (CP1, CP2, CP3, and CP4), especially referring to personal beliefs or justifications</td>
</tr>
<tr>
<td>Miller late</td>
<td>Statements made by Ms. Miller during the last whole group meeting (PLE3), final interviews, and the last 3 co-planning sessions (CP5, CP6 and CP7), especially referring to personal beliefs or justifications</td>
</tr>
<tr>
<td>Smith early</td>
<td>Statements made by Ms. Smith during the first whole group meeting (PLE1), initial interviews, and the first 4 co-planning sessions (CP1, CP2, CP3, and CP4), especially referring to personal beliefs or justifications</td>
</tr>
<tr>
<td>Smith late</td>
<td>Statements made by Ms. Miller during the last whole group meeting (PLE3), final interviews, and the last 3 co-planning sessions (CP5, CP6 and CP7), especially referring to personal beliefs or justifications</td>
</tr>
<tr>
<td>Taylor early</td>
<td>Statements made by Ms. Taylor during the first whole group meeting (PLE1), initial interviews, and the first 3 co-planning sessions (CP1, CP2, and CP3), especially referring to personal beliefs or justifications</td>
</tr>
<tr>
<td>Taylor late</td>
<td>Statements made by Ms. Taylor during the last whole group meeting (PLE3), final interviews, and the last 2 co-planning sessions (CP6 and CP7), especially referring to personal beliefs or justifications</td>
</tr>
<tr>
<td>-------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Taylor mid</td>
<td>Statements made by Ms. Taylor during the second whole group meeting (PLE2) and the 4th and 5th co-planning sessions (CP4 and CP5), especially referring to personal beliefs or justifications</td>
</tr>
<tr>
<td>Williams early</td>
<td>Statements made by Ms. Williams during the first whole group meeting (PLE1), initial interviews, and the first 3 co-planning sessions (CP1, CP2, and CP3), especially referring to his personal beliefs or justifications</td>
</tr>
<tr>
<td>Williams late</td>
<td>Statements made by Ms. Williams during the last whole group meeting (PLE3), final interviews, and the last 2 co-planning sessions (CP6 and CP7), especially referring to personal beliefs or justifications</td>
</tr>
<tr>
<td>Williams mid</td>
<td>Statements made by Ms. Williams during the second whole group meeting (PLE2) and the 4th and 5th co-planning sessions (CP4 and CP5), especially referring to personal beliefs or justifications</td>
</tr>
<tr>
<td>ICTP - BELF - efficacy</td>
<td>Statements made by a teacher during a co-planning session concerning their ability or non-ability with a particular topic or subject</td>
</tr>
<tr>
<td>ICTP - BELF - express excitement/value</td>
<td>Statements made by a teacher during a co-planning session which expressed excitement about a particular connection or activity, or which ascribed value to a particular connection or activity</td>
</tr>
<tr>
<td>ICTP - BELF - rationale for decisions</td>
<td>Statements made by a teacher during a co-planning session which described a rationale or reasoning for a particular decision, or for general decisions</td>
</tr>
<tr>
<td>ICTP - CONT - discuss/clarify math content</td>
<td>Statements made by a teacher during a co-planning session which were meant to discuss or clarify mathematics content or concepts</td>
</tr>
<tr>
<td>ICTP - CONT - discuss/clarify science content</td>
<td>Statements made by a teacher during a co-planning session which were meant to discuss or clarify science content or concepts</td>
</tr>
<tr>
<td>ICTP - CONT - math/science connection</td>
<td>Statements made by a teacher during a co-planning session which were meant to draw connections</td>
</tr>
<tr>
<td>ICTP - CONT - name upcoming topic in math</td>
<td>Statements made by a teacher during a co-planning session which were to name upcoming (within the next week or two) content or topics in mathematics.</td>
</tr>
<tr>
<td>ICTP - CONT - name upcoming topic in science</td>
<td>Statements made by a teacher during a co-planning session which were to name upcoming (within the next week or two) content or topics in science.</td>
</tr>
<tr>
<td>ICTP - CONT - past topic in math</td>
<td>Statements made by a teacher during a co-planning session which were meant to name or describe a topic that the teacher had already taught in mathematics, and was not going back to revisit as a part of regular planning or teaching.</td>
</tr>
<tr>
<td>ICTP - CONT - past topic in science</td>
<td>Statements made by a teacher during a co-planning session which were meant to name or describe a topic that the teacher had already taught in science, and was not going back to revisit as a part of regular planning or teaching.</td>
</tr>
<tr>
<td>ICTP - CONT - related knowledge</td>
<td>Statements made by a teacher during a co-planning session about information or knowledge that was related to the conversation in some way, but not a part of curriculum or content for either class.</td>
</tr>
<tr>
<td>ICTP - FAC - facilitator asking for more specific</td>
<td>Attempts made by the facilitator to have the teachers explain or clarify content or concepts further or more deeply.</td>
</tr>
<tr>
<td>ICTP - FUT - future plans</td>
<td>Statements made by a teacher during a co-planning session about plans that would be made in the future (either next year or more than 1 month in the future).</td>
</tr>
<tr>
<td>ICTP - ICT planning process</td>
<td>For the Miller and Smith case: used before other ICTP codes were created (to refer to the ICT co-planning process). After other codes were created, used in all cases for statements that were made which directly referred to the co-planning process.</td>
</tr>
<tr>
<td>ICTP - LOG - responsibilities for connected project/activity</td>
<td>Statements made by a teacher during a co-planning session intended to take or assign responsibilities for a project or activity which the teachers were co-planning.</td>
</tr>
<tr>
<td>ICTP - LOG - timeline</td>
<td>Statements made by a teacher during a co-planning session about the timing or sequence of topics within for their class</td>
</tr>
<tr>
<td>ICTP - LOG - other</td>
<td>Statements made by a teacher during a co-planning session about logistical concerns that are not listed above</td>
</tr>
<tr>
<td>ICTP - PROJ - 1 mention/describe existing project</td>
<td>Statements made by a teacher during a co-planning session to mention or describe an existing project, either that they were planning to draw connections to or implement in their class</td>
</tr>
<tr>
<td>ICTP - PROJ - 2 possible project/activity</td>
<td>Suggestions made by a teacher during a co-planning session about possible connections to an existing activity or project, or to create a new activity or project</td>
</tr>
<tr>
<td>ICTP - PROJ - 3 details for connected project/activity</td>
<td>Statements made by a teacher during a co-planning session regarding details for a connected activity or project</td>
</tr>
<tr>
<td>ICTP - PROJ - 4 reflect on project/activity/lesson</td>
<td>Statements made by a teacher during a co-planning session about an activity or project that was implemented in the classroom during the intervention</td>
</tr>
<tr>
<td>ICTP - PROJ - 5 about next year</td>
<td>Statements made by a teacher during a co-planning session about intentions for a project during the following school year</td>
</tr>
<tr>
<td>ICTP - STUD - about students</td>
<td>Statements made by a teacher during a co-planning session about students, or referring to student behavior or understanding</td>
</tr>
<tr>
<td>ICTP - TEST - mention EOG/testing</td>
<td>Statements made by a teacher during a co-planning session about standardized testing</td>
</tr>
</tbody>
</table>
Appendix O

Co-planned Activities for Miller and Smith Case

The following list is of smaller connections that Ms. Miller and Ms. Smith discussed during co-planning sessions.

8th grade science and math – Ideas for connections

1. **Lab practicum**: In preparation for end of course exams, students can perform activities at stations in small groups that involve both science and math. Students can rotate through stations.

2. **Rock dating and scatterplots**: If we know how old various rocks are at different depths, we can create a scatterplot and predict how old rocks in between known layers are.

3. **Paleoclimatology and prediction models**: Use data from ice cores such as concentrations of dust, methane, and carbon dioxide to determine atmospheric conditions at various times.

4. **Age of earth and scientific notation/ ratios and proportion**: Use a roll of register tape to mark out different periods in earth history. If you use the scale of 1 mm = 500,000 years, it fits within about 9 meters and change. You can use this to reinforce ratio and proportions, as well as scientific notation.

5. **Volume in science and mathematics**: The volume of many science objects can be found. Go through your science teacher’s closet and see what you can find. Compare objects of similar shapes.
   a. Volume of irregular objects are often measured in science classes by submersion. Volume of regular objects may be measured the same way. Students can also convert between mL and cm\(^3\), or other appropriate units.
   b. Discuss the relationship between **density and volume**. Volume is a big topic in both math and science. Density is often discussed in science, but can be discussed as a rate in math.

Beginning on the next page are student worksheets for the larger activities that Ms. Miller and Ms. Smith co-planned.
The Pythagorean Spiral Project - math

Materials needed: poster board, ruler, protractor, pencil, colored pencils or markers

Step 1: Place the poster board in landscape orientation. Measure from the top left hand corner 27.5 cm right and 20.5 cm down. This will be the starting point for your diagram. It will assure that your diagram stays on the page.

Step 2: Using your ruler create a segment that is 10 cm across starting point and heading towards the center of the poster. Make this segment perpendicular to the side of the poster. Use your compass and ruler (without measuring) to construct a congruent segment that is perpendicular to the original. Connect the endpoints of the two segments to create a right isosceles triangle.

Step 3: On a separate piece of paper, use the Pythagorean Theorem to calculate the length of the hypotenuse. Show all work and write your answer in reduced radical form.

Step 4: Using the hypotenuse of the first triangle, create another right triangle on top of the previous hypotenuse. The old hypotenuse will be the new base and construct a perpendicular segment to this, with a length of 10. Then connect the two segments to form a new hypotenuse.

Step 5: On your separate piece of paper, show the calculations to find the length of the new hypotenuse.

Step 6: Continue to repeat this process of connecting and constructing new triangles with a side length of 10, using the previous hypotenuse as the other side. Continue to show your calculations on your separate piece of paper. Construct triangles until you have formed a full spiral.

Step 7: Decorating instructions on separate page.

TO TURN IN: Your poster with light pencil lines shown for constructions. Your work for each hypotenuse length on a separate sheet of paper.

Grading Rubric for Pythagorean Spiral Project

<table>
<thead>
<tr>
<th>Number of Points</th>
<th>Use of Protractor Constructions</th>
<th>Calculations for each hypotenuse</th>
<th>Poster Result</th>
<th>Decorations</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>Evidence of each protractor construction shown</td>
<td>All work is shown using the Pythagorean Theorem and each answer is simplified</td>
<td>The result shows 17 right triangles that rotate around to the right and the last triangle overlaps the original</td>
<td>From Science teacher.</td>
</tr>
<tr>
<td>20</td>
<td>Evidence of most protractor constructions shown</td>
<td>All work is shown using the Pythagorean Theorem but some answers are not properly simplified</td>
<td>The result shows an error in construction resulting in one fewer or one more triangle</td>
<td>From Science teacher.</td>
</tr>
<tr>
<td>15</td>
<td>Partial or incorrect constructions shown</td>
<td>All work is shown but with errors in calculation and/or simplification</td>
<td>The result goes the wrong direction and/or is off by more than one triangle</td>
<td>From Science teacher.</td>
</tr>
<tr>
<td>10</td>
<td>Construction markings are not visible</td>
<td>Only partial work is shown and/or no evidence of the Pythagorean Theorem</td>
<td>The result does not appear to have followed the proper requirements</td>
<td>From Science teacher.</td>
</tr>
</tbody>
</table>

Extra credit will be given if turned in early.
Pythagorean Theorem project - science

Demonstrate the history of LIFE on earth!

Directions:
1. Once you complete drawing your Pythagorean Spiral, count how many segments you have. Write it here: ________
2. You are going to represent the history of life on earth since life TRULY began to show diversity. This means you will show mainly the Paleozoic, Mesozoic and Cenozoic Time periods. In order to account for the 4,060,000,000 years of the Precambrian era. You must: Choose one corner of your posterboard and make a small note (see the example below) about this missing time.
3. The remaining history if wrapped up in approximately 540,000,000 years.

Your spiral will represent this amount of time. Determine the following:
   a. How many years did the Paleozoic last? _________________
   b. How many years did the Mesozoic last? _________________
   c. The Cenozoic? _________________

What about the Precambrian Era?
This era represents ---- years of earth history. Much of this era included the formation of the planet, ---- something about the oceans and atmosphere and the earliest life forms.

It was during this time that enough oxygen built up in the atmosphere to help make life on land possible.

** Add a cool drawing or something of max points.
Fill in the table:

<table>
<thead>
<tr>
<th>Geologic Era:</th>
<th>Years it lasted:</th>
<th>% of time out of the 540,000,000 years</th>
<th>% of triangles out of _______ (total) from #1 above.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. Now you will artfully decorate your spiral to represent the history of life on earth. To get full credit you should:
   a. Begin your time at the very first (inner) triangle.
   b. Have the correct % of triangles represent each era.
   c. Include in your triangles EACH of the Geologic PERIODS.
   d. Draw/sketch/design things in your triangles to represent life as it shows up in the fossil record. Make sure it’s in correct sequence!! (meaning, TRex should not represent your “first” dinosaur!!)
   e. Be creative and have fun with your design.
Radioactive M&Ms

Pre-Lab Questions:

1. On the periodic table, the number for carbon is _____, and the atomic mass is _______. What do each of these numbers tell us?
2. Give the term for an element that has the same atomic number, but different atomic mass: ________________________.
3. What particle in the nucleus is responsible for this difference in mass?
4. Some isotopes are stable. What does this mean?
5. Some isotopes are unstable. What does this mean?
6. What is the atomic mass number for the stable isotope of carbon?
7. What is the atomic mass number for the unstable isotope of carbon?
8. What is given off by unstable isotopes?
9. During radioactive decay, the _________ isotope decays into a __________ isotope that has a different ________________ number.

Materials:
M&M™ candy pieces resealable bag graph paper

Procedures:
1. Place 50 atoms of candium (pieces of candy) in the bag.
2. Seal the bag and gently shake for 10 seconds.
3. Gently pour out candy. Each time candy is poured out will count as 20 “years.”
4. Count the number of pieces with the print side up—and record the data next to trial 1. These atoms have "decayed".
5. Return only the pieces with the print side down to the bag. Reseal the bag.
6. Consume the "decayed atoms”.
7. Gently shake the sealed bag for 10 seconds.
8. Continue shaking, counting, and consuming until all the atoms have decayed.
9. On a separate piece of graph paper, graph the number of undecayed atoms vs. years.
Graph:

<table>
<thead>
<tr>
<th>Trial</th>
<th>Year</th>
<th>Number of Atoms Decayed</th>
<th>Number of undecayed atoms remaining</th>
<th>Class Total</th>
<th>Class Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>40</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Conclusions:
1. What is the independent variable?
2. What is the dependent variable?
3. What is the domain for the independent variable? How should you label the axis?
4. What is the range for the dependent variable? How should you label the axis?
5. What is a half-life?
6. In the experiment, what was the half-life of the element candium?
7. At the end of two half-lives, what fraction of the atoms had not decayed?
8. At the end of 3 half-lives, what fraction of the atoms had not decayed?
9. Is the data linear? How do you know?
10. Describe the shape of the curve drawn.

Bonus:

11. Repeat the experiment using half-lives of 5 seconds, 20 seconds, and 1 minute. Compare the resulting graphs.
12. Repeat the experiment three more times, starting with 30 atoms, 80 atoms, and 100 atoms of candium. Compare the resulting graphs.
Part A: Colony Morphology (Decomposers)

1. Trace your colonies. Use the clear film. Tape it to your petri plate and trace your colonies.
   Locate 35 colonies that look different and label them 1, 2, and 3. (or more if you can/want).
   For each of the colonies, fill in the chart below.

   Use the colony morphology guides to assist you. Also, use the small rulers, mm side to
   measure diameters of your colonies.

   Plate data:
   Date plating was done: _____________  Source: _______________

<table>
<thead>
<tr>
<th>Colony</th>
<th>Form</th>
<th>Size (mm)</th>
<th>Surface</th>
<th>Texture</th>
<th>Color</th>
<th>Elevation</th>
<th>Margin</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

   2. Compare your colonies to each other and to other groups. Pick one of your colonies that is
   similar in shape to another colony. Record the information below.

<table>
<thead>
<tr>
<th>Colony group and number</th>
<th>Form</th>
<th>Size (mm)</th>
<th>Surface, Texture, Color, Elevation, Margin</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

   Explain how you know that the colonies that you chose are similar.

   Are the colonies you chose congruent? Why or why not?
Evolutionary Arms Race  Microbe Clock
http://www.pbs.org/wgbh/evolution/survival/clock/

Read the Introduction:

1. What is the problem with “bacteria inventing itself”?

2. About how many species of bacteria have evolved resistance?

Click on “explore what allows brainless bacteria to challenge the best of 21st century medicine”:

1. BEFORE you “start the clock” read the information. What happens if bacteria are treated with an “insufficient” dose of antibiotic?

2. Each time the same antibiotic is used, the resistant bacteria will what?

3. Identify something else that can increase antibiotic resistance.

4. Click “more” and read about “lethal bacteria”. Name the most common cause of serious infection in the United States.

5. How many of these cases occur each year and how many deaths are caused by it?

6. Click “more” and read about the spread of the disease. How is Streptococcus Pneumoniae spread from person to person?

7. Where do the cells “cling” to in the person who comes in contact?

8. Name the most common illnesses caused by Streptococcus Pneumoniae.

9. Click “more” to read about miracle drugs. Name the type of antibiotic that has been successful at reducing mortality (death) rates.

10. Click “more” to read about complete resistance. How much of the pneumococcus strains have evolved resistance?
11. Click “more” to read about “end of miracle”. How many available antibiotics were available to treat serious bacterial infections?

12. Name a bacterial disease that has evolved drug resistance.

VIEW KEY: fill in the chart

<table>
<thead>
<tr>
<th>Type of Bacterial Growth:</th>
<th>Color Code:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

BEFORE starting the MICROBE CLOCK: have someone in your group ready to record each of the following. You won’t be able to pause the clock but you can re-watch it if necessary.

MICROBE CLOCK:

<table>
<thead>
<tr>
<th>Time</th>
<th>Current Population (millions)</th>
<th>No. of Replications (in millions)</th>
<th>No. of Mutations</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 sec</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 sec</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 sec</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30 sec</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40 sec</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50 sec</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60 sec</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

GRAPHING:
You will be graphing the above data on three different graphs. For each graph, tell the independent and dependent variables and the scales that you will use.

1. Independent variable________________ Dependent variable________________
   Scale__________________________ Scale__________________________
2. Independent variable________________ Dependent variable________________
   Scale__________________________
For each graph, correctly label the axes with words and numbers, and graph the appropriate data.

1. 

2. 

3. 

Explain what happens to each population over the course of one minute.

Is the growth linear? How can you tell?

Is the rate of growth speeding up or slowing down over time?
Gapminder Project

Go to gapminder.org/world
Click on the top right tab, “DATA”
Go to the search box at the top right.

Search for one of the following: TB (all forms of TB, deaths per 100,000 estimated), HIV (newly HIV infected, all ages), Cervical Cancer (new cases per 100,000). Click on the table.

Pick one country and make a table for that country over time. The following information must be written on separate paper.

Disease:_______________ Country:_______________
Years:___________

<table>
<thead>
<tr>
<th>Year</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Next, plot your points on a graph (on separate graph paper). Draw your line of best fit.

Finally, find the equation for your line. Use the calculator to check your equation.

See the example:

Repeat the directions for 2 other countries. You can use the same disease or a different disease. You need a total of 3 data tables and scatterplots.

On a separate piece of paper, answer each of the following in paragraph form:

1. What disease did you choose? Research the disease (google) and describe the symptoms and how it is spread.
2. What country did you choose? What continent is it on? Look up 3 facts about your country.
3. What was the trend for the data that you chose? Does your data follow a strong linear correlation? If yes, explain the slope in the context of the data. If no, explain why not.
4. What are some possible reasons for the trend that you described in #3?
Explore a Career in Biotechnology: Go [HERE](#) to learn more. (You will fill out a chart about various careers described here!)

How is Biotech Changing the World?

Careers in Biotechnology: Click [Here](#) to Fill out the Chart

1. Read “Your Future in Biotechnology.” Out of “researcher in a lab, an executive in a fast-paced business environment, a greenhouse technician, or an engineer building a new manufacturing facility,” which description would you be most interested in?

2. Six Career TYPES: Fill in the table with the information about each career type. You will click on each career-type, read a description of a person working in that job and then click on each of the items listed to find out more information.

<table>
<thead>
<tr>
<th>Career Type</th>
<th>High School Recommended Number of Sciences (count how many from grades 9-12)</th>
<th>Highest Level of High School Math Recommended</th>
<th>Name one or two CTE electives that are recommended in High School</th>
<th>Type of College Degree Normally Required</th>
<th>Name 2-3 Sample Job Titles and average salary</th>
<th>Name 2-3 Disciplines that a person can focus on after graduation:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scientist</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Laboratory Technician</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engineer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Process Technician</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maintenance &amp; Instrumentation Technicians</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corporate Scientific Professionals</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Economic Benefits of Biotechnology to North Carolina: Go here to learn more.

1. Click on the tab that says “growing the economy”. How many NC residents are employed by Biotech companies?

2. How many economic activity is generated by the industry in NC, each year?

3. Go to this link to learn more about Biotech in North Carolina. How many biotech companies are in NC?

4. What is the average salary of NC biotech employees?

5. Click on Biotech Sectors available in NC and fill in the chart!
Once you Complete the Chart, answer the final Question below:

<table>
<thead>
<tr>
<th>SECTOR:</th>
<th>In your own words, what is it? (Define after reading some material)</th>
<th>What industries benefits from this sector? (medicine, farming)</th>
<th>Add one reason how this sector benefits North Carolinians:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bio Defense</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vaccines &amp; Biomanufacturing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Human Health</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marine Biotech</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biofuels</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nanobiotechnology</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

6. If you could choose any part of NC to live and work, which region would you choose and what Biotechnology Job would you want? ** Click [here](#) to help you decide.

Region________________________

job_________________________
Ask your classmates what job and what region they would choose. Collect your data below.

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>9</td>
<td>10</td>
<td>11</td>
<td>12</td>
</tr>
<tr>
<td>13</td>
<td>14</td>
<td>15</td>
<td>16</td>
</tr>
<tr>
<td>17</td>
<td>18</td>
<td>19</td>
<td>20</td>
</tr>
<tr>
<td>21</td>
<td>22</td>
<td>23</td>
<td>24</td>
</tr>
<tr>
<td>25</td>
<td>26</td>
<td>27</td>
<td>28</td>
</tr>
<tr>
<td>29</td>
<td>30</td>
<td>31</td>
<td>32</td>
</tr>
</tbody>
</table>

7. Choose mutually exclusive categories to help you to organize your data, and create a 2 way table. For example, you might choose medical jobs vs. non-medical, or eastern region vs. other regions. Label and fill in the 2 way table below. The third column and row are for your totals.

8. Find the percentages of the total for each category. What can you tell from your data? Write at least 2 statements to generalize your data.
Appendix P

Co-planned Activities for Jones and Williams Case

The following list is of smaller connections that Mr. Jones and Ms. Williams discussed during co-planning sessions.

9th grade science and math – Ideas for connections

1. **Velocity, acceleration, and slope (math 1):** (This really could have been done as a part of the roller coaster project, but it wasn’t thought of until after the project was completed and the teachers were reflecting on it.) Velocity is the rate of change of distance, which is slope when referring to linear equations. Acceleration is the rate of change of velocity. The equations for average velocity and acceleration from Physical Science can be compared to the slope formula in math. This can be demonstrated on the graph of the marble’s height over time by connecting two points and finding the slope of the segment on the graph. This can also be used to draw connections between slope being constant for linear functions and changing for nonlinear (quadratic in this case) functions.

2. **Radioactive decay and exponential decay (math 1):** The connection is the same idea as the M&M lab for the 8th grade teachers. Differences are: In Physical Science, there is an emphasis on alpha, beta, and gamma rays, and how they affect decay rates. This could be compared to the $k$ in $y = ae^{kt}$. In 9th grade math, there is also an emphasis on the equation, and the role of the constants in the equation. These can also be related between the two classes.

3. **Waves and graphic transformations (math 2):** This applies to optic and sound waves. Waves are often used as an example in trigonometric modeling in math class, but more specific connections may be drawn between light colors or sound pitch, frequency, and period, and between brightness or volume and amplitude.

4. **Waves and coordinate midpoint and distance (math 1):** Waves go in all directions, even though we often draw them horizontally. Draw a wave being emitted from a source (light or sound). For simpler questions, fit to a coordinate grid and find the distance or midpoint between nodes, and discuss in context of the parts of the wave. You can use the same example to find subsequent nodes. For more challenging questions, use known information about wavelength for particular waves to pick appropriate scales for the axes.

5. **Optics and geometric angles (math 2):** The angle of incidence is equal to the angle of refraction when light bounces off of a flat mirror. There are various angles involved when light passes through different media. For a fun experiment, submerge Pyrex test tube in cooking oil (google for exactly what type of oil). Since these both have the same angle of refraction, the test tube seems to disappear. Relate this to parallel lines.
6. **Watts and amps and volume of water in pipes/ volume of a cylinder (math 2):**
   Current in a wire can be related to water in a pipe. Thicker wires can carry more current. Use volume formulas for a cylinder to determine the amount of water a pipe can hold (or theoretically, the number or electrons a wire can hold?).

7. **Circuits and fundamental counting principle (math 1):** This was going to be completed as a larger activity in math class, but implementation did not take place. Use light bulbs, batteries, and wires to create as many different combinations or circuits as possible. Use fundamental counting principle to determine if you got all possibilities. Do for series and for parallel circuits.

8. **Ohm’s law and batteries and graphing variation (math 1 or 2):** Discuss the relationship to Ohm’s Law between the type and number of batteries and the number of light bulbs in relationship to Ohm’s law and direct variation. (e.g., as the number of light bulbs increases, and the number of batteries stays the same, resistance (R) increases while voltage (V) is held constant in the equation V = IR. This since I and R have an inverse relationship, this causes current (I) to lower, and the lights get dimmer.

9. **2 way tables and science data (math 1):** 2 way tables are a way to organize and compare categorical statistics. There are many opportunities for these in science, especially if you use proportions to determine differences among categories. For example, in a bag of mixed candies (with 2 kinds of candy, e.g., M&Ms and Skittles), does a scoop from the top yield the same proportion of candies as a scoop from the bottom? What type of proportions would you expect from a homogenous mixture? The teachers also discussed the same idea with pond water sampling in Earth and Environmental Science.

10. **Mixtures and sampling (math 1):** Discuss the differences that different types of sampling (e.g., stratified, random, biased, unbiased) might have on results for different types of mixtures. Would the outcome be reliable for homogenous mixtures? Heterogeneous? Colloids?

11. **Mixtures and 2 way tables with probability (math 1):** see # 9 above. If you shake a large bag of trail mix, it may act like a colloid (because some items are denser than others). Even though the bag looked evenly mixed, find the probability of picking a raisin from a scoop toward the top of the bag, and from a scoop toward the bottom of the bag. This also lends itself well to discussing conditional probability.

   **Beginning on the next page are student worksheets for the larger activities that Mr. Jones and Ms. Williams co-planned.**
Roller Coaster Project

Introduction: Six Flags Amusement Park has been hearing from its customers that their roller coasters are boring. The public is threatening that if the amusement park does not build a new, more exciting roller coaster they will stop going to the amusement park.

You are part of a team of engineers that has just been asked to submit a new roller coaster design to the amusement park. Using the concepts of forces, motion, and energy, design and build a model of a workable roller coaster that could be built in the Six Flags Amusement Park.

To appease the public, your roller coaster must have a “thrill factor.” There must be at least one loop, at least one turn, and if possible, a “jump.” Your roller coaster also needs to be safe for the public, so you will also need to calculate the speed, acceleration, PE and KE on various locations of your roller coaster.

You will need to be able to explain your roller coaster to the board of directors of Six Flags. You will need to include in your explanation why you think your roller coaster is the “best choice” and should be built in the amusement park. Keep in mind that the board of directors is made up of a team of scientists. You will want to impress them with your knowledge of how forces, motion and energy help your roller coaster work, why it is safe to ride, and why it is “thrilling.”

Purpose: This project will be a culminating project of the concepts of physics we covered so far this semester. It will allow you to demonstrate your knowledge of motion, energy, and forces, as well as other areas that may apply. It is meant to be a fun project to do in class as a group. No one student is responsible for all portions of this project. All members of the group should perform work.

Requirements:
1) The Roller Coaster. Using any materials that you wish, construct a roller coaster with your group that will meet the requirements. I will be supplying pipe insulation and basic building supplies such as tape, staples, glue, scissors, etc. You do not have to use my materials if you do not want to.
   a. We will be using marbles for the “roller coaster cars.”
   b. Possible materials: tubing, wood, boxes, foil, glue, PVC piping, plastic bottles, etc…

2) Presentation of roller coaster. This should be three minutes max, and should demonstrate the areas of physics as well as perform a run of the roller coaster.

3) Data table/calculations see rubric for more information

Presentation to the Board: Tuesday, February 16th (construction should be completed on Friday)
Resources:
Physics of Roller Coaster readings
  ● Roller Coaster Physics
  ● Roller Coaster Gforces
  ● Energy Transformation of a Roller Coaster

Video: The Physics Behind the Fun

Rules

1) Your roller coaster must fit within the confines of your “construction area” and must be easily moved to another location (you may not tape roller coasters to walls).

2) You may NOT alter the pipe insulation provided by me if you choose to use it. Remember, you only have a certain amount of supplies. You may not have any replacement supplies if your idea doesn’t work.

3) Your roller coaster must bring your marble safely to a stop. Drops and jumps are permitted, but the marble must be safely caught by the track without getting stuck.

4) Hills and loops must involve trading kinetic energy for potential energy. Horizontal loops are considered turns.

5) Hold on to your marble!!! You must pay for lost marbles, and many roller coasters will work best with one, specific marble. You may need to redesign your roller coaster if you lose your marble.

6) Do not mess around with another group’s roller coaster. This will result in an automatic zero, and removal from the class for the rest of the project.

7) Extra time will not be permitted. Deadlines are absolute. The tape changes shape as it dries out, and roller coasters stop working after a few days and are often unusable after a while. You may come in at lunch or stay after school if you need more time.

8) Your group is responsible for completely removing your roller coaster and cleaning the surrounding area after completion of the project.
Calculations and Analysis

EVERYONE MUST HAND IN ALL ANSWERS ON SEPARATE PAPER INDIVIDUALLY!

1. On a separate piece of paper, draw a picture of your roller coaster.
2. On a separate sheet of graph paper, SKETCH a graph of the height of your roller coaster car (marble) over time as it travels the track. DO NOT FORGET that it will not go back in time! Label the axes appropriately (with numbers and a description). You can also label important places on the graph as you see fit.
3. SKETCH and LABEL the following points on both your picture and your graph of your roller coaster:
   a. Where the kinetic energy is the highest
   b. Where the kinetic energy is the lowest
   c. Where the potential energy is the highest
   d. Where the potential energy is the lowest
   e. Where there is positive acceleration
   f. Where there is negative acceleration (deceleration)
   g. Newton’s 1st Law
   h. Newton’s 2nd Law
   i. Newton’s 3rd Law
   j. Two forces that might slow your marble down (what kinds of forces have we talked about in class?)
   k. One interval over which your roller coaster resembles a parabola
   l. One interval over which your roller coaster is linear (or close to it)
4. Measure and record the following measurements for your roller coaster.
   Time of ride = _____________________ (seconds)
   Mass of the marble=_________________ (kg)
   Go weigh your marble (you may have to weigh it in a cup, then weigh the cup, and subtract to get just the weight of the marble).
   Weight of the marble=_________________ (N)
   Length of the track = ________________ (meters)

Using the measurements above, calculate the following items for your roller coaster. Please show all of your work and label all of your answers with the correct units!
5. Average velocity of the ride. Remember your formulas!
6. Average acceleration of the ride. Remember your formulas!
7. Velocity of marble at one location when it is descending (really this is average velocity over two points that are fairly close)
8. Velocity of the marble at one location when it is ascending
9. Acceleration of marble at one location when it is descending (really this is average acceleration over two points that are fairly close)
10. Acceleration of the marble at one location when it is ascending
11. The Force at one location on your roller coaster. Remember your force equation? (Use your acceleration from above)

12. Gravitational Potential Energy at the beginning of your ride \( P.E = m \times h \times 9.8 \text{m/s}^2 \)

13. Kinetic Energy at one location on your roller coaster: \( K.E = \frac{m \times v^2}{2} \)

14. Explain in sentences how you used quadratic modeling either in the construction of your roller coaster, or to answer any of the above questions.

---

**Peer & Self Evaluation (10 points)**

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Points Possible</th>
<th>Points Earned/ Reasons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peer Evaluation: (teamwork and respect) Did you help each other? Did you work together, or did everyone try to do their own thing? Did you listen to each other? Did everyone get to share their ideas? Were any group members put down?</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Individual participation; Did you do your fair share of the work? Did you help with every step, or just do one part?</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Total points</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>
Roller Coaster Project Rubrics

Criteria for Calculations and Analysis (50 points): Roller coaster includes all labels and all calculations must be shown with correct units. Picture of roller coaster matches graph of height over time.

Criteria for Presentation (15 points): (Your presentation must include some answers from above, but not all of them)

<table>
<thead>
<tr>
<th>Possible Points</th>
<th>Points Earned</th>
</tr>
</thead>
<tbody>
<tr>
<td>Presentation was appropriate length (23 minutes)</td>
<td>5</td>
</tr>
<tr>
<td>Information was organized</td>
<td>5</td>
</tr>
<tr>
<td>Presentation was understandable</td>
<td>5</td>
</tr>
<tr>
<td>Total Points</td>
<td>15</td>
</tr>
</tbody>
</table>

Criterion for The Actual Roller Coaster (25 points)

<table>
<thead>
<tr>
<th>Possible points</th>
<th>Points Earned</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appearance: Does the roller coaster look good? Is it neat? Does it have a name?</td>
<td>5</td>
</tr>
<tr>
<td>Safety: Does the marble stay on the track? Does the marble complete the entire track without getting stuck or stopping? Is it safely brought to a stop?</td>
<td>5</td>
</tr>
<tr>
<td>Number of loops/curves: Does the roller coaster have at least one loop? At least one curve?</td>
<td>5</td>
</tr>
<tr>
<td>Building: Does your marble go off the track? Does it touch anything other than the track before the end? Did you follow the rules?</td>
<td>5</td>
</tr>
<tr>
<td>Thrill: Is the track open for all/part of the ride? How abrupt are any changes in motion? Are there any jumps?</td>
<td>5</td>
</tr>
<tr>
<td>Total Points</td>
<td>25</td>
</tr>
</tbody>
</table>

For an evaluation to be counted, you must give a comment explaining the score to the designers. You may not give something a score of zero unless that feature is missing completely. You must give at least two positive comments for your scores to count. Any overly negative comments will be thrown out.

Comments:

Total Possible Points for Project: 100
Reference Table Review Project

The purpose of this activity is to help you review:

- **N-Q**: Reason quantitatively and use units to solve problems.
- **A-CED**: Create equations that describe numbers or relationships.
- **A-REI**: Understand solving equations in solving a simple equation as following from the equality of numbers asserted at the previous step.
- **F-IF**: Interpret functions that arise in application in terms of the context.
- **F-IF**: Analyze functions using different representations.

Directions: In your group, complete each of the following. Prepare either a Powerpoint or a Google Slides presentation to answer each. The number of slides that you should use is indicated for each part. In addition, create one slide with a title and your names.

**Part I**: Pick 3 of the formulas from the formula sheet. Write the formula and write a Let statement for each variable. Tell how many variables the formula has. Then write one example EOC question using each formula and answer your own question. (1 slide for each, 3 slides total)

**Example:**

<table>
<thead>
<tr>
<th>Formula: $F = ma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>This formula has 3 variables.</td>
</tr>
<tr>
<td>Let $F =$ force</td>
</tr>
<tr>
<td>Let $m =$ mass</td>
</tr>
<tr>
<td>Let $a =$ acceleration</td>
</tr>
</tbody>
</table>

**Question:** The force due to gravity can be given by the formula $F = ma$. Find the force of gravity pulling on an object with a mass of 12 kg and acceleration of 9.8 m/s^2.

**Answer:** $F = (12)(9.8)$

$F = 117.6$

**Part II**: Pick 3 formulas from the formula sheet. You can use the same ones as above, or 3 different ones. For each one, write a question that says to solve for a different variable. For each of these, decorate with an image that describes the formula.

**Example:**

<table>
<thead>
<tr>
<th>Question: Solve for m.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$F = ma$</td>
</tr>
<tr>
<td>Answer: $\frac{F}{a} = m$</td>
</tr>
</tbody>
</table>

Image from https://11phe.wikispaces.com/Newtons+3+Laws+of+Motion?responseToken=1d117008fd009335c4f47b52f9d66dc9

423
**Part III:** Pick 3 formulas from the formula sheet. You can use the same ones as above, or 3 different ones. For each one, pick two of the variables to be true variables, and pick a value for all other variables to be held constant. Which is the dependent variable, and which is the independent variable, and why? Is your new formula a function? Why or why not? Is it linear? Why or why not? Express your new function as a table and a graph. If it is linear describe the rate of change. If it is not linear, tell why you cannot describe the rate of change. (3 slides, 1 for each formula)

**Example:**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Formula:</strong> $F = ma$</td>
<td></td>
</tr>
<tr>
<td>I am picking $m$ to be held constant. I am picking a mass of 50 kg for $m$.</td>
<td></td>
</tr>
<tr>
<td>The independent variable is $a$; the dependent variable is $F$. This is because I can pick $a$ to figure out $F$.</td>
<td></td>
</tr>
<tr>
<td>My new formula, $F = 50a$, is a function because for every value of $a$, you only get out one value of $F$.</td>
<td></td>
</tr>
<tr>
<td>My new formula is linear because the graph makes a straight line.</td>
<td></td>
</tr>
<tr>
<td>The rate of change is 50. For every 1 unit change in $a$, there is a 50 unit change in $F$.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$a$</th>
<th>$F$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>250</td>
<td>250</td>
</tr>
</tbody>
</table>

**Part IV:** Pick 1 formula from the formula sheet. You can use one of your above ones, or a different one. Write a real world context (example) that your formula would model (If you need help, look in your science book). Include the domain and range for your context. Describe the trend that is described in your formula. (1 slide)

**Example:**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Formula:</strong> $F = ma$</td>
<td></td>
</tr>
<tr>
<td>Johnny wants to know his weight ($F$) on different planets. He finds the acceleration due to gravity. Since he knows his weight on Earth is 50, and the acceleration is 9.81, he divides to find $m = 5.096$. Domain is $x &gt; 0$ and range is $y &gt; 0$ because you don’t have negative gravity and negative weight. The trend is that as acceleration goes up, force goes up.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Planet</th>
<th>$a$</th>
<th>$F$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mercury</td>
<td>274.13</td>
<td>13978.20</td>
</tr>
<tr>
<td>Venus</td>
<td>8.87</td>
<td>45.21</td>
</tr>
<tr>
<td>Earth</td>
<td>9.81</td>
<td>50</td>
</tr>
<tr>
<td>Mars</td>
<td>3.77</td>
<td>19.22</td>
</tr>
<tr>
<td>Jupiter</td>
<td>25.95</td>
<td>132.26</td>
</tr>
<tr>
<td>Saturn</td>
<td>11.08</td>
<td>56.47</td>
</tr>
<tr>
<td>Uranus</td>
<td>10.67</td>
<td>54.38</td>
</tr>
<tr>
<td>Neptune</td>
<td>0.42</td>
<td>2.14</td>
</tr>
</tbody>
</table>
**Grading:** Each slide is worth 10 points.

## Physical Science Reference Tables

### Motion and Energy

\[ v = \frac{\Delta d}{\Delta t} \]

- \( v \) = velocity
- \( d \) = position

\[ \alpha = \frac{v_f - v_i}{\Delta t} \]

- \( \alpha \) = uniform acceleration
- \( t \) = time

\[ F = ma \]

- \( F \) = force

\[ F_g = mg \]

- \( m \) = mass

\[ W = F \Delta d \]

- \( F_g \) = weight

\[ P = \frac{W}{\Delta t} \]

- \( g \) = acceleration due gravity on Earth = 9.8 m/s/s
- \( W \) = work

\[ PE_g = mgh = F_g h \]

- \( PE_g \) = gravitational potential energy

\[ KE = \frac{1}{2} mv^2 \]

- \( h \) = height

\[ v_w = f \lambda \]

- \( KE \) = kinetic energy
- \( v_w \) = wave velocity
- \( f \) = frequency
- \( \lambda \) = wavelength

### Electricity

\[ V = IR \]

- \( V \) = electrical potential difference

\[ P = VI \]

- \( I \) = current
- \( R \) = resistance
- \( P \) = power

### Density

\[ D = \frac{m}{V} \]

- \( D \) = density
- \( m \) = mass
- \( V \) = volume
Ohm’s Law

Electricity is the movement of electrons. Electrons create charge, which we can harness to do work. Your light bulb, your stereo, your phone, etc., are all harnessing the movement of the electrons in order to do work. They all operate using the same basic power source: the movement of electrons.

The three basic principles for this activity can be explained using electrons, or more specifically, the charge they create:

- Voltage is the difference in charge between two points.
- Current is the rate at which charge is flowing.
- Resistance is a material’s tendency to resist the flow of charge (current).

I. Objectives

In this activity, you should be able to:
1. Identify the relationship between the voltage (V) and current (I)
2. Identify the relationship between the resistance (R) and current (I)

II. Procedure

1. Open https://phet.colorado.edu/en/simulation/ohmslaw and click the play button.
2. Drag the adjuster under the voltage (V) up and down. Observe what happens to the illustrations on the left side. Write your observation in Table 1.
3. Do the same under resistance (R). Write your observation in Table 2.
4. Complete Table 3 using Ohm’s Law equation, then answer analysis questions in complete sentences.

III. Observations

Write in the blank “decreasing” if the value decreases and “increasing” if the value increases. Sketch a graph for each relating the two variables. Label the graph

<table>
<thead>
<tr>
<th>Adjusted</th>
<th>Resistance (R)</th>
<th>Current (I)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Down</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Graph 1
Table 2

<table>
<thead>
<tr>
<th>Adjusted</th>
<th>Voltage (V)</th>
<th>Current (I)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Down</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3

<table>
<thead>
<tr>
<th>Resistance (R) Ω</th>
<th>Voltage (V) V</th>
<th>Current (I) A</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>9</td>
<td>0.8</td>
</tr>
<tr>
<td>200</td>
<td></td>
<td>0.5</td>
</tr>
<tr>
<td>125</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

IV. Analysis Questions

1. What happens to the value of the current (I) when the value of the resistance (R) increases?

2. What is the relationship between the current (I) and the resistance (R)?

3. What happens to the value of the current (I) when the value of the voltage (V) increases?

4. What is the relationship between the current (I) and the resistance (V)?

Practice Problems

1. If a circuit has a voltage of 45 V and a current of 5.0 A, what is the resistance?
2. If a circuit has a voltage of 400 V and a resistance of 80 Ω, what is the current?
3. In this circuit, there is a resistance of 400 Ω and a current of 0.01 A, what is the voltage?
Phase Change Lab

**Purpose:** To graph the phase change as water is changes from ice to steam

**Materials:** 600 mL beaker, crushed ice, thermometer, hot plate, stopwatch, graph paper

**Review:**

States (Phases) of Matter -
- **Solid**: matter that has definite volume and shape.
  - The molecules are packed together tightly and move slowly (vibrate).
- **Liquid**: matter that has definite volume but not shape.
  - Since the molecules of a liquid are loosely packed and move with greater speed, a liquid can flow and spread.
- **Gas**: matter that has no definite volume or shape.
  - Molecules of a gas are so loosely arranged and move so rapidly that they will fill their container.

Kinetic Theory of Matter -
- All matter is composed of tiny particles (molecules) that are always moving. This is known as the kinetic theory of matter.
- We measure this kinetic energy with a thermometer as temperature.
- The amount of kinetic energy is proportional to temperature. Increased temperature means increased kinetic energy (movement of molecules).

**Procedure:**
1. Fill a 600 mL beaker about half full with ice
2. Place the beaker on a hot plate. DO NOT TURN ON THE HOT PLATE YET!
3. Insert a thermometer into the ice. Wait 1 – 2 minutes for the thermometer to adjust to the temperature of the ice. After waiting, record the temperature in degrees Celsius next to 0 minutes in your data table (on separate paper)
4. Turn the hot plate on to setting #5 on the dial.
5. Observe and record the temperature at one minute intervals. The ice will turn to liquid water and eventually begin to boil. Continue to record the temperature at one minute intervals until it has been boiling for about 5 minutes.
   a. Note the time and temperature that the ice is completely melted.
   b. Note the time and temperature that the water boils.
6. After the water has been boiling for 5 minutes, turn off the hot plate and allow the water to cool. Do not touch the beaker until it is cool.
7. Plot your data on graph paper.
a. Label the points at which the ice completely melted, and at which the water began to boil.

Questions (answer these on separate paper and hand in with your table and graph):
1. Using your graph, describe what happened to the temperature of the water over time.
2. What was the initial temperature of the water? How does this relate to the y-intercept for your graph?
3. What was the rate of change when the water was completely in solid form?
4. Write an equation that models the temperature of the ice when it was completely solid.
5. Tell the domain and range for your equation in #4.
6. Explain any horizontal (flat) portions of your graph.
7. What is the relationship between the slope at the horizontal points on your graph and the rate that the temperature of water is changing?
8. At what temperature did the ice completely melt?
9. What was the rate of change when the water was completely in liquid form?
10. At what temperature did the water begin to boil?
11. What was the maximum temperature reached by the water? Explain why the water’s temperature could not get higher.
12. Label the areas on your graph that correspond to the heat of fusion and the heat of vaporization for water.
13. Copy the phase change diagram to your separate paper and fill in the blanks. You may need to refer back to your notes/phase change concept map.

14. Explain why your graph did not have line segments A and E.
Appendix Q

Co-planned Activities for King and Taylor Case

The following list is of smaller connections that Mr. King and Ms. Taylor discussed during co-planning sessions.

10th grade science and math – Ideas for connections

1. **Exponents, microscopic size, and logarithmic scale**: Use the website ScaleOfTheUniverse.com to explore the differences in relative size among very large or very small things. Relate this to a discussion of what $10^2$ or $10^3$ means on the microscope. Does a mm on a clear ruler viewed at x10 look the same as a cm viewed by the naked eye? Small things such as cells are often measured and discussed in scientific notation, or in units such as microns. Mathematically, what do these mean?

2. **Absolute hot and exponents**: Most of us have heard of absolute zero, the theoretical temperature at which molecular movement stops. Absolute hot seems just as unreachable. Look up absolute hot. If it is written in scientific notation, would the exponent be the same or different from Celsius and Fahrenheit? Why?

3. **pH and logarithmic scale**: This was going to be a larger activity, but never got implemented. Have students create a graph relating H+ ions to pH of a substance. Have students test the pH of different substances and place them on the graph. Discuss the difference in H+ ions needed for the pH to go up by 1 point. Extensions: Have students calculate the number of ions. Do the same graph and/or calculations for pOH, and note the transformation in the graph.

4. **Types of graphs and application in science**: Students are often encouraged to display their data graphically in science class, but often resort back to their middle school pie chart and bar graph. Work together to help students become more mathematically sophisticated with their science graphs. Discuss the purposes and value of different types of graphs, and how to create them in programs like Word, Excel, and Google Sheets. Note: a lot of relationships in science are not linear, but many high school labs have students plot and analyze the data as if it is. Discuss the relationships in different science data and see if you can find a better type of model when applicable.

5. **Significant figures in science and math**: Students in lower grades in math often do a lot of rounding. In science, students usually learn about significant figures in high school. Discuss when rounding is appropriate and when it is not given different contexts in science.

6. **Asymptotes for logarithmic and exponential functions and tonicity in science**: In the potato lab, the teachers assumed an asymptote at -30, given their data. Discuss the reasoning behind that assumption based on knowledge about the situation, and compare
to the trend in data. You can extend to consider asymptotes in other similar situations, or to consider other trends in cellular processes.

7. **Saturated fats and angles**: The different types of bonds in different saturated vs. unsaturated fats change the angle at which the molecules are connected. Saturated fats have all single carbon bonds, which makes them lay flat and be more densely packed. Unsaturated fats have a double bond somewhere, which makes the molecules connect at 120 degree angles, and the chains are unable to remain flat. That is why unsaturated fats are typically liquids, like olive oil, and saturated fats are typically solids, like butter. Diagrams of this are often misleading because it is difficult to capture the 3D nature of this phenomenon. These angles can be explored in math, as well as the relationship of the different angle types to the packing of molecules. There will be more space across from larger angles and less across from smaller angles because of triangle inequalities.

8. **Cell cycle and Greek prefixes**: (This is really not a math/science connection, but interesting, so I left it in.) The cell cycle involves interphase, prophase, metaphase, telophase, and anaphase. Inter means between; pro means before; meta means during; telos is the end goal; ana means against.

9. **Operations on functions and cancer growth**: In normal cell growth, there is an equilibrium in which cells grow, reproduce, and die at a steady rate, so it looks like no change is occurring. Imagine the function grow(x) = kx being added to the function die(x) = -kx to model the amount of cells that have been made or destroyed over time. With cancer, cells do not die at the normal rate (if they die at all), and they are also created at a faster rate than normal. Students can change the above functions in various ways to model these changes separately, and they can also add the functions to see the combined effects.

10. **Waves and trig graphs**: This applies to optic and sound waves. Waves are often used as an example in trigonometric modeling in math class, but more specific connections may be drawn between light colors or sound pitch, frequency, and period, and between brightness or volume and amplitude. For upper level or honors math, connections may also be drawn between harmonious and non-harmonious notes and the addition of trigonometric functions.

11. **Predator and prey cycle and phase shift in trig graphs**: The population of predator and prey species can each follow a sinusoidal curve as the species try to jockey for position in an environment. The graphs should be related. For example, after the deer population spikes, and wolf population spikes, which causes the deer population to fall. These can be discussed in terms of phase shift. Since there are always more producers than consumers, this can also be discussed in terms of vertical shift and amplitude of the graph. Finally, when the numbers seem to be unchanging, the concept of equilibrium in science may be compared and contrasted with the equilibrium of a trigonometric graph in math.
12. **Probability and genetics**: There is a lot that can be discussed here, depending on the depth that the class will go with both topics. Students can use Punnett Squares to list genetic possibilities and find probabilities. They can use the concept of conditional probability (e.g., what is the probability that a child will be colorblind given that the child is a girl). Multiple traits can be examined, as well sex-linked traits.

13. **2 way tables and Punnett Squares**: This is more of a contrast than a comparison. These look alike, but 2 way tables are usually for the purpose of comparing categorical statistics, and Punnett Squares are for the purpose of listing possible genetic combinations. For students that are learning about both (one in math class and the other in science class), the similarities and differences in these may be an important conversation to have. An activity may be to have students gather data and use a 2 way table to find if boys and girls have an equal probability of having a particular genetic trait, and then to use a Punnett Square given specific parents to find the probability of the child having the trait. Comparisons like these can also be used to show that just because a trait is dominant does not mean it is popular.

14. **Tree diagrams and Punnett Squares**: Tree diagrams can be used to help students to understand how to create Punnett Squares for multiple characteristics. This can be related to the Basic Counting Principle in mathematics.

15. **Trig graphs and ex vivo lung profusion**: The amount of oxygen in the lungs can be modeled with a sinusoidal function, because breathing is a periodic bodily function. Breathing rate and oxygen levels in a person’s body may have other contributing factors, such as exercise and emotions. This may be modeled by compositions of functions, assuming various parameters.

16. **Economics and independent and independent variables**: (This was not about a science/math connection either, but it was discussed during co-planning, and it is useful, so I left it in.) In graphing supply and demand curves in economics, it may be useful to consider the independent and dependent variables, because it is not obvious whether the price depends on quantity, or whether quantity depends on price. (Price is graphed on the y-axis).

17. **Independent assortment and probability**: Collect data about two genetic traits to see if they are mutually independent using a 2 way table (e.g., blonde hair and gender, or brown hair and brown eyes).

18. **Biotechnology and standard deviation**: In lab work, samples are taken, and often considered invalid if they do not fall within certain bounds. Discuss the relationship between this and standard deviation in statistics. You can also discuss why controls and sampling are very important in biotechnology careers.
19. **Protein synthesis and probability:** Amino acids are made from strings of nucleic bases, which then combine to form strings of DNA and RNA. There are 64 combinations, but only 20 nucleic acids. In DNA reproduction, sometimes these get copied wrong. Discuss the probability of the “mistake” being benign (no resulting change) or resulting in a significant change in DNA (e.g., sickle cell anemia). Variations include discussion of substitution, insertion, or deletion.

20. **Predator/prey lab:** This is an activity from Biology in which students pick cards that label them as either a “deer,” “resource,” or “wolf.” The “deer” students then have to run across the field (football field) to find the resources that they need and evade the “wolf” students. In biology, this touches on several lessons. For example, in order for the activity to be sustainable, there must be far less consumers than producers. For the deer, there may be an availability of resources, but they still need to find them and evade capture. If proportions are set well at the beginning of the activity, an equilibrium is sustained. In extending this to math, the deer population may be modeled by a sinusoidal curve, and the wolf population may be modeled by another sinusoidal curve that is a phase shift of the first (and vertical shift). In other words, a rise in deer population is followed by a rise in wolf population; a fall in deer population is followed by a fall in wolf population.

**Beginning on the next page are student worksheets for the larger activities that Mr. King and Ms. Taylor co-planned.**
How do cells respond to different concentrations of sucrose?

**Materials:** Plastic cups (6 per group), tape, plastic cling wrap, permanent markers, corer, sucrose solutions of 0 to 1 M, raw potatoes, paper towels

**Pre-activity discussion:** To gather additional evidence for plant cell response to different environments we will expose large quantities of plant cells to differing concentrations of sucrose in solution. What can we measure? What should be held constant?

**Instructions:**

- **Day 1:** Create 4 potato cores for each solution, by cutting potatoes into 3 cm slices and then use a corer to produce a core (36 cores in all). Make sure there is no skin on the potatoes. Keep the cores covered with plastic wrap until all are cut and ready to be massed.

  Create a data table. Cores will be massed before and after they are placed in the solutions.
  Mass the cores for each solution. Record.
  Label cups with the appropriate molar solutions (0, .2, .4, .6, .8, 1.0, A, B). Into each cup add 4 cores and 50 mL of the appropriate solution. Then cover with plastic wrap and set aside overnight.

- **Day 2:** For each solution, remove all 4 cores, blot briefly with a paper towel, then mass the cores. Record.
  For each solution, find the percent difference in the potatoes’ mass.
  Graph the percent change in mass as a function of the molarity of the solution.
  Using appropriate variables, write the equation of the curve.
  Predict the molarities of the two unknown solutions.
  Predict the molarity that would be an isotonic solution.
Post-activity discussion:
1. What are the independent and dependent variables?
2. What type of function best represents the data? Why?
   (The rest of these questions will continue assuming students chose
   exponential because it is an almost perfect fit, depending on how
   careful measurements were, and because we expect the percent
   change to level off after a while.)
3. Have students show/describe their graphs and equations.
4. Why does the water move?
5. Explain the x- and y- intercepts in terms of the data.
6. When is the solution hypertonic? Hypotonic? How do you know?
7. What ways can we find the molarity of an isotonic solution?
8. What ways can we find the molarity of the unknown solutions?

Sample data:
You will use the "floating leaf disk" method to measure the rate of photosynthesis. To begin, cut several disks from a spinach leaf and put these leaf disks in a cup of water.

1. Do your leaf disks float? Use the information in this diagram of a cross-section of a leaf to explain why a leaf disk would float.

![Diagram of leaf cross-section with labeled parts: cuticle, upper epidermal cells, palisade mesophyll cells, spongy mesophyll cells, sub-stomatal air space, lower epidermal cells, guard cells, stoma. The white oval in the center of each cell represents a vacuole which is filled with water with dissolved substances. The dark spots in the mesophyll cells represent chloroplasts.](http://www.mrothery.co.uk/images/Image88.gif)

2. Where does photosynthesis occur in a leaf? State which organelles carry out photosynthesis and which type or types of leaf cells have this organelle.

3. Explain why it is useful to the plant to have air spaces around the spongy mesophyll cells in the leaves. (Hint: Recall the chemical equation for photosynthesis: \[ \text{light} \quad 6 \text{ CO}_2 + 6 \text{ H}_2\text{O} \quad \rightarrow \quad 6 \text{ O}_2 + \text{C}_6\text{H}_{12}\text{O}_6. \])

4. To measure the rate of photosynthesis, you will replace the air in the spongy mesophyll in your leaf disks with a liquid. This will cause the leaf disks to sink. Then you will put these leaf disks in water with dissolved CO\(_2\) and measure the amount of time it takes for the leaf
disks to float. Which product of photosynthesis will accumulate in the spongy mesophyll and cause the leaf disks to float?

For photosynthesis to occur in the leaf disks that have had the air sucked out, you will need to provide the leaf disks with light and a good source of CO\(_2\) dissolved in water. For this purpose, you will use a solution of sodium bicarbonate (NaHCO\(_3\)) in water. Sodium bicarbonate reacts with water as follows:

\[
\text{NaHCO}_3 + \text{H}_2\text{O} \rightleftharpoons \text{NaOH} + \text{H}_2\text{CO}_3
\]

\[
\text{NaOH} + \text{H}_2\text{O} + \text{CO}_2
\]

5. Think about what will happen in leaf disks that you put in a solution of sodium bicarbonate vs. leaf disks that you put in water (with no sodium bicarbonate). Which leaf disks will carry out photosynthesis and produce O\(_2\)?

___ leaf disks in a solution of sodium bicarbonate

___ leaf disks in water (with no sodium bicarbonate)

Explain your reasoning.

You can test your predictions by seeing whether the leaf disks float as a result of producing O\(_2\) when placed in sodium bicarbonate solution vs. water. Use the following procedure.

**Procedure**

a. Label one cup sodium bicarbonate and fill it about one-quarter full with sodium bicarbonate solution. Label a second cup water and fill it about one-quarter full with water. Add one drop of dilute detergent to each cup.

b. Next you will prepare your leaf disks, taking care not to damage them. First, prepare two pieces of paper by folding each of them in half and then unfolding it. Your teacher will supply you with a straw, hole punch, or scissors to prepare the leaf disks. Punch out a piece of leaf tissue, avoiding large veins. (If you are using a hole punch, keep it clamped shut as you tap the punch on the table to release the leaf disk onto the piece of paper.) Repeat until you have 10 leaf disks on each piece of paper.

c. Remove the plunger from a syringe, and use one of the folded papers to pour 10 leaf disks into the syringe. Tap them down to the tip of the syringe.

d. Replace the plunger, and push it down to about the 1 mL mark, being careful not to squash the leaf pieces.

e. Suck up ~5 mL of the sodium bicarbonate/detergent solution into the syringe. Hold the syringe upright and push out as much of the air as possible.

f. Put your thumb over the tip of the syringe, and pull back slowly on the plunger to about the 10 mL mark. This creates a vacuum, and pulls air out of the leaf. Tilt and swirl the syringe to make sure all disks are submerged in the solution, then hold it for 10 seconds, and then let go of the plunger without removing your thumb from the tip of the syringe. The plunger will snap back into position and solution will enter the leaf disks. If the leaf disks drop to the bottom of the solution in the syringe, you are done. If not, do this again.

g. Remove the plunger and empty the disks into the cup containing sodium bicarbonate solution. Then swirl the cup to dislodge any disks that are stuck to the side of the cup.
h. **Repeat** steps c-g, but use the water/detergent solution instead of sodium bicarbonate.

i. Place both cups under a bright **light**.

**Safety Precaution:** Be careful to keep all liquids away from the light source and electrical cord.

6. At the end of each minute, record the number of floating disks (any disk that is no longer touching the bottom).

<table>
<thead>
<tr>
<th>Minutes</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
<th>19</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>In Water</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bicarbonate Solution</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

7. Use your data to make a graph of your results, using different symbols for the leaf disks in water vs. the leaf disks in bicarbonate solution. Be sure to label the axes and symbols.

8. Do your data support your predictions? Explain.

Both photosynthesis and cellular respiration occur in leaf disks in bicarbonate solution.

<table>
<thead>
<tr>
<th>Photosynthesis</th>
<th>$6 \text{ CO}_2 + 6 \text{ H}_2\text{O} \rightarrow 6 \text{ O}_2 + \text{C}<em>6\text{H}</em>{12}\text{O}_6$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cellular respiration</td>
<td>$6 \text{ O}_2 + \text{C}<em>6\text{H}</em>{12}\text{O}_6 \rightarrow 6 \text{ CO}_2 + 6 \text{ H}_2\text{O}$</td>
</tr>
<tr>
<td></td>
<td>$\text{ energy}$</td>
</tr>
<tr>
<td></td>
<td>$\uparrow$</td>
</tr>
<tr>
<td></td>
<td>$\sim29 \text{ ADP + phosphate}$</td>
</tr>
<tr>
<td></td>
<td>$\rightarrow \sim29 \text{ ATP}$</td>
</tr>
</tbody>
</table>
Note that some of the O$_2$ produced by photosynthesis is used for cellular respiration. Thus, the floating leaf disk method measures the rate of net photosynthesis, which is the rate of photosynthesis minus the rate of cellular respiration.

9. In the above chart, draw arrows to indicate how the products of cellular respiration can be used for photosynthesis and the products of photosynthesis can be used for cellular respiration.

10. Suppose that a leaf disk that has had the air sucked out is placed in bicarbonate solution under a dim light that results in a low rate of photosynthesis that just equals the rate of cellular respiration. Would you expect this leaf disk to float? Explain why or why not.

11. What happens to the sugar molecules produced by net photosynthesis? I.e., how does a plant use the sugar molecules produced by photosynthesis that are not used in cellular respiration?

12. Why do leaf cells need to carry out cellular respiration?
Part 2. Investigating a Factor That Influences the Rate of Photosynthesis

Now that you have a way of measuring the rate of net photosynthesis, you can investigate factors that influence the rate of net photosynthesis. You have already shown that net photosynthesis does not occur if CO$_2$ is not available. What other changes in your experimental set-up might influence the rate of net photosynthesis?

13. Complete the table to describe two additional factors or variables that you think may influence the rate of net photosynthesis and describe the effects you would expect to observe.

<table>
<thead>
<tr>
<th>Name or describe a factor that may influence the rate of net photosynthesis.</th>
<th>Factor 1</th>
<th>Factor 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>What effect do you think this factor will have on the rate of photosynthesis? Explain your reasoning.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>What effect do you think this factor will have on the rate of cellular respiration? Explain your reasoning.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>What effect do you think this factor will have on the rate of net photosynthesis? Explain your reasoning.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Design an experiment that could test the effect of a factor on the rate of net photosynthesis. Your teacher can supply you with:

- sodium bicarbonate, water, scale and graduated cylinder to make solutions with different concentrations of sodium bicarbonate
- a ruler to measure distance from the light source (light intensity decreases with distance; specifically, light intensity is approximately proportional to 1/distance$^2$)
- aluminum foil or a box to prevent light from reaching the disks in the beaker
- different color filters or cellophane wrap that allow through only green light, blue light or red light
- a thermometer and a larger container that can be filled with hot water or ice to serve as a warming or cooling bath for the beaker with the solution of sodium bicarbonate and leaf disks.

You may be able to use additional equipment or supplies available in your classroom or brought in by one of the students in your group.

14. Describe your proposed experiment, including your research question or hypothesis, your experimental set up, how you will collect and analyze your data, and how you will interpret your data to answer your question or test your hypothesis.
Teacher notes/reflection on photosynthesis lab:

- In # 6 and 7, the table and graph are shown as a bivariate graph, which measured number of disks against time. Changes in this graph type would be a great opportunity to discuss statistical measures and graphing. Does the number of leaves that float to the surface during any given minute make a normal curve? Would it if the leaves of every student in the class were included? Is it skewed?
- Distinctions between frequency and cumulative frequency can easily be made with this data.
- The purpose for each lab is to compare the time it takes for leaves to float in different situations. There are many ways to compare statistics, from looking at mean, median, mode, and range, to t-tests and other statistical tests. Think about what statistical information would be appropriate to discuss with students at your grade level.
- For part 2, students should only change 1 variable so that they can compare the results to their control data. What if 2 variables were changed? Why would this make inconclusive results? In high school math, we graph all functions on a coordinate plane with one input variable (x) and one output variable (y). Changing 2 variables would have to be done in a systematic way to obtain a sampling of combinations of values from the two variables, and would result in a 3 variable (surface) graph. You can imagine what these graphs would look like.
How does surface area affect cellular diffusion?

**Materials:** Plastic cups (2 per group), iodine, raw potatoes, tools for cutting potatoes, plastic wrap, paper towels

**Pre-activity discussion:** To measure the effects of cells having different shapes and sizes, we will soak potato sections of different shapes and sizes in iodine. What can we measure? What should we compare?

Instructions:

- **Day 1:** Carefully cut the potato into sections of measurable shapes and sizes. These can be smaller or larger, with circular or straight edges. Make sure there is no skin on the potatoes. Keep the potato sections covered with plastic wrap until all are cut and ready to be measured. Measure each potato section to find the volume and surface area. Calculate the volume to surface area ratio. Record each in a table.

  After completing measurements, submerge each potato section in the cup with iodine. Cover with plastic wrap and set aside overnight.

- **Day 2:** Remove each potato section from the iodine and carefully pour the iodine into the large container. Blot each briefly with a paper towel. Cut into each potato section to find the amount that it absorbed the iodine. Cut off all iodine and measure the new volume of the potato section. Record. Calculate the ratio of volume of unreached potato (new section) to the original. Record. Graph the ratio of volumes as a function of the ratio of original volume to surface area. What conclusions can you draw?

- **Follow-up questions:** Why do cells divide instead of just growing larger? Think of a cell as a sphere. What about the cell determined how much “food” it consumes and how much waste it produces? What about the cell limits how much food and waste it can transfer? Why are most cells not spherical in shape? What advantages would a long, skinny cell have over a more regularly shaped cell?