THESIS

AN INTEGRATED MATHEMATICS/SCIENCE ACTIVITY FOR SECONDARY STUDENTS: DEVELOPMENT, IMPLEMENTATION, AND STUDENT FEEDBACK

Submitted by

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In partial fulfillment of the requirements

For the Degree of Master of Science

Colorado State University

Fort Collins, Colorado

Summer 2016

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ABSTRACT

AN INTEGRATED MATHEMATICS/SCIENCE ACTIVITY FOR SECONDARY STUDENTS: DEVELOPMENT, IMPLEMENTATION, AND STUDENT FEEDBACK

Mathematics teachers are often challenged by their students to give reasoning for why learning mathematics is necessary. An approach to address this question is to show students the value in learning mathematics by enlightening them on the connections that mathematics has with other disciplines and the real-world applications of mathematics. Integration is a method of teaching that can be used to give students insight as to how mathematics is useful in a variety of different fields. In addition to engaging students with relevant curriculum, leading students to discover the connections between mathematics and science (among other fields) is helpful in showing students why learning mathematics is valuable.

This thesis reports on my experiences in developing and implementing an integrated mathematics/science activity in a STEM Technology class at a local high school as well as discusses student feedback about the activity, about their interdisciplinary STEM Technology class, and about the integration of mathematics and science in the classroom.

ACKNOWLEDGEMENTS

I would first like to thank my fiancé, Liam Duncan, for helping me to maintain my sanity through the last few years and for always being my strongest supporter. I would not be where I am today without you. My friend and officemate Jessica also deserves a thank you for letting me turn my desk chair around every day and talk her ear off about my most recent struggles in graduate school and in life.

Thank you to the local high schools and teachers who let me pick their brains about integration and allowed me to implement my activity, I could not have done this without those opportunities.

Lastly, my committee deserves a huge thank you for their guidance and support through every step of the process. Mary Pilgrim, you are the best advisor I could have ever hoped for and I will never be able to thank you enough for all of the doors that you have opened for me. Your guidance and constant support on this thesis project, on my future career, and on life in general have been incredibly helpful for me these last two years. I am grateful to have had the chance to work with you and I hope we can continue to work together. The other members of my committee, Patrick Shipman and Gene Gloeckner, also deserve an enormous thank you. Patrick, thank you for meeting with Mary and I every week to check on my progress and to provide interesting ideas for my project. Gene, thank you for teaching me everything I could have ever wanted to know (and more!) about quantitative research and for helping me struggle through IRB submissions. My thesis project could not have turned out the way it did without each and every one of you! Thank you all!

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Research Problem

Mathematics teachers are often challenged by their students to give reasoning for why learning mathematics is necessary. Unfortunately, many secondary students see no value in learning mathematics and do not feel as though it connects with their lives. One approach to combat this issue is to use an interdisciplinary approach to teach mathematics. Interdisciplinary curriculum can give students insight as to how mathematics is useful in a variety of different fields. In addition to engaging students with relevant curriculum, leading students to discover the connections between mathematics and science (among other fields) can help to show students why learning mathematics is valuable.

Purpose of Study

This study was conducted for the purpose of making recommendations to educators who want to implement an interdisciplinary mathematics/science approach in their own classroom. In order to become more experienced with this approach, I reviewed literature surrounding this topic, interviewed teachers currently using this approach, developed and implemented an integrated mathematics/science activity at a local high school, and gathered student feedback about the activity, about their STEM Technology class, and about the integration of mathematics and science in the classroom.

Research Questions

The research questions for this study were based on the 25-question survey that the students completed at the end of the activity.

1. What is the mean score for each of the 15 Likert scale statements?

2. Is there a statistically significant difference between the 2 levels (above 90%, below 90%) of spring midterm course grades on scores for any of the 15 Likert scale statements?
3. Is there a statistically significant association between student achievement in their STEM Technology class and scores for any of the 15 Likert scale statements?

   Sub-questions:

   3a. Are there statistically significant associations between the fall final course grades and scores for any of the 15 Likert scale statements?

   3b. Are there statistically significant associations between the spring midterm course grades and scores for any of the 15 Likert scale statements?
4. Are there statistically significant associations among the scores for the 15 Likert scale statements?
5. What are the common themes found in the responses of the open-ended response portion of the survey?

Data Collected

The data collected in this study consisted of student responses from 18 students on a 25-question survey and student course grades for their STEM Technology class. The first portion of the survey had 15 statements and asked students to rate the degree to which they agreed or disagreed with a given statement. The second portion of the survey had 10 writing prompts for students to respond to in 1-3 sentences each. Each of these two portions of the survey was broken into 3 categories: statements and prompts about the activity, statements and prompts about their STEM Technology class, and statements and prompts focused on interdisciplinary mathematics and science. The course grades collected were the fall final course grade and the spring midterm course grade for their STEM Technology class.

The Researcher's Perspective on Integration of Mathematics and Science

It is my belief that the integration of mathematics and science in secondary education can yield many meaningful benefits for students if done effectively. I do not believe, however, that all of mathematics and science should be integrated. There are many topics in both mathematics and science that would be taught more effectively if taught separately. In order to effectively and efficiently integrate topics, a base of knowledge in each discipline is most likely required, therefore it is important that students learn some content of mathematics and some content of science in separate settings.

Study Delimitations Limitations

Delimitations

By choice, the data collected in this study was delimited to only the students in the STEM Technology class at a local high school. This is because one of the goals of the study was to obtain student feedback on their experiences being enrolled in an interdisciplinary course.

Limitations

There was no random assignment in this study, the students were already enrolled in the STEM Technology class long before participating in the activity and survey for this project. Every student in the class was in 9^{th} grade and most of the students were considered to be "advanced" students. This means that it cannot be assumed that the group of students who participated in this study is representative of a larger population of secondary students. The sample size for the data was only 18 students, which results in less power for the statistics.

CHAPTER 2: REVIEW OF LITERATURE

This chapter provides a discussion on the major topics regarding interdisciplinary/integrated curriculum for mathematics and science found in the literature. This chapter also features interview responses from two teachers who currently teach this type of course at a local high school.

A Brief History of Integration

This review of literature on the integration of mathematics and science in education is certainly not the first. Along with numerous studies and publications regarding this topic, there exist a multitude of reviews of literature that have been around for many years.

The Beginnings

In an article published in 1996, Beane claimed that the concept of curriculum integration began more than a century earlier although the intention may have been different (p. 7). In the same year (1996), George stated that, "excellent teachers have been infusing the traditional curriculum with real world problems and puzzling situations for a century" (p 13). Here, he does not explicitly refer to curriculum integration but rather that incorporation of real world problems into curriculum is a vital piece of curriculum integration. In a historical analysis of literature on integration mathematics and science education, Berlin and Lee (2005) found that in the first bibliography on the topic the earliest referenced document was published in 1905 (p. 17). Taking all of these statements into account, it seems that the topic of curriculum integration first arose sometime between the late 19th century and the early 20th century. In 1931, 19 speeches about integration were given at a National Education Association (NEA) Convention and just 5 years later, in 1936, the term "integration" officially had its own place in the Education Index

(Beane, 1996, p. 7). Beane (1996) claims that the idea of integration became dormant in the 1960s and remained as such until the early 1990s (p. 8). Evidenced in the historical analysis done by Berlin and Lee (2005), the previous statement may not be completely accurate although they would agree that the popularity of this topic increased enormously from the early 1990s on.

Literature and Research Trends

The previously mentioned historical analysis given by Berlin and Lee (2005) describes the trends in educational research and literature regarding integration. These two researchers analyze both the number of documents published on the topic during different periods of time as well as the nature and theme of the publications. Berlin and Lee obtained their data in this analysis from two previously published bibliographies, one published by Berlin in 1991 and the other published by both Berlin and Lee in 2003. The first bibliography discusses literature published between 1901 and the first half of 1991 while the second focuses on literature published only between the second half of 1991 through the year 2001 (p. 15). In order to analyze the nature of these documents, these researchers categorized each publication into one of five topics: curriculum, instruction, research, curriculum-instruction, and curriculum-evaluation. The most interesting finding was that number of publications included in the first bibliography (1901-1991) was 568 and the number of publications included in the second bibliography (1991-2001) was 402 (p. 17). Using this data, the average number of publications per year for from 1901 to 1991 was slightly over 6 whereas the average number of publications per year from 1991 to 2001 was slightly over 40. Clearly there was a tremendous increase in the popularity of this idea starting in the early 1990s. Diving more in depth, Berlin and Lee (2005) noticed that the pattern of growth began in the 1970s and that the increase may have been caused by factors such as increased amount of federal funding, support of the idea in national reform documents, and teacher education programs (p. 18).

Recent Events

In 1999, Czerniak, Weber Sandmann, and Ahern claimed that, “almost every national reform is currently stressing the need to integrate or make connections among the curriculum” (p. 421). Similarly, in the historical analysis of integration documents by Berlin and Lee (2005), it was found that mathematics and science integration was recommended in numerous national education reform documents written by organizations such as American Association for the Advancement of Science (1989, 1993, 1998), International Technology Education Association (1996, 2000), National Council of Teachers of Mathematics (1989, 1991, 195, 2000), National Science Teachers Association (1992, 1997) (p. 15).

On a related note, one of the hottest topics in modern education is the use of state and/or national standards. For both mathematics and language arts, the Common Core State Standards have been adopted in forty-two states, the District of Columbia, four territories, and the Department of Defense Education Activity (DoDEA) (National Governors Association Center for Best Practices & Council of Chief State School Officers, n.d.). Each state individually determines which set of science standards to use (currently, the Common Core State Standards do not include science standards). While mathematics and science integration is not mentioned straightforwardly in the Common Core State Standards (perhaps because the standards do not include science), 37 of the 326 (approximately 11.35%) mathematics standards explicitly mention incorporating real world problems, real life problems, and real world contexts. Incorporating real world context into curriculum is an integral part of mathematics/science integration. In addition, many of the standards that don’t say the exact words “real life” or “real world" still refer to science concepts. For example, one of the standards in "the number system" domain for 7th grade states, "describe situations in which opposite quantities combine to make 0. For example, a hydrogen atom has 0 charge because its two constituents are oppositely charged." Another example is the "measurement and data" domain for 3rd grade that says "measure and estimate liquid volumes and masses of objects using standard units of grams (g), kilograms (kg), and liters (l) and add, subtract, multiply, or divide to solve one-step word problems involving masses or volumes that are given in the same units, e.g., by using drawings (such as a beaker with a measurement scale) to represent the problem" (National Governors Association Center for Best Practices & Council of Chief State School Officers, n.d.). Clearly both of these examples use science concepts either as a way of motivating the mathematics or as a way of giving examples of where the mathematics appears in the real world.

Other recent developments include technology being used as a tool to help integrate mathematics and science (Pang & Good, 2000, p. 78; Niess, 2005, p. 510) and some universities offering degrees in interdisciplinary studies (Elliot, Oty, McArthus, & Clark, 2001, p. 811) to combat one of the teaching challenges of integration - the lack of pre-service training that teacher experience that occurs.

Confusion of Terms

In order to describe the details of combining mathematics and science in the classroom, we first must examine what it means to have an integrated or interdisciplinary curriculum. Because the idea is inherently complex (George, 1996, p. 15), defining integration is not so simple. In fact, there does not exist a commonly agreed upon definition of what it means to have an integrated curriculum or classroom. Many critics of curriculum integration argue that while the idea is intriguing, there is not enough research-based evidence to support the claim that an integrated approach is superior to the traditional approach. According to Basista and Matthews (2002), "the current lack of empirical evidence of the effectiveness of integration can possibly be attributed to an unfocused operational definition of an integrated curriculum" (p. 360). This theory is also shared by Czerniak, Weber, Sandmann, and Ahern (1999) who explain that, "a common definition of integration does not exist that can be used as a basis for designing, carrying out, and interpreting results of research" (p. 422).

Throughout the literature on integrated/interdisciplinary curriculum and instruction, it seems that while researchers and authors are speaking of similar ideas, those ideas are identified by different names. The 2 most commonly used names for this type of instruction are integrated and interdisciplinary. In considering one of these terms, integration for example, its "true meaning" varies in the literature. The same is true for the term interdisciplinary. While to some this may not appear to be particularly troublesome, Stinson, Harkness, Meyer, and Stallworth (2009) argue that a common understanding for the meaning of integration is essential and remains to be a significant obstacle to integrated instruction (p. 153). Let's examine some of the ways that the various terms are used throughout the literature on the topic.

Integration

We will begin with the most commonly used term - integration. While the term alone doesn't immediately lend itself to confusion, the obscurity lies in the fact that, as Lonning and DeFranco (1997) put it, "integration means different things to different educators" (p. 212). To see what is meant by that, consider a few of the following examples. In an attempt to define integration, Lederman and Niess (1997) state that, "in curriculum/instructional integration, the different subject matters form a seamless whole. No clear distinction exists between or within mathematics and science, or among other academic disciplines." (p. 57). In practice if an educator were to abide by this definition, any outsider could walk into their classroom to watch an entire lesson and at the end still not be able to determine whether the class that they are in is a math or science class. Beane (1995) would agree with this definition in that the activities created for an integrated curriculum should be done so without regard to subject/discipline boundaries.

To make matters even more complicated, some authors even go as far as defining several different types of integration. For instance, Davidson, Miller, and Metheny (1995) categorize integration in 5 ways: discipline specific integration, content specific integration, process integration, methodological integration, and thematic integration. These 5 types of integration will be described in more depth in the methods and model section of this literature review. Another instance in which the definition of integration is broken down into categories is done by Hurley (2001) who categorizes by the extent to which the integration occurs and not necessarily by the type of integration. Hurley's categories (which will also be described in more detail later) are sequenced integration, parallel integration, partial integration, enhanced integration, and total integration.

There also exist much broader definitions for integration. Huntley (1998) defines integration as "an integrated curriculum is one in which a teacher, or teachers, explicitly assimilates concepts from more than one discipline during instruction" (p. 321). Mason (1996) mentions only that integration involves elements from more than one discipline and the curriculum somehow relates to a theme or problem (p. 264). Lonning and DeFranco (1997) simply state that integrated is a word used to describe the nature of a relationship between multiple disciplines being used in an interdisciplinary unit (p. 313).

Interdisciplinary

In addition to the definition that Lederman and Niess (1997) give for integration, they also give a definition for interdisciplinary to compare it to. They say that with an interdisciplinary approach, "although connections between subject matters are emphasized, there remains perceived value in the unique characteristics and distinctions among the various disciplines" (p. 57). Lederman and Niess (1997) also say that one of the benefits of using an interdisciplinary approach instead of an integrated approach is that the teacher is free to explicitly discuss any important mathematics or science content or ideas and it need not be related to only the problem at hand. Many other definitions for interdisciplinary curriculum and instruction exist. For examples, Jacobs (1989) states that, "interdisciplinary refers to a knowledge view and curriculum approach that consciously applies methodology and language from more than one discipline to examine a central theme, issue, problem, topic, or experience." (as cited in Lonning, DeFranco, & Weinland, 1998, p. 313), McDonald and Czerniak (1994) say that "interdisciplinary units concentrate on organizing themes or concepts, and enable students to integrate scientific processes, communication skills, problem solving, critical thinking, and creativity" (p. 9), and Huntley (1998) claims that "an interdisciplinary curriculum is one in which the focus of instruction is on one discipline, and one or more other disciplines are used to support or facilitate content in the first domain" (p. 320). Although the terms integrated and interdisciplinary are the most commonly used to describe this approach to curriculum and instruction, there are many other less widely used terms.

Other Terms Found in Literature

In addition to integrated and interdisciplinary, an abundance of other terms are also used. Some other names used are: "connections, cooperation, coordinated, correlated, crossdisciplinary, fused, interactions, interdependent, interdisciplinary, interrelated, linked, multidisciplinary, transdisciplinary, and unified" (Berlin & Lee, 2005, p. 18). Yet another commonly used term is thematic. Lederman and Niess (1997) also give a definition for thematic: "Thematic pertains to unifying or underlying commonalities among subjects and topics" (p. 57), and claim that thematic instruction severely reduces the range of content matter that can be included.

While most authors make clear the distinction between terms, some authors use the terms interchangeably. Clearly, there is not an agreed upon definition for the concept and there may never be. An interesting question and statement posed by Hurley (2001) is, "would a generic model for definition-building enable continued discourse? Such a model might consist of a statement that addresses 1. Domains of integration. 2. Basis for the domain emphasized (if there is one). 3. Form of integration. 4. Methods and language" (p. 265/266). For the purposes of this thesis, the terms integrated and interdisciplinary will be used interchangeably and will refer to any curriculum and/or instruction in which an effort is made to combine content, process skills, and/or language from two or more disciplines in order to enhance learning in all disciplines included.

Rationale for Integration

Why has integration been studied so heavily in past years? There have been many studies that have shown that integration has positive effects on student learning, achievement, and attitude. Many researchers also believe that the content and learning of mathematics and science being so closely related is reason enough for integration in the classroom.

Need for Integration

The most basic justification for using integration is that the single-subject approach is inadequate in many ways. According to Beane (1995), the single-subject approach has a deadening effect on the lives of students and only offers disconnected ideas and a jumbled assortment of facts and skills (p. 618). In some ways, this approach does not sufficiently prepare students because, "traditional curriculum fails to meet the needs of students in a complex, technologically advanced, interdependent world" (Mason, 1996, p. 264). Upon entering middle school and high school, students are supposed to understand ideas that are connected to several disciplines (Gardner & Boix-Mansilla, 1994, p. 14) and literature suggests that this can be made easier for students by using an integrated approach to education. Along these same lines, the single-subject approach is a poor representation of problem solving in the real world because solving problems of significance outside of school requires both knowledge and skills from more than one discipline.

In traditional education, boundaries are drawn between each of the disciplines and within each discipline courses are taken in a particular order (for example- Algebra 1 then Geometry then Algebra 2 or Physical Science then Biology then Chemistry). In many cases these sequences are somewhat arbitrary (Beane, 1995, p. 620) and could be taught in a different order with little to no negative consequences. Likewise, the boundaries drawn between disciplines have never been set in stone and are ever changing (Beane, 1995, p. 617; Gardner & Boix-Mansilla, 1994, p. 17) because there are numerous concepts taught in school that are meaningfully related to more than one discipline. These concepts that overlap into several disciplines would make an excellent choice to base interdisciplinary units around.

Integrated curriculum can provide more opportunities than the traditional, single-subject approach for students to engage in meaningful, relevant learning rather than simple memorization. Often it seems that content in each discipline is taught as if memorization of a slew of fragmented facts is the most important goal (McDonald & Czerniak, 1994, p. 9). One reason that this is a problem is that “the brain processes information through patterns and connections with an emphasis on coherence rather than fragmentation” (Beane, 1996, p. 8). Integration of disciplines could be a possible solution to this issue because it can help students to “develop deeply organized knowledge structures that are richly interconnected” (Huntley, 1998, p. 320), can give teachers the ability to center curriculum on real life problems rather than fragmented information (Beane, 1995, p. 622), and can provide opportunities for students to dive deeper into study more than traditional curriculum where often the focus is on amount of material covered and not deep understanding of the material (Mason, 1996, p. 268).

In addition to meaningful and relevant learning, the powerful connections that are made and the in-depth study of concepts lead students to discover the “big picture” ideas and view the concepts within a larger context (Lonning, DeFranco, & Weinland, 1998, p. 312). This is in part due students having to use knowledge from multiple disciplines to solve problems (Meier, Hovde, & Meier, 1996, p. 230) and students viewing problems from multiple perspectives and in greater depth (McDonald & Czerniak, 1994, p. 9).

According to McBride and Silverman (1991), if students recognize the content as relevant to their own lives then their motivation to learn will often increase (p. 286/287) and Czerniak, et al. (1999) claim that traditional curriculum is not relevant to students and doesn’t emphasize real problems (p. 421). To make the content more relevant for students, conditions need to be created to encourage students to make connections (Meier, Hovde, & Meier, 1996, p.

234) and curriculum integration should be based on problems, issues, and concerns encountered in life itself because these are the most important and powerful ideas (Beane, 1995, p. 616/620).

One of the less obvious advantages to using an integrated approach is that using a variety of forms of assessment becomes much easier than it would be using a traditional approach. Teachers should use a variety of assessment in their classrooms (Furner & Kumar, 2007, p. 187) to engage students and to give students opportunities to show what they have learned in multiple ways rather than simply by testing. Depending on the discipline of focus (if there is one), some forms of assessment could make more sense than others (Gardner & Boix-Mansilla, 1994, p. 18) but an assortment of assessment types should still be used regardless of the discipline. Because integration typically addresses more than one discipline, there are many projects, tests, portfolios, and other forms of assessment that would be appropriate for whichever content is of focus. Given by Stinson et al. (2009), another advantage of interdisciplinary curriculum is that the use of instructional time can be made both more efficient and effective by blending concepts from more than one discipline into one unit (p. 153).

Need for Mathematics and Science Integration

Integrated curriculum can be made for many combinations of disciplines. The disciplines of mathematics and science are perhaps the two disciplines in education that can be the most justifiably connected. One of the reasons for this is that science and mathematics are so closely related that in many situations it would be more meaningful for students and more efficient to teach the content using an integrated approach (Berlin & White, 1994, p. 3). Another reason that these two disciplines could be connected smoothly, according to Bossé, Lee, Swinson, & Faulconer (2010), is because they are learned using similar processes (p. 268). When science and mathematics are combined, each serves as a valuable tool in the learning of the other.

Science provides mathematics with context and concrete examples to make the learning of mathematics more relevant and interesting while mathematics serves as a useful tool to understand and analyze the science concepts more deeply (Basista & Mathews, 2002, p. 359; McBride & Silverman, 1991, p. 286/287).

Some of the skills and processes that are used in both mathematical problem solving and scientific inquiry are classifying, collection and organizing data, communicating, controlling variables, developing models, estimating, experimenting, graphing, inferring, interpreting data, making hypotheses, measuring, observing, recognizing patterns, predicting, task engagement, generating curiosity, disequilibrium, investigating, systematic exploration, multimodal, formal and informal language, justifying and defending solutions, reasoning, synthesizing ideas, demonstrating conceptual and procedural understanding, and using internal and external connections and relationships (Berlin & White, 1994, p. 3; Bossé, Lee, Swinson, & Faulconer, 2010, p. 269). More broadly categorized by McBride and Silverman (1991), "the methodology of mathematical inquiry shares with the scientific method a focus on exploration, investigation, conjecture, evidence, and reasoning" (p. 285). While mathematics and science clearly share many processes and methodologies, it is also important that much of the content overlaps so that the curriculum could be built around content that fits well together. Some of the "big ideas" related to content in both mathematics and science are balance, conservation, equilibrium, measurement, models, patterns, probability, reflection, refraction, scale, symmetry, systems, variable, and vectors (Berlin & White, 1994, p. 3). Any of these topics could be used as a theme upon which a mathematics/science interdisciplinary unit is based around.

The fact that science and mathematics have so many processes, skills, and content in common is not a coincidence. Many discoveries in mathematics were first brought to light in a scientific setting when scientists and mathematics attempted to analyze and model naturally occurring phenomena. It makes sense then that many significant real-world problems that involve either mathematics or science will often be related to both fields. In order to find solutions to real-world problems in these fields, knowledge of both mathematics and science (and potentially more disciplines) is frequently required (Berlin & White, 1994, p. 2).

Student Outcomes

Students are often disengaged in the classroom because the content is decontextualized and the students have a difficult time making connections and determining applications on their own. Regarding this issue, Venville et al. (1998) claim that the contextualized style of solving problems is a benefit of integration highly regarded by mathematics teachers (p. 299). According to Beane (1995), curriculum should be developed so that it helps students to "broaden and deepen their understanding of themselves and their world" by integrating learning experiences into their schemes of meaning and that students should be "engaged in seeking, acquiring, and using knowledge in an organic- not an artificial- way" (p. 616-618). Referring to integrated curriculum, Beane (1995) says that using authentic, real-life themes requires a wider range of content and basing the content around a theme makes the content more accessible for students, making it more easily connected to existing knowledge. Similarly, Davidson et al. (1995) say that integration can provide students with a more "reality-based learning experience" (p. 229).

McDonald and Czerniak (1994) agree with Beane that the theme that the content is based around serves as a useful tool for students in connecting content with their view of the world. In addition, McDonald and Czerniak say that an interdisciplinary approach allow students to "personalize their learning by weaving together ideas from different curricular domains, encouraging flexibility of thought, and examining an idea from different perspectives" as well as helping students to develop an integrated view of learning, society, and the world (p. 9).

Another reason why integration is important is the impact that it has on students' skill development and achievement. Two of the most important skills that students cultivate by participating in an integrated mathematics/science curriculum are problem solving skills and critical thinking skills. According to McDonald and Czerniak (1994), "Interdisciplinary units concentrate on organizing themes or concepts, and enable students to integrate scientific processes, communication skills, problem solving, critical thinking, and creativity; thus, empowering them for future learning" (p. 9). These authors are not the only ones who claim that integrated classrooms have a positive impact on problem solving skills and critical thinking skills; Basista and Mathews (2002), Beane (1996), Czerniak at al. (1999), Elliot et al. (2001), and Hurley (2001) also mention the development of these skills as a result of integrated curriculum.

In a study conducted by Hurley (2001) comparing integrated and non-integrated classes for the various methods of integration that she proposed (sequential, parallel, partial, enhanced, and total), the mean effect size for science achievement (integrated vs. non-integrated) was .37 and the mean effect size for mathematics achievement was .27 (p. 261). This means that overall the students in the integrated courses performed significantly better in both mathematics and science than the students in the non-integrated courses did. Her study showed that of all of her proposed methods of integration, "science achievement was greatest when mathematics was used to either enhance science or in total integration with science" with effect sizes of .66 and .96, respectively (p. 264/265). For mathematics, with an effect size of .85, student achievement was greatest when taught in sequence with science (p. 264/265).

Other skills mentioned in the literature that are said to be heightened by interdisciplinary curriculum are language and communication skills (Basista & Mathews, 2002; McDonald & Czerniak, 1994), creativity (Beane, 1996; Venville et al., 1998; McDonald & Czerniak, 1994), group working and collaborative learning skills (Venville et al., 1998), and science process skills (Basista & Mathews, 2002; McDonald & Czerniak, 1994). Development of certain skills is an essential part of any education. A student's attitude and motivation can have a tremendous impact of the student's willingness to participate in activities that promote the development of these skills. In many cases, integrated curriculum has been shown to increase student motivation and attitude toward learning (Berlin & White, 1994, p. 4; Bragaw, Bragaw, & Smith, 1995, p. 45; Elliott, Oty, McArthur, & Clark, 2001, p. 815; Mason, 1996, p. 265; McBride & Silverman, 1991, p. 286/287; Stohlmann, Moore, McClelland, & Roehrig, 2011, p. 32; Venville, Wallace, Rennie, & Malone, 1998, p. 299).

In regard to a study conducted in a middle school in Virginia where students participated in an interdisciplinary project, Bragaw et al. (1995) stated that students were excited to explore the content in the activity and that the most important impact of the interdisciplinary style was the heightened interest of the students in what they were learning (p. 45). In their document search, Berlin and White (1994) found evidence that suggested that mathematics/science integration may improve student understanding and help students develop more positive attitudes toward both science and mathematics (p. 2) and also claimed that "student motivation to achieve may be enhanced by integrated science and mathematics experiences based upon personal and social issues and interests. Engagement in these types of experiences may also help to encourage, support, and nurture student confidence in their ability (i.e., self-efficacy) to do science and mathematics" (p. 4).

In the study conducted by Elliot et al. (2001) at Southeastern Oklahoma State University comparing an integrated math/science course with a regular College Algebra course using student performance and survey data, they found that the students in the integrated section had significantly more positive attitudes at the end of the semester, thought that the course was more interesting and practical ($p<0.005$), and had better attitudes toward mathematics ($p<0.05$) than the students in the traditional section did (p. 815). In addition, the researchers thought that by engaging in the interdisciplinary projects, students began to believe that mathematics is useful, important, and even interesting (p. 815).

In addition to promoting skill development and positive attitude, integrated curriculum has also been said to strengthen relationships between students and teachers (Venville, Wallace, Rennie, & Malone, 1998, p. 298), help students to recognize the value in doing research (Bragaw, Bragaw, & Smith, 1995, p. 44), and provide activities for students to engage in both inductive and deductive "ways of knowing" (Berlin & White, 1994, p. 3). Another favorable piece of integration is its ability to boost the number of opportunities for meaningful use of technology in the classroom. Based on a study of integration and technology use for seventh grade to ninth grade students, Venville et al. (1998) state that the teachers noticed that, "students better understood mathematics and science concepts when they applied their knowledge to a practical task in technology and, conversely, the technology products were said to be of better quality when the students were able to use mathematics and science skills and knowledge to improve their designs" (p. 299).

Benefits for Teachers

While interdisciplinary curriculum clearly has numerous potential benefits for students, teachers can also benefit from using this approach in their classroom. Because the single-subject approach is typically irrelevant to real-life issues and concerns, it can have a negative effect on teachers just as it can on students. Teachers who are unhappy or bored with their jobs may be less likely to teach effectively. According to Venville et al. (1998), teachers who use integrated curriculum feel as thought they benefitted because they can choose content that they believe motivates and interests their students (p. 299). Likewise, teachers can select content that they are also intrigued about making it easier to teach enthusiastically. Other teacher benefits found in the literature include combining funds, organizing blocks of time, more effective scheduling (McDonald & Czerniak, 1994, p. 9), and collaborating with teachers from other areas of learning (Venville, Wallace, Rennie, & Malone, 1998, p. 299). While effective integration often requires funding for curriculum development, supplies, and technology, these expenses can go toward more than one course such as both science and mathematics.

Methods and Models

Throughout the literature on integrated curriculum and instruction, many different models are presented. Some of the models provide a very specific, step-by-step guide on how to develop curriculum, some describe specific types of integration, and some provide criteria to characterize lessons. The models to be discussed are integration continuums, theme-based models, and more.

Mathematics-Science Integration Continuums

Each of the 4 continuums to be presented has 5 main categories along the spectrum. The first 2 continuums are almost identical. Huntley (1998) describes a continuum (Figure 1.1) with categories mathematics for the sake of mathematics, mathematics with science, mathematics and science, science with mathematics, and science for the sake of science (p. 322). In mathematics for the sake of mathematics, the content is solely mathematics and is taught as a formal system. Mathematics with science is primarily a mathematics course where science content and/or methods are used only for context and relevance. Mathematics and science is both a mathematics course and a science course in which both disciplines play a role in explaining the world. Science with mathematics is a science course that emphasized mathematics as a tool to help explain science concepts and solve science problems. In science for the sake of science, the only focus is on science content and methods. Roebuck and Warden (1998) produced a very similar continuum (Figure 1.1) with the 5 categories math for math's sake, science-driven math, math and science in concert, math-driven science, and science for science's sake (p. 328). In both of these continuums, the ends consist of completely separate instruction that focuses on only one discipline. The next steps toward the middle of the continuum represent some integration in which the primary focus is still on one discipline but learning is enhanced by incorporating content and methods from the other discipline. The middle of each continuum illustrates full integration where both disciplines carry equal weight in the classroom.

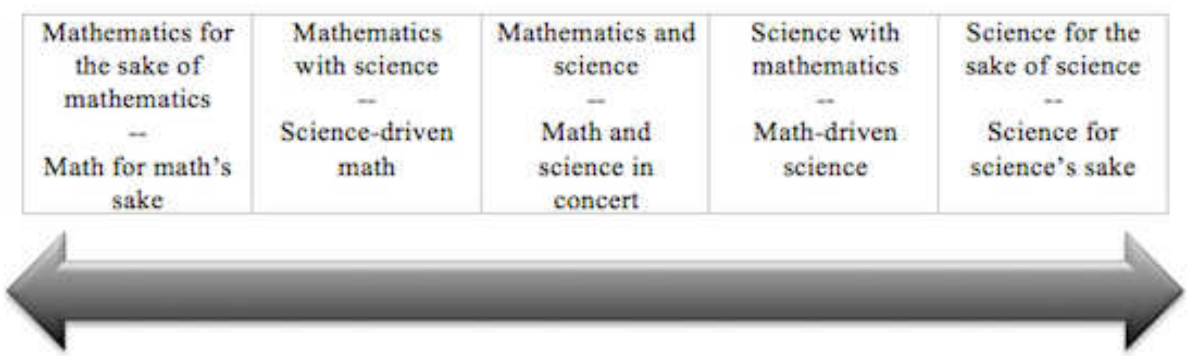


Figure 1.1: Mathematics/Science Integration Continuum

Lonning and DeFranco (1997) also created a 5-category continuum for mathematics-science integration. Again, on either end is independent mathematics and independent science. Moving toward the center of the continuum, the next categories are mathematics focus and science focus. In these categories, the content meets curricular goals and objectives for the appropriate grade level in one of the disciplines but includes concepts from the other discipline that are not necessarily grade level appropriate. Finally, in the center of the continuum lies balanced mathematics and science, where the curriculum is delivered in a meaningful way and the content from both disciplines help to meet appropriate grade level goals and objectives. In regard to this continuum, Lonning and DeFranco stated that, "the continuum model is intended to be used by curriculum developers to clarify the relationship between the mathematics and science activities and concepts and to guide the modification of lessons" (p. 212).

Hurley (2001) created a continuum with 5 main categories as well however hers is quite different. Hurley's 5 steps correspond to general forms of integration, from the least integration to the most integration: sequenced, parallel, partial, enhanced, and total (p. 263). Sequenced integration occurs when the science and the mathematics are planned and taught sequentially, one after the other. In parallel integration, science and mathematics are planned/taught concurrently via parallel concepts. Partial integration occurs if science and mathematics are sometimes taught together and sometime taught separately. In enhanced integration, the main focus is either on mathematics or science and is enhanced by the other discipline. Lastly, total integration occurs when science and mathematics are taught completely together and each are of equal focus.

Theme-Based Models

Numerous models for mathematics/science curriculum development are based on a central theme. Lonning, DeFranco, and Weinland (1998) argue that the process of creating an integrated unit consists of two phases- (1) theme development and (2) creating balanced integrated activities based on the theme (p. 314). They say that phase 1 should begin with a review of the school/district/state curriculum documents to look at the scope and sequence of the curriculum. The purpose of this would be to ensure that content and objectives are grade level appropriate and are grounded in the school's curriculum (p. 314). Beane (1995) says that the theme should be constructed based on the problems, issues, and concerns of life as it is being lived in a real world" (p. 617). Beane agrees that the next step after creating the theme is to develop activities that address the theme and related issues (p. 619). Although Beane's idea about the process of unit creation is similar to the many other authors who discuss this, he believes that there should be no intermediate step in determining which content areas contribute to the theme. Some other authors (Lonning, DeFranco, & Weinland, 1998; McDonald & Czerniak, 1994) state that part of the process is identifying the different content domains that relate meaningfully to the theme and analyzing the extent at which integration between disciplines is occurring in each activity. Beliefs about what this part of the process should entail are most likely based upon how a researcher defines integrated or interdisciplinary.

McDonald and Czerniak (1994) provide a more specific 5-step process for the development of an interdisciplinary unit: (1) theme identification, (2) identification of content domains related to theme, (3) identification of concepts within each domain related to the theme that can be meaningfully developed, (4) development of "map" or "web" that connects concepts in an educationally effective way, and (5) development of specific activities (p. 5). For this model, the specific activities should encourage communication and cooperation while promoting creativity and personalization (p. 6).

Additional Models

Although many models and methods are either theme-based or based on a continuum, there are others worth mentioning. Davidson et al. (1995) describe 5 categories of integration: discipline specific integration, content specific integration, process integration, methodological integration, and thematic integration. Discipline specific integration involves an activity incorporating two branches of the same discipline (for examples both algebra and geometry or both biology and physical science). Content specific integration uses one mathematics objective and one science objective in an activity. Process integration occurs when students "experience the processes of science and perform the needed mathematics" (p. 228). In methodological integration, "'good' science methodology is integrated in 'good' mathematics teaching" (p. 228). Lastly, like many other authors, they say that activities for thematic integration are built off of a central theme in which multiple disciplines interact.

Another notable model mentioned by Elliot et al. (2001) is one used at Southeastern Oklahoma State University in the "Algebra for the Sciences" course. In this course, science experiments and lectures were used to introduce topics. This was motivation for mathematical discussion about these topics. At the end of each topic/unit, the students were given an interdisciplinary project to complete. This is an example of science concepts being used to interest students in mathematics. This, along with a second method, is described by two different sets of authors- McBride and Silverman (1991) and Roebuck and Warden (1998). McBride and Silverman say that two approaches for the integration of mathematics and science are "(a) science activities to illustrate the meaning of mathematics concepts and to motivate students to want to learn mathematics content and (b) application of mathematics to science content to enable students to gain deeper understandings of science concepts" (p. 290). Similarly, Roebuck and Warden (1998) claim that the connections between mathematics and science can be considered in two ways: using mathematical skills for solutions of science problems and using science concepts to give context to mathematical computations.

A few other models also worth mentioning are the Berlin-White Integrated Science and Mathematics (BWISM) model and approaches described by Venville, Wallace, Rennie, and

Malone. Berlin and White (1994) developed the BWISM model which identifies 6 aspects, described in more detail later: (a) ways of learning, (b) ways of knowing, (c) process and thinking skills, (d) content knowledge, (e) attitudes and perspectives, and (f) teaching strategies" (p. 3). Venville et al. (1998) discuss 11 different approaches to integration: thematic approach, cross-curricular approach, technology-based projects, competitions, school special approach, topic integration, integrated assignments, synchronized content and processes, local community projects, teaching approaches, and natural/informal integration. While there exist several different models for using this approach in the classroom, it is not necessary to only stick to one. More than one can be used at one time but teachers should decide how they want integration to occur before trying to implement.

Challenges to Integration

Integration of disciplines can provide both students and teachers with numerous benefits that a single-subject, traditional approach to education cannot but as with most things, there are unquestionable challenges to using an integrated curriculum.

General Challenges

In theory, integrated curriculum may seem favorable in many ways, but for practical purposes research is vital in determining the effectiveness of interdisciplinary curriculum compared to traditional curriculum. Some critics of integration say that there is a lack of empirical research conducted on the topic to show which approach is more effective (Basista & Mathews, 2002, p. 360; Czerniak, Weber, Sandmann, & Ahern, 1999, p. 422). One possibility as to why there may be a lack of evidence is there not being an agreed upon operational definition of integration to use for research (Basista & Mathews, 2002, p. 360). Another possibility is that the research that has been conducted has tended to be published in the forms of dissertations and theses, which are readily less available to the public than other documents (Hurley, 2001, p. 261).

An integrated approach to education is only effective when properly implemented. Merely integrating for the sake of integrating will not yield the same student benefits because as George (1996) states, “a traditional curriculum delivered well, I think, would be far better than an integrated curriculum delivered poorly” (p. 19). Poorly implemented integration heightens the risk of leaving students with gaps in their knowledge (Basista & Mathews, 2002, p. 361). Integration should not be forced, it should only occur when using it would be as effective or more effective than using a traditional approach. One of the reasons that integration can be ineffective is that it could be tempting to choose the content for a unit based on how well it fits with the theme, material availability, teacher interests, and/or how fun it would be for students rather than focusing on which ideas would be the most important and useful for the students to learn (Roth, 1994, p. 45).

Another potential risk of employing an integrated curriculum is that there’s a chance that not all of the material currently covered in the single-subject approach would surface in the integrated approach, potentially leaving gaps in the students’ knowledge (Beane, 1995, p. 620; Mason, 1996, p. 263; Roth, 1994, p. 44). This is especially true if using a theme-based approach to integration because the content that can be included is largely restricted to the chosen theme (Lederman & Niess, 1997, p. 58). According to Beane (1995), while this is true it should not be seen as a big problem because the themes are chosen based on real-life issues and problems call forth the most powerful ideas that students should focus on (p. 620).

Although a great deal of content and processes are common to both mathematics and science, some topics may not be so easily integrated. Some researchers argue that even when using interdisciplinary curriculum there are certain times when mathematics and science should be taught separately (Davidson, Miller, & Methany, 1995, p. 227; Mason, 1996, p. 266). One reason for teaching some content of each discipline separately would be so that students know the basic skills, concepts, and procedures before trying to apply them to more contextual problems (Davison, Miller, & Methany, 1995, p. 227). Some additional challenges that are mentioned in the literature are daily scheduling issues (Beane, 1995, p. 619), development of a standard scope/sequence (George, 1996, p. 18), and time management for students (Venville, Wallace, Rennie, & Malone, 1998, p. 299). Regarding time management, Venville et al. said that some students have difficulties managing their time wisely and completing long-term projects (p. 299). While this may be a difficulty, it could also be viewed as a learning experience for the student to develop time management skills.

Challenges for Teachers

Perhaps the most problematic challenges that teachers must overcome when attempting to employ an integrated curriculum are having little to no training in developing or implementing this type of course and only being trained in one discipline (Koirala & Bowman, 2003, p. 145). Pre-service teachers are often not required to or even offered to take courses in training to teach interdisciplinary courses (George, 1996, p. 18) and have most likely never experienced this type of course as a student (Mason, 1996, p. 267). In order to make this less of an obstacle, teacher training programs should offer courses that instruct prospective teachers on different models of integrated instruction, how to effectively implement integration, demonstrate examples of integration, and make teachers aware of the useful materials for integration that are available to them (Mason, 1996, p. 267; McBride & Silverman, 1991, p. 289). While the majority of teachers are not adequately trained in interdisciplinary instruction from a pedagogical standpoint, most are also not trained in more than one discipline. Rightly so, many teachers feel uncomfortable teaching content from disciplines that they haven't extensively studied (Basista & Mathews, 2002, p. 360; George, 1996, p. 16; Mason, 1996, p. 267; Venville, Wallace, Rennie, & Malone, 1998, p. 299). In order to successfully integrate curriculum, teachers must "manage a complex and delicate balance between knowing their own learning area deeply and knowing the specifics and commonalities between the different learning areas" (Venville, Wallace, Rennie, & Malone, 1998, p. 299). To combat this issue, pre-service training programs should include courses that focus on both disciplinary and interdisciplinary knowledge (Mason, 1996, p. 269) as well as the connections between areas of study (Roebuck & Warden, 1998, p. 332).

Another dilemma that could deter teachers from wanting to try using an integrated approach is a lack of time. As it is, teachers have very little planning time to plan classes that use the single-subject approach with content that they are very familiar with. The time needed to plan and implement an interdisciplinary curriculum greatly increases because teachers are working with content that they are not as knowledgeable in or experienced with and teachers most likely have to collaborate with other teachers in the school in order to discuss connections between content areas, potential themes, and to make activities (George, 1996, p. 17; Lonning & DeFranco, 1997, p. 214; Meier, Hovde, & Meier, 1996, p. 233; Venville, Wallace, Rennie, & Malone, 1998, p.299). Collaboration can be frustrating because of the amount of time it requires but it could also be difficult even to find another teacher at the same school from another discipline who is motivated to try an integrated approach and who is easy to work with. If teachers are trying out an integrated approach, especially for the first time, it could be very helpful to allow for more planning time in their daily schedule in order to coordinate with others.

As with anything teachers want to try, administrative support is both necessary and helpful. This means that if a teacher wishes to employ an interdisciplinary course at their school, they must convince the school administration that it is both possible and worthwhile (Huntley, 1998, p. 326). In much of the literature (Basista & Mathews, 2002, p. 362; Venville, Wallace, Rennie, & Malone, 1998, p. 298), administrative support was mentioned as essential for a successful execution of this type of course. Another unavoidable factor in this approach being successfully carried out is obtaining funding (Huntley, 1998, p. 326; Meier, Hovde, & Meier, 1996, p. 233). Funding is extremely helpful in integrating mathematics and science because teachers may need to travel to training sessions and seminars, purchase new textbooks and curriculum materials, and potentially obtain new technology for effective teaching. Two other challenges that teachers must confront include schools not having a precedent set for integration and adjusting classroom management techniques due to an increase in hands-on activities (McBride & Silverman, 1991, p. 288).

In traditional education, currently both teachers and students are evaluated using standardized tests, which are based on a set of standards that teachers are required to teach to their students for each class at each grade level. Even in the single-subject approach, teachers may feel that there is not time enough to cover each standard sufficiently. This pressure could increase when using an integrated approach because the curriculum would not be entirely built around the standards for each discipline (Meier, Hovde, & Meier, 1996, p. 231). If standardized testing persists for each individual discipline, teachers could be deterred from wanting to try an integrated approach (Mason, 1996, p. 267) because if the students don't cover the right standards in the right order, they may perform poorly on a particular standardized test which would in turn reflect poorly on the teacher and the school (George, 1996, p. 17).

Implementation Considerations and Recommendations

There are many things that educators who want to employ an integrated approach in their classrooms should consider. To initiate the development process, McDonald and Czerniak (1994) recommend that teachers first discuss the idea with colleagues from other disciplines to find a topic of interest to all parties and then start by developing just an integrated unit (p. 10). The best topics to choose, according to Beane (1995) are those that focus on real-world problems and issues (p. 617). The question of focus in developing any curriculum should be "how can these topics best be taught?" rather than "how can these topics best be integrated?" because with some topics a more traditional approach could be more effective (Lonning & DeFranco, 1997, p. 215). In a study conducted by Huntley (1998), teachers using integration said that the factors that were the most enabling were strong collegial support (similar professional goals, personal characteristics, and beliefs about curriculum and pedagogy), strong and flexible administrative support for team teaching (class/student scheduling, classroom proximity, joint planning time), and financial support (for materials and professional development) (p. 327). Lastly, Berlin and White (1994) recommend that instructional decisions are based on the following considerations: time for collaborative as well as individual inquiry-based/problem-solving learning, opportunities for communication and multiple representational modes, opportunities to use laboratory instruments and other tools, appropriate and ongoing using of technology such as calculators and computers, opportunities for successful experiences, and alternative, authentic assessments (p. 4).

Teacher Interviews

Two years ago at a local high school, a science teacher and a mathematics teacher made the decision to team up and create an interdisciplinary course. For the purposes of this literature review, individual interviews regarding experiences with this course were conducted with each of the two teachers, lasting approximately an hour each in length. Throughout this discussion, the science teacher will be referred to as Mr. Hansen and the mathematics teacher will be referred to as Ms. Grove (names have been changed). Mr. Hansen has been teaching science for 8 eight years and Ms. Grove has been teaching mathematics for 13 years. Each of the teachers have been involved in creating and teaching this course for 2 years but neither teacher had any training on integration during pre-service years.

Course Beginnings

The course was originally piloted as a blended Biology/Algebra course because the failure rates in the past for each of these courses separately had each been between 30% and 50%. Mr. Hansen believes that this failure rate is due to disengaged students who felt that the material was not relevant. The teachers wanted to try something new and different and work toward building the ideal educational experience for their students.

After the first year, Mr. Hansen and Ms. Grove decided to expand the course from only integrating Biology and Algebra to integrating many different areas of science and mathematics- Algebraic Concepts and 21st Century Skills Lab. This decision was made because trying to find meaningful connections between only Algebra and Biology was challenging, students were interested in multiple areas of science, and the teachers ran into issues attempting to meet every standard of both Algebra 1 and Biology. For the second year, the teachers wanted a student-driven course that incorporated more hands-on projects and analysis of real-world data.

Course Description

One of the goals for both years of this course was to "shift the locus of control from teacher centered to student centered" so the teachers could base the curriculum off of the following questions: (1) what are the students interested in? (2) how can we support the students in learning about it? and (3) what evidence can the students demonstrate to show that they've grown in both mathematics and science? Another aim of the course was to deliver a more critical thinking based and applied education to students who had never experienced it before.

The course consists of mostly students in 9th grade, some in 10th grade, and a few in 11th and 12th grade. The target population for the course is students who need more help with mathematics rather than with science, more specifically students already passed Algebra 1 but weren't ready to move on to the next math course. The number of students in the course is about 30 and roughly 80% of the class fit the original criteria for the target population. Mr. Hansen also mentioned that they were hoping for students who didn't necessarily view themselves as "math or science people" and who had been largely disengaged in school but had still shown a willingness to be there. Mr. Hansen noted that it would be powerful if students could self-select into this course so that it was truly their choice to be there. For math, the students take Algebra 1 before taking this course and will take either Geometry or Algebra 2 after taking this course. Mr. Hansen said that it was difficult to decide which science course the students should take after taking this course. Traditionally, the next science course that the students would take is an Earth Systems Science course that is highly content driven.

Ms. Grove said that before starting to develop the original course, the two teachers searched around for existing models for development and implementation but did not find any that fit what they were looking to accomplish. The teachers do have resources (textbooks, online data sets, etc.) to use for some activities and they attended a professional development conference at High Tech High in California. Because Mr. Hansen had been teaching science and

Ms. Grove had been teaching mathematics for so long, they decided to pull together and use their expertise from their own disciplines to create units for the course.

Each unit is typically guided by the science concepts because it is easier to find mathematics content that fits the science topic than the other way around. Much of the mathematics is done in the form of studying real data sets that describe some aspect of the science content. The data either comes from online data sets or from students actually collecting the data themselves. The course is taught during a double period, so the students receive both mathematics and science credit and the students have a separate grade for mathematics and science. The activities that are graded are tests, projects, and labs. Each grade they receive corresponds to one of five criteria in mathematics and one of five criteria in science. Despite their disagreements with the traditional ABCDF grading system, the teachers must assign one of these grades to the students' transcripts, so together they discussed and agreed upon standards for the quality work that would earn the students a particular grade. Quality of work rather than quantity of work is highly emphasized to the students, who know the grading standards and rubric well in advance of being graded. A portion (20%) of both the mathematics and science grade is based on student growth and learning so the students are assessed on positive growth and how active they are at looking at their own growth.

Integrated Education vs. Traditional Education

Mr. Hansen and Ms. Grove were asked to reflect on the differences in multiple facets of teaching that they have experienced in using a traditional approach and in using an interdisciplinary approach. When asked about unit planning, Mr. Hansen said that his units are less strictly planned out when using an integrated approach because he doesn't feel as pressured by time allowed for each topic. He also said that he begins planning with the end in mind more than he does when using a traditional approach because he needs to know what the culminating event will be to make sure that the students develop all of the necessary skills and knowledge to be successful. While this is true of a traditional unit as well, the curriculum is already laid out for the teacher in such a way that the skills are developed in a certain order. Ms. Grove said that while she is used to collaborating with other mathematics teachers, the difference with integration is collaborating on more than one subject and it's more difficult to collaborate to fit together two disciplines. In regard to daily lesson planning, lesson objectives are more based on developing certain skills and experiences rather than on a need to cover particular content. Using the integrated approach, lesson planning happens a bit more "on the fly" not because of a lack of preparation but because "we're really trying to honor all of the different learning that is occurring and the pace that the students are at", according to Mr. Hansen. Both teachers mentioned that they first attempted to do unit plans and then tried weekly plans but eventually realized that they really needed to plan day by day to honor the student-driven nature of the course.

When it comes to actual class time, Mr. Hansen said that classroom activities are more hands on than the activities in the "regular" courses that he teaches. He also stated that he felt like more of a facilitator than a teacher in the integrated class and that the teachers use a more constructivist method of teaching. When asked how they decide who teaches first and how much each day, Mr. Hansen replied that sometimes it depends on the content and sometimes it depends on who is both physically and mentally available to teach during each part of class. While they each would prefer to teach their own content, both teachers are familiar enough with the content from the other discipline that they can teach it if need be. Ms. Grove said that she uses so much scaffolding and problem-driven instruction in her traditional courses that using these approaches in the integrated course was not much of an adjustment. The main thing that has changed in teaching methods for her is time management because she finds it much more difficult to gauge the amount of time the students will use for activities due to the student-driven nature of the course.

Both teachers stated that classroom management and differentiation is different for these two approaches of teaching. In reference to differentiation, Mr. Hansen claimed that, “I think that a room like this, for the first time in my life I understand differentiation. It had been such a challenge for me to imagine how to get them content-wise to the same place.” He feels like integration “lends itself beautifully” to allowing students to work at the level that they’re comfortable with while still pushing themselves to work hard and learn a lot. Ms. Grove agreed that differentiation in this class largely comes in the form of allowing students to pursue their interests and work at their own level and that this also solves many classroom management problems. Both teachers argued that the classroom management issues that do arise in the integrated course stem from the population of students that were placed in the course (lower level mathematics students) rather than from the way that the course is run.

Assessment and use of standards in this course were each said to differ from those in traditional courses by both teachers. In the integrated course, types of assessment are different in that there are more hands-on projects and labs. In terms of grading assessments, the grades in the integrated course are based more on student growth and quality of work rather than the correctness the traditional course grades are based on. Ms. Grove really likes that the assessments have more real-world context in the integrated course. In regard to use of standards, Mr. Hansen said that the process often works in reverse in the integrated course. Instead of basing the lessons off of which particular standards are to be addressed, the standards are assigned in retrospective after the lessons are taught. This is because “it’s very hard to have a student-driven classroom with teacher-driven standards.” Each teacher claimed that they hit numerous standards in this course although the course itself is not standards based.

Because of the student outcomes evidenced by the literature on interdisciplinary classrooms, the teachers were asked to discuss the problem solving skills, critical thinking skills, engagement, and attitude of their students in both of the types of courses that they teach. According to Ms. Grove, the problem solving skills and critical thinking skills of the students in the integrated course are far superior tp those of other kids their age even only being one-quarter the way through the class (when this interview was conducted). Both teachers believe that the students are more engaged under this project-based model because it is more hands on and the students have more freedom to choose what they are learning about. The attitudes of the students also seem to be more positive because the students are interested in seeing the connections and practical applications. Mr. Hansen said that when he asked the students, this was the reason that they gave for the pass rate the first year being much higher than that of a traditional course.

One other facet of teaching the integrated course that the teachers said is different than in a traditional course is use of technology. The teachers said that while they definitely use technology much more in this course, they also use it much more innovatively. In this course, some of the technologies used aren’t common to every classroom- tools like 3D printers, programming, and circuits. Each student in the school also has a laptop issued to them by the school so they can use this in class to research topics, find data sets, conduct analyses, and write up their findings.

Student Benefits and Challenges

According to both teachers, one of the benefits is that students care about what they are learning in the class and they are excited about the projects that the do. In this class, because the students get to collect and use their own data for analysis much of the time, the students take more ownership of their learning and the teachers are not asked the question, "when are we ever going to use this?" by the students as they would be in a traditional class. Another benefit is that the students understand why what they learn and what they do in class matters and where it might be used in the real world outside of school. One of Ms. Grove's goals is that students will remember the applications of certain types of functions (logarithmic, quadratic, exponential, etc.) both when they see them in other classes and when they see them in outside of school. More specifically, Ms. Grove said she hopes that in ten years from now when students come across data sets or graphs in newspapers or other sources they can determine whether the data are factual, they could analyze them, and they could make sense of them. Ms. Grove believes that giving the students more control over their own learning and education is a huge benefit. Mr. Hansen hopes that one of the benefits is that students begin to see themselves as people who have the power to contribute to society through the lens of science and mathematics.

The main challenge for the students that the teachers mentioned was that the students don't get to experience this model of curriculum in their other classes. Ms. Grove said that on more than one occasion, she had former students from the Biology/Algebra course who said that they were very unhappy in the new course that they were in because they had moved back into the traditional, lecture-based approach to education. She said that the students tell her that they feel like they don't get to think as much and that they are just spitting out answers that don't mean anything in the courses that they take afterward.

Teacher Benefits and Challenges

Both teachers had a lot to say when asked about rewards of teaching this course and the challenges that they face. One of the rewards of developing and teaching this class is bringing play back into the class, according to Mr. Hansen. He said that he and Ms. Grove were inspired again by beautiful and artistic things and were excited to get to teach students based on what they wanted to teach and what the students wanted to learn. Not only that, but Mr. Hansen also said that he was learning a lot himself like how to wire a circuit and how to program and use a 3D printer. With this class, the teachers have more freedom and less pressure from external sources such as standards and strict schedules. Both of the teachers mentioned that it was incredibly rewarding to empower a group of students who previously felt as though they weren't smart or good at school. Ms. Grove said that it's rewarding to watch these students understand and find their own value in learning. Another rewarding experience of teaching this class according to both teachers is the professional partnership that has developed with co-teaching. Mr. Hansen even said that he feels that he grown as an educator more in the last 2 years than he did in his first 6. Lastly, Ms. Grove mentioned that it's rewarding to know that they have the support of the school and the community and that they have people investing in them.

While the teachers find developing and teaching this course extremely gratifying, they face many struggles every day. Both teachers said that the main challenge in teaching this course is that it's incredibly time consuming and they never feel as though they are caught up. This is largely because it's a pilot course so the teachers are building it from scratch but they also said that collaboration eats up the majority of time they have to plan for both this class and their others. The teachers also had to seek out external sources of funding for this course by writing numerous grants that took up a lot of time. Mr. Hansen said that some challenges that they face happen simply because change is hard. They've found the loss of control and difficulty in planning to be big adjustments with the student-driven nature of the course and they also feel as though they teach every subject now, not just mathematics or science. Finally, Mr. Hansen mentioned that the creation of this course has somewhat disrupted the harmony in the science department because many of the teachers who believe in a theory based approach to education do not necessarily agree with how the course is run.

Recommendations and Considerations for Other Educators

One recommendation given by the teachers is to have 2 or more teachers collaborating to create and teach an integrated course. Because this approach requires a tremendous amount of collaboration, co-teaching will be much easier if all of the collaborators have compatible personalities, work ethics, educational goals, and teaching philosophies. Each teacher said that the most helpful resources they have at their disposal for developing and implementing this course is a common planning period, grant money, administrative support, and having attended professional development at High Tech High. Without these resources, teaching this course would be much more difficult. Lastly, one consideration for educators who want to attempt this approach is that the outcome will be vastly different depending on the population of students. While these teachers find it rewarding to work with the population of students that they do, they believe that having a self-select option and potentially running the course with an older, more mature group of student would yield enormously different results. The last recommendation given by Ms. Grove, "Do it!"

CHAPTER 3: RESEARCH METHODOLOGY

Research Paradigm

This was a mixed methods study in which both quantitative and qualitative data were collected. The main purpose of the study was to make recommendations to other educators who want to use an interdisciplinary mathematics/science approach in their own classroom. To gain experience, I developed and implemented an integrated mathematics/science activity based on the role that surface area to volume ratio plays in nature at a local high school. The students engaged in hands-on exercises, group work, class discussion, mathematical reasoning, and scientific reasoning during the activity, which lasted for 3 class periods of their STEM Technology class. After participating in the activity, the students filled out a survey that included 15 Likert scale statements that were analyzed quantitatively and 10 open-ended writing prompts that were analyzed qualitatively. The survey questions were based on knowledge gained from the literature review and the teacher interviews.

STEM Technology

The cooperating local high school has a one-to-one iPad initiative, so each of the students at the school has their own iPad to use inside and outside of class for educational purposes. The STEM Technology class that the activity was implemented in meets 5 days a week for approximately 51 minutes each day and consists of 18 9^{th} grade students. The classroom is packed full of neat technology such as computers, a 3D printer, building materials, and more for the students to use on their projects.

The coursework consists mainly of open-ended projects that students work on and present on in groups. For the first semester of the course, each group worked projects with the same guidelines at the same time but were somewhat able to suit their projects to their own interests. For the second semester, there are many different projects worked on at one time by the class with only 1-2 groups working on the same project at the same time. Each project lasts approximately 1.5-2 weeks and then the groups switch projects. By the end of the semester, each group will have had the chance to work on each project at some point. Some of the project topics for the second semester include Lego robotics, 3D printing, circuit boards, and ArcGIS mapping.

Theoretical Framework for Activity Development

Framework

The activity was developed keeping in mind guidelines presented by Berlin & White (1994) in "The Berlin-White Integrated Science and Mathematics Model" (BWISMM) that focus on six aspects that are important for integrated teaching. The first component mentioned in the model is ways of learning. This explains that the students "must be involved in an active, exploratory learning process with opportunities for social discourse" (p. 3). The second element is ways of knowing. The authors claim that integrated science and mathematics give students a chance to move back and forth between inductive and deductive ways of knowing and reasoning (p. 3). The third is process and thinking skills. The overlap of process and thinking skills in mathematics and science is emphasized in much of the literature and is a large piece of the argument behind the importance of integration of the two subjects. The fourth aspect is content knowledge, another large piece in the argument for integration. Berlin & White state, "there are times when the content of science and the content of mathematics have enough in common so that it would be more meaningful to the student and more efficient to integrate science and mathematics education" (p.3). The fifth component, attitudes and perceptions, relates to the values and ways of thinking that are shared between science and mathematics and how engagement in integrated mathematics-science experiences can help to encourage and support student confidence in mathematics and science. For the last aspect, teaching strategies, the authors list the following considerations: collaboration time as well as individual inquiry-based/problem solving learning, opportunities for multiple representational modes and for communication, opportunity for meaningful use of technology, and opportunities for authentic assessment (p. 4). While Berlin & White discuss the significant pieces to consider in teaching integrated curriculum, their model does very little in showing how to actually develop an integrated unit.

For the purposes of developing an integrated/interdisciplinary unit, the model described Lonning, DeFranco, and Weinland (1998) is more useful. The two main phases of development that the authors present are the development of a theme and the process of creating balanced integrated activities (p. 314). The first step in developing a theme, which helps to ensure that activities will be grade level appropriate, is to examine the district/school's scope and sequence or other curriculum documents or state frameworks (currently, the Common Core State Standards). The next step is called the "zooming process", which is used to enlarge or narrow a potential theme in order to ensure that the theme is grounded in the school's curriculum. Once the theme is created, creation of balanced integrated activities begins. This step involves collaboration between a team of teachers/writers creating activities and assessing the degree of integration between the disciplines within each activities and where the activity falls on the continuum (p. 315).

Role in Activity

These two frameworks were used for different purposes in my project. The BWISMM was used more for focusing on the pedagogical aspect of the activity and what the best way of implementing the activity was while the model created by Lonning, DeFranco, and Weinland was used more in tying the content from math and science together to create the activities for each day.

In order to satisfy the first component of the BWISMM, the students engaged in a hands-on, active learning exercise that involved experimenting with Microencapsulated Liquid Crystal sheets. The students worked in groups and were encouraged to discuss each piece of the activity with their partner before submitting an answer. During the activity, students used both inductive reasoning (for example, in investigating the behavior of the surface area to volume ratio of an object as the size of the object increases) and deductive reasoning (for example, in predicting the behavior of surface area to volume ratio of a variety of objects using knowledge about the ratio for hemispheres), satisfying the second aspect of the BWISMM. For the third component, students had to think critically and logically in order to answer some of the questions in the activity. Because the activity involved both mathematics and science and connected the topics from each discipline in a meaningful manner, the fourth component was satisfied. The fifth aspect was addressed mainly in the student survey when the students were asked to give feedback about the activity and how it helped them see the connections between mathematics and science and when the students were asked to explain how the learning of mathematics and the learning of science are similar. The sixth aspect of the BWISMM was satisfied in many ways. The students were given time to collaborate with others during the activity and they were also given time to reflect back on their responses. The students were also provided opportunities for multiple representational modes such as semi-anonymous Google form responses, Google, sheets responses, and class discussion. The students engaged in meaningful use of technology such as Google forms, Google sheets, and experimenting with Microencapsulated Liquid Crystal sheets.

Using the model for development put forth by Lonning, DeFranco, and Weinland, the theme created was the role surface area to volume ratio in biology and in nature. This theme was chosen because of a discussion I had with the STEM Technology teacher about the other courses that the students were enrolled in (almost all in geometry, some also in biology). This ensured that the topic would be meaningful for students to learn and the topic would relate to the curriculum that students were engaging in in their other courses. With this theme in mind, the exercises were created for the 3-day long activity.

Integrated Mathematics/Science Activity

The integrated activity implemented at a local high school lasted for 3 days in the students' STEM Technology class. The first class period was approximately 35 minutes, the second class period was 51 minutes, and the third class period was 51 minutes of which 15-20 minutes were used for the completion of the survey. The students worked through the activity in pairs. For each of the 3 days, the students were given directions and then guided through the activity using Google forms. There were 6 Google forms between the 3 days of the activity – 1 for the first day, 3 for the second day, and 2 for the third day. Once each group submitted their form, all of the responses were projected onto a SMART Board for class discussion. The Google forms that the students filled out can be found in Appendix A along with selected student responses to the Google form questions.

All but 1 of the students in the STEM Technology class were also taking a Geometry class and a few of the students in the class were taking a Biology class. The activity was based on the concept of surface area to volume ratio and its role in biology and nature in order to try to tie in topics from the students' other courses.

Day 1

For the first day of the activity, the students experimented with Microencapsulated Liquid Crystal sheets (MELCs) in order to visualize how surface area to volume ratio affects heat retention in water droplets. MELCs respond to temperature change input with a color change output so the students could investigate how the colors on the MELCs changed as a drop of hot water cooled down to room temperature. The key idea for this day was for the students to compare the amount of time it takes for a small drop of hot water versus a larger drop of hot water to cool back to room temperature. The students filmed this experiment with the camera on their iPads so they could re-watch the experiment the on day 2 when asked to reflect back on the experiment. This experiment led into discussion about why a small drop of water cools more quickly than a large drop of water. The answer lies in the surface area to volume ratio.

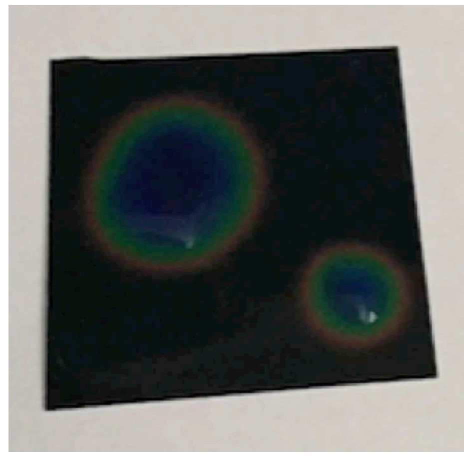


Figure 3.1: Microencapsulated Liquid Crystal Sheet with Large/Small Drop of Warm Water

Day 2

The second day of the activity was the one that emphasized mathematics the most. For the first part of day 2, in order to explore the mathematical properties of day 1's experiment, the students were given formulas for the surface area and volume of a sphere and were asked to write formulas for the surface area and the volume of a hemisphere. They were then asked to compare the surface area to volume ratio of a sphere to the surface area to volume ratio of a hemisphere.

For the second part of math day, each pair of students was assigned a radius and was asked to calculate the surface area, the volume, and the surface area to volume ratio of a hemisphere with that given radius. The students were sent a link to a Google sheet and filled in the information for their assigned radius. Once the table was filled in for all 9 pairs of students, the data were displayed on the SMART Board. Using the data, a graph was constructed in Google sheets that modeled both the surface area and the volume of a hemisphere as the length of the radius increases. The students then answered questions using a Google form based on the information and graph displayed on the SMART Board. The students used this information to revisit day 1's experiment and try to explain the findings mathematically.

For the third portion of day 2, the students are asked to mathematically explore the surface area to volume ratio of cubes and cylinders of the size of the objects increase. The students should recognize that the property that surface area to volume ratio decreases as the size of an object increases holds true with these shapes as well.

Day 3

On day 3, the students learned about applications of surface area to volume ratio in biology and in nature. For the first part of day 3, the students were shown images of a variety of oddly shaped objects and were asked to describe what the surface area to volume ratio would be for each of the objects. While these questions are completely dependent on the size of the object and what one considers to be a small ratio or a large ratio, these questions were intended to get students thinking about the surface area to volume ratio for a variety of shapes and sizes. The students are then asked to brainstorm ideas of how surface area to volume ratio shows up in nature with their partners.

For the second part of day 3, the students are given a variety of scenarios in which surface area to volume ratio plays in important role and are asked to explain the concepts using what they learned about the surface area to volume ratio of objects as their size increases. After seeing numerous examples, the students had the chance to brainstorm more examples again with their partner. Day 3 ended with a class discussion of the examples that each group constructed.

Content Standards Addressed

Mathematics Standards

The table below shows the main Common Core State Standards for Mathematics (which was can found at http://www.corestandards.org/Math/) that were addressed in the activity.

Table 3.1: Common Core State Standards for Mathematics Address in Activity

Common Core State Standard (CCSS.Math.Content.)	Description of Standard
6.RP.A.3	Use ratio and rate reasoning to solve real-world and mathematical problems
7.NS.A.3	Solve real-world and mathematical problems involving the four operations with rational numbers
8.F.B.5	Describe qualitatively the functional relationship between two quantities by analyzing a graph
8.G.C.9	Know the formulas for the volumes of cones, cylinders, and spheres and use them to solve real-world and mathematical problems
HSN.Q.A.1	Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays
HSA.CED.A.4	Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations
HSA.REI.A.2	Solve simple rational and radical equations in one variable
HSG.GMD.A.3	Use volume formulas for cylinders, pyramids, cones, and spheres to solve problems

HSG.MG.A.1	Use geometric shapes, their measures, and their properties to describe objects

Science Standards

The main science standard that was addressed in this activity was high school Life Science standards 9: Evolution occurs as the heritable characteristic of populations change across generations and can lead populations to become better adapted to their environments. This was addressed during discussion of how surface area to volume ratio connects to how animals evolve to adapt to the environment. These standards can be found at http://www.cde.state.co.us/sites/default/files/documents/coscience/documents/science_hs.pdf.

Standards for Mathematical Practice Addressed

The activity addressed all 8 of the Common Core standards for mathematical practice. These standards include: (1) make sense of problems and persevere in solving them, (2) reason abstractly and quantitatively, (3) construct viable arguments and critique the reasoning of others, (4) model with mathematics, (5) use appropriate tools strategically, (6) attend to precision, (7) look for and make use of structure, and (8) look for and express regularity in repeated reasoning. These standards can be found at http://www.corestandards.org/Math/Practice/.

Data Collection

The data collection for this study was conducted via a 25-question survey, found in Appendix B, given to each of the 18 9^{th} grade students who participated in the integrated mathematics/science activity. The surveys were administered by the assistant principal of the school without their STEM Technology teacher or myself present. Each of the students had approximately 15-20 minutes to complete the survey. The surveys were sent to the assistant principal before the day that they were administered and the assistant principal gave each survey a student code so that I was not given any identifying information about the student but could still match student grades to the survey data.

The first portion of the survey consisted of 15 statements and asked students to rate the extent to which they agreed or disagreed with the statement. The second portion of the survey consisted of 10 writing prompts and the students were asked to respond to each with 1-3 sentences. In both the first and second portion of the survey, the statements and prompts were broken up into 3 categories: statements and prompts about the activity, statements and prompts about their class, and statements and prompts focused on interdisciplinary mathematics and science.

Each of the 25 survey questions was written based on the information gathered from the literature review. Because the surveys were only administered one time to one group of students, a reliability test was not conducted. In order to check the validity of the survey, myself, 2 faculty members at CSU, and 2 administrators at the school in which the survey was administered reviewed the survey. The survey underwent multiple drafts, each informed by the suggestions from the reviewers.

The other data that were collected for analysis with the survey data were the students' fall semester final course grades for their STEM Technology class and the students' spring midterm/current course grades for their STEM Technology class. The assistant principal sent these grades to me in an Excel spreadsheet with the grades attached to the codes that matched the surveys. Student names were never included in the data that were collected.

Research Questions

The research questions for this study were based on the 25-question survey that the students completed at the end of the activity.

1. What is the mean score for each of the 15 Likert scale statements?

For research question 1, Microsoft Excel was used to calculate means for Likert scale responses

2. Is there a statistically significant difference between the 2 levels (above 90%, below 90%) of spring midterm course grades on scores for any of the 15 Likert scale statements?

Because the data for the Likert scale responses were ordinal, a Mann-Whitney U test was performed to determine whether there are statistically significant differences in the way that A students and non-A students responded to these statements

3. Is there a statistically significant association between student achievement in their STEM Technology class and scores for any of the 15 Likert scale statements?

    Sub-questions:

    3a. Are there statistically significant associations between the fall final course grades and scores for any of the 15 Likert scale statements?

    To investigate if there was a statistically significant association between fall final course grades and the data from any one of the 15 Likert scale statements, 15 correlations were computed. Because the data for the Likert scale responses were ordinal, the Spearman rho statistic was calculated for each.

    3b. Are there statistically significant associations between the spring midterm course grades and scores for any of the 15 Likert scale statements?

    To investigate if there was a statistically significant association between spring midterm course grades and the data from any one of the 15 Likert scale statements, 15 correlations were computed. Because the data for the Likert scale responses were ordinal and because the spring midterm course grades were not approximately normally distributed (skewness statistic -1.587), the Spearman rho statistic was calculated for each.

4. Are there statistically significant associations among the scores for the 15 Likert scale statements?

To investigate if there was a statistically significant association between the data from any pair of the 15 Likert scale statement responses, 105 correlations were computed. Because the data for the Likert scale responses were ordinal and because the spring midterm course grades were not approximately normally distributed, the Spearman rho statistic was calculated for each.

5. What are the common themes found in the responses of the open-ended response portion of the survey?

In order to explore the open-ended responses and try to find reoccurring themes, the responses were first read through student by student to examine what each individual student focused on and then were read through prompt by prompt to investigate common themes for each prompt. The per-prompt themes were then examined as a whole to create themes for the entire survey.

CHAPTER 4: RESULTS

This chapter presents results to the 5 research questions posed in chapter 3. Quantitative findings will be shared first, followed by qualitative findings.

Quantitative Results

For research question 1, Microsoft Excel was used to calculate means for Likert scale responses. For questions 2 to 4, the statistical software package SPSS Statistics 18.0 was used to analyze quantitative data.

Research Question 1

The first research question asked what the mean response is for each of the Likert scale statements on the student surveys. Table 4.1 that shows the mean Likert scale response for the entire class. The students were asked to mark the extent to which they agreed or disagreed with each statement. A response of 1 indicated that the student strongly disagreed with the statement, 2 indicated that the student disagreed with the statement, 3 indicated that the student was neutral about the statement, 4 indicated that the student agreed with the statement, and 5 indicated that the student strongly agreed with the statement.

Table 4.1: Mean Likert Scale Responses

Survey Statement	Mean Response
1. This activity helped me to see that mathematics and science are connected in the real world.	4
2. I prefer activities that involve only science topics without other subjects involved.	2.83
3. I prefer activities that involve only mathematics topics without other subject involved.	2.56
4. The math questions in this activity helped me to better understand the science questions.	3.39
5. The science questions in this activity made the math more interesting.	3.82
6. I had to think hard to answer some of the questions in this activity.	4
7. This activity was boring.	2.33

8. I find the projects and activities that I do in this class interesting.	4.11
9. What I learn in my math class will be more helpful in the real world than what I learn in this class.	2.94
10. What I learn in this class will be more helpful in the real world than what I learn in my science class.	2.94
11. The things that I learn in this class are more relevant to my life than the things that I learn in my other classes.	3.22
12. I have the opportunity to be creative in this class more than I do in my other classes.	4.11
13. Mathematics and science topics do not overlap at all in the real world.	1.61
14. I am more motivated to work hard in school when I know that what I am doing has a real-world application.	3.89
15. I am more engaged when technology is involved in my learning.	3.5

The mean response of statement 1 indicates that, on average, the students agreed that the activity showed them that mathematics and science are connected in the real world. The mean responses for statements 2 and 3 indicate that while students feel relatively neutral about activities with only math or only science versus activities with more subjects involved, on average they disagree that they prefer activities involving only math or only science. The mean responses for statements 4 and 5 show that the students felt that the mathematics and the science enriched each other because the mathematics made the science more understandable and the science made the mathematics more interesting. The mean responses for statements 6 and 7 indicate that the some of the questions in the activity made the students think a lot before answering and that the students did not think that the activity was boring.

The mean response for question 8 indicates that the generally students are very interested in the projects they do in their STEM Technology class. Interestingly, the mean responses for statements 9 and 10 show that the students feel close to neutral about whether what they learn in this class will be more helpful to them than what they learn in their math class and science class. The students also felt relatively neutral about whether or not this class is more relevant to their lives than their other classes, shown in the mean responses for statement 11. One of the statements that the students, on average, agreed with the most was that they have the chance to be creative in this class more than they do in their other classes.

The students, on average, did not agree that mathematics and science do not overlap in the real world. For the last two statements students, on average, agreed that they are more motivated to work hard when there is real-world application to what they are learning and that they feel more engaged when technology is used in learning.

Research Question 2

The second research question asked if there is a statistically significant difference between the 2 levels (above 90%, below 90%) of spring midterm course grades on any of the Likert scale responses. For this question, the students who had above 90% on their midterm course grade will be referred to as A students ($N = 11$) and the students who had below 90% on their midterm course grade will be referred to as non-A students ($N = 7$). The levels were broken up in this way because there are only 18 students in the class and the grades were not evenly distributed amongst A, B, C, D, and F. Even dividing this way, there are more students who have above 90% than below 90%. Because the data for the Likert scale responses were ordinal, a Mann-Whitney U test was performed to determine whether there are statistically significant differences in the way that A students and non-A students responded to these statements. Because multiple tests were conducted at once, only differences with a *p*-value of 0.01 or less were considered to be statistically significant.

The only statement in which the differences in responses were statistically significant was statement 14: "I am more motivated to work hard in school when I know that what I am doing has a real-world application." The 7 non-A students had higher mean ranks (13.93) than the 11 A students (6.68) for responses on this statement, $U = 7.5$, $p = 0.003$, $r = -0.69$, which according to Cohen (1988) is a much larger than typical effect size. This indicates that the non-A students more than the A students agreed that they are more motivated to work hard in school when they know that what are doing has real-world application. For the 14 remaining Likert scale statements, there was no statistically significant difference between the responses of the A students and the non-A students.

Research Question 3

This research questions asked if there are statistically significant associations between fall final course grades and any of the 15 Likert scale responses or between the spring midterm course grades and any of the 15 Likert scale responses. To investigate if there was a statistically significant association between fall final course grades and the data from any one of the 15 Likert scale statements, 15 correlations were computed. Because the data for the Likert scale responses were ordinal, the Spearman rho statistic was calculated for each. Because multiple correlations were conducted simultaneously, associations were only considered to be statistically significant with a *p*-value of 0.01 or less. There were no statistically significant associations using the adjusted *p*-value.

To investigate if there was a statistically significant association between spring midterm course grades and the data from any one of the 15 Likert scale statements, 15 correlations were computed. Because the data for the Likert scale responses were ordinal and because the spring midterm course grades were not approximately normally distributed (skewness statistic -1.587), the Spearman rho statistic was calculated for each. Using a *p*-value of 0.01 for significance, statistically significant associations were found between spring midterm course grades and statement 13 ($r(16) = .585$, $p = 0.017$) and spring midterm course grades and statement 14 ($r(16) = -.589$, $p = 0.016$). The association with statement 13 means that the more students tended to agree with the statement "Mathematics and science topics do not overlap at all in the real world", the higher their spring midterm course grades tended to be. This could possibly be to do the reversed wording of the statement. The association with statement 14 indicates that the more that students agreed with the statement "I am more motivated to work hard in school when I know that what I am doing has a real-world application", the lower their spring midterm grades tended to be.

Research Question 4

This research question asked if there are any statistically significant associations among the 15 Likert scale scores. To investigate if there was a statistically significant association between the data from any pair of the 15 Likert scale statement responses, 105 correlations were computed. Because the data for the Likert scale responses were ordinal and because the spring midterm course grades were not approximately normally distributed, the Spearman rho statistic was calculated for each. Because numerous correlations were run at once, the only correlations considered to be statically significant are those with a *p*-value of less than 0.01. Table 4.2 shows both the Likert scale statement responses that had statistically significant associations at the adjusted 0.01 *p*-value and the Likert scale statement responses that had statistically significant associations at the traditional 0.05 *p*-value.

Table 4.2: Statistically Significant Associations Between Likert Scale Statement Responses

<table>
<tr><th>Statement</th><th>Correlated With</th><th>Spearman Rho Statistic</th><th>Effect Size</th></tr>
<tr><td rowspan="5">1. This activity helped me to see that mathematics and science are connected in the real world.</td><td>Statement 3</td><td>$r(16) = -.5, p = 0.039$</td><td>Larger than typical</td></tr>
<tr><td>Statement 4</td><td>$r(16) = .66, p = 0.006$</td><td>Larger than typical</td></tr>
<tr><td>Statement 5</td><td>$r(16) = .76, p = 0.001$</td><td>Much larger than typical</td></tr>
<tr><td>Statement 7</td><td>$r(16) = -.8, p < 0.001$</td><td>Much larger than typical</td></tr>
<tr><td>Statement 11</td><td>$r(16) = .57, p = 0.021$</td><td>Larger than typical</td></tr>
<tr><td>2. I prefer activities that involve only science topics without other subjects</td><td>Statement 3</td><td>$r(16) = .54, p = 0.030$</td><td>Larger than typical</td></tr>
</table>

involved.			
3. I prefer activities that involve only mathematics topics without other subject involved.	Statement 1	$r(16) = -.5, p = 0.039$	Larger than typical
	Statement 2	$r(16) = .54, p = 0.030$	Larger than typical
	Statement 7	$r(16) = .62, p = 0.011$	Larger than typical
	Statement 8	$r(16) = -.6, p = 0.014$	Larger than typical
4. The math questions in this activity helped me to better understand the science questions.	Statement 1	$r(16) = .66, p = 0.006$	Larger than typical
	Statement 5	$r(16) = .61, p = 0.011$	Larger than typical
	Statement 6	$r(16) = .56, p = 0.023$	Larger than typical
	Statement 7	$r(16) = -.65, p = 0.006$	Larger than typical
	Statement 10	$r(16) = .58, p = 0.019$	Larger than typical
	Statement 11	$r(16) = .55, p = 0.028$	Larger than typical
5. The science questions in this activity made the math more interesting.	Statement 1	$r(16) = .76, p = 0.001$	Much larger than typical
	Statement 4	$r(16) = .61, p = 0.011$	Larger than typical
	Statement 7	$r(16) = -.9, p < 0.001$	Much larger than typical
	Statement 9	$r(16) = -.53, p = 0.035$	Larger than typical
	Statement 11	$r(16) = .5, p = 0.048$	Larger than typical
6. I had to think hard to answer some of the questions in this activity.	Statement 4	$r(16) = .56, p = 0.023$	Larger than typical
7. This activity was boring.	Statement 1	$r(16) = -.8, p < 0.001$	Much larger than typical
	Statement 3	$r(16) = .62, p = 0.011$	Larger than typical
	Statement 4	$r(16) = -.65, p = 0.006$	Larger than typical
	Statement 5	$r(16) = -.9, p < 0.001$	Much larger than typical
	Statement 11	$r(16) = -.53, p = 0.032$	Larger than typical
8. I find the projects and activities that I do in this class interesting.	Statement 3	$r(16) = -.6, p = 0.014$	Larger than typical
	Statement 10	$r(16) = .5, p = 0.048$	Larger than typical
9. What I learn in my math class will be more helpful in the real world than what I learn in this class.	Statement 5	$r(16) = -.53, p = 0.035$	Larger than typical
	Statement 11	$r(16) = -.56, p = 0.024$	Larger than typical
10. What I learn in this class will be more helpful in the real world than what I learn in my science class.	Statement 4	$r(16) = .58, p = 0.019$	Larger than typical
	Statement 8	$r(16) = .5, p = 0.048$	Larger than typical
	Statement 11	$r(16) = .68, p = 0.004$	Larger than typical
11. The things that I learn in this class are more relevant to my life than the things that I learn in my other classes.	Statement 1	$r(16) = .57, p = 0.021$	Larger than typical
	Statement 4	$r(16) = .55, p = 0.028$	Larger than typical
	Statement 5	$r(16) = .5, p = 0.048$	Larger than typical
	Statement 7	$r(16) = -.53, p = 0.032$	Larger than typical
	Statement 9	$r(16) = -.56, p = 0.024$	Larger than typical
	Statement 10	$r(16) = .68, p = 0.004$	Larger than typical
	Statement 12	$r(16) = .63, p = 0.009$	Larger than typical

12. I have the opportunity to be creative in this class more than I do in my other classes.	Statement 11	$r(16) = .63, p = 0.009$	Larger than typical
13. Mathematics and science topics do not overlap at all in the real world.	Statement 14	$r(16) = -.7, p = 0.002$	Much larger than typical
14. I am more motivated to work hard in school when I know that what I am doing has a real-world application.	Statement 13	$r(16) = -.7, p = 0.002$	Much larger than typical
15. I am more engaged when technology is involved in my learning.	N/A	N/A	N/A

Statement 1 had a statistically significant association with statements 4, 5, and 7. Statement 1's association with statement 4 indicates that the more that students agreed with the statement that the activity helped them to see the connection that mathematics and science have in the real world, the more they tended to agree that the math questions helped them to better understand the science questions. Statement 1's association with statement 5 indicates that the more that students agreed with the statement that the activity helped them to see the connection that mathematics and science have in the real world, the more they tended to agree that the science questions made the math questions more interesting. Statement 1's association with statement 7 indicates that the more that students agreed with the statement that the activity helped them to see the connection that mathematics and science have in the real world, the more they tended to disagree with the statement that the activity was boring.

In addition to having a statistically significant association with statement 1, statement 4 also had a statistically significant association with statement 7. Statement 4's association with statement 7 indicates that the more that students agreed with the statement that that math questions in the activity helped them to better understand the science questions, the more they tended to disagree that the activity was boring.

In addition to having statistically significant associations with statement 1, statement 5 also had statistically significant associations with statement 7. Statement 5's association with statement 7 indicates that the more that students agreed with the statement that the science questions in the activity made the math questions more interesting, the more they tended to disagree with the statement that the activity was boring.

Statement 10 had a statistically significant association with statement 11. This means that the more that students agreed with the statement that what they learn in their STEM Technology class will be more helpful in the real world than what they learn in their science class, the more the students tended to agree with the statement that the things that they learn in their STEM Technology class are more relevant to their lives than the things that they learn in their other classes.

In addition to having statistically significant associations with statement 10, statement 11 also had a statistically significant association with statement 12. This statistic indicates that the more that students agreed with the statement that what they learn in their STEM Technology class is more relevant to their lives than the things that they learn in their other classes, the more that they tended to agree with the statement that the have more opportunity to be creative in their STEM Technology class than they do in their other classes.

Statement 13 had a statistically significant association with statement 14. This means that the more that students agreed with the statement that mathematics and science topics do not overlap at all in the real world, the more the students tended to disagree with the statement that they are more motivated to work hard in school when they know that what they are doing has a real-world application.

Qualitative Results

In order to explore the open-ended responses and try to find reoccurring themes, the responses were first read through student by student to examine what each individual student focused on and then were read through prompt by prompt to investigate common themes for each prompt. The per-prompt themes were then examined as a whole to create themes for the entire survey.

Research Question 5

This research question asked what are the common themes found through the open-ended, written response portion of the student surveys. The 5 main themes that were discussed by many students throughout the open-ended response portion of the survey were collaboration, creativity, open-ended projects, hands-on activities, and connections between subjects and to the real world.

Collaboration

For 3 out of the first 7 written response prompts, collaboration was brought up by many of the students. The first prompt in which this theme was present was in discussing what their favorite things about the activity were. Three of the 18 students who answered this prompt mentioned that working in groups and collaborating with others was one of their favorite things about the activity. The second prompt in which this theme appeared was in discussing what they enjoy about their STEM Technology class where 2 of the students mentioned that working with people, sharing ideas, and communicating were among their favorite things. Interestingly, the last prompt in which this theme was apparent was in discussing what was challenging about their

STEM Technology class. One of the students who mentioned that working with people was one of the things they enjoyed about the class said that communicating with partners was one of the things that they found challenging about the class. Other students who brought up collaboration said that it was challenging "working with unworthy partners" and it was challenging "expressing my opinions without making people mad."

Creativity

While the creativity theme was only apparent in responses to the prompt about what they enjoy about their STEM Technology class, creativity and/or free thinking was mentioned by 7 of the 18 students. Many of the students mentioned that they can be more creative in their STEM Technology class than they can in their other classes while some other students claimed that the projects in their STEM Technology class allow them to "think outside of the box" and become more free and independent thinkers. This may stem from most of their projects being open-ended.

Open-ended Projects

On 2 of the first 7 prompts, many students mentioned the open-endedness of the projects that they do in class. For the prompt about what they enjoy about their STEM Technology class, 5 of the 18 students who responded said that they enjoyed that the projects were fairly open-ended, that they could explore the topics, and that they were able to take them in the direction that they wanted to. The students also discussed open-ended projects for the writing prompt about how their STEM Technology class is different from their other classes. Four of the 16 students who answered this prompt discussed that this class is different from their other classes in that it's more open-ended and they have more freedom to learn about what they are interested in.

Hands-on Activities

The students also enjoy that the projects in their STEM Technology class are very hands-on. This theme was discussed in 4 out of the first 7 prompts in the open-ended response portion of the survey. This was first discussed when students wrote about their favorite parts of the activity. Twelve of the 18 students either explicitly stated that they liked that the activity was hands-on while others said that their favorite part was "actually doing the experiment" or "experimenting and examining the color changing paper." When asked about what they disliked about the activity, 3 of the students said that the wished that it was even more hands-on. Four out of 18 students said that they liked the hands-on projects when discussing what they enjoy about their STEM Technology class. Hands-on projects also came up when the students were asked to explain how their STEM Technology class is different from their other classes.

Real-world Applications and Connections Between Subjects

For most of the writing prompts, many of the students mentioned real-world applications and connections between subjects. This theme was apparent in the prompt about their favorite parts of the activity, the challenging parts of the activity, what they learned most by doing the activity, what they enjoy about their STEM Technology class, what they find challenging about their STEM Technology class, how their STEM Technology class is different than their other classes, and more. Seven of the 18 students claimed that either the real-world application or seeing the connections between mathematics and science was their favorite part of the activity while 5 of the 18 students (1 from the 7 who said it was their favorite part) said that trying to think of real-world applications was one of the challenging parts of the activity. When asked what they learned most by doing the activity, 11 of the 18 students included something about real-world applications or connections between mathematics and science in their response.

Examples of this are: “What I learned most by doing this activity was that math really does play a big role in science”, “What I learned most by doing this activity was how math and science are relevant to our daily lives”, and “What I learned most by doing this activity was how the ratio of surface area and volume applies to the real world.” In writing about their STEM Technology class, 2 out of 15 students said that applying it to the real world is what they find challenging about the class and 11 out of 15 students said that their STEM Technology class is different from their other classes because they use more than one topic at a time. Some examples of this include: “This class is different than my other (one-subject) classes because I can use all of my knowledge form other classes in here” and “This class is different than my other (one-subject) classes because there is a whole mix of different things being taught at once, but in a relevant manner.”

In addition to the responses that fit into one of those themes, the students gave many other interesting responses for the first 7 prompts. Some students really enjoyed the technology and group computer work that was used in the activity while other students stated that doing the computer work was one of the things that they disliked about the activity because it made the activity more boring. Many of the students said that they didn’t like having to do the math for the activity, although some still admitted that the math was helpful in understanding the overarching concept. Some students said that they felt like they needed more time to think about and answer the questions during the activity while others said that they were done early and had to wait for the rest of the class to finish.

The last 3 writing prompts on the open-ended portion of the survey were about the connections between mathematics and science and also yielded interesting responses. Prompt 8 asked students to decide if they think that math and science should be taught completely separately, sometimes separately and sometimes together, or always together. The only students who thought that they should be taught completely separately said, “they go hand in hand but the pace is completely different. For example, biology doesn’t go with a certain math class.” This is interesting because while the student recognizes that the two disciplines are strongly connected, he/she also realizes that it would be difficult to fully integrate them because of the current sequencing of mathematics and science classes. Eleven of the 15 students who responded said that math and science should be taught sometimes separately and sometimes together for reasons such as: “it is good to have an understanding of each subject so it is easier to apply them to each other”, “it makes the class more interesting”, and “some things that we do in science makes more sense when they are done with math.” Three of the 15 students believe that mathematics and science should always be taught together because “science and math speak for each other.”

For prompt 9, students were asked to explain how science and math are similar. The responses could be categorized into 3 categories: basics (formulas, data, etc.), using one in the other, and role in the world. Six of the 15 students who responded to this prompt said that math and science are similar because they use the same formulas, equations, and calculations. Seven of the 15 students mentioned something about how you can’t have one without the other or how they can be used together. In 3 of the 15 student responses, the role that science and math play in the world was discussed (or simply stated).

Prompt 10 is one that I believe was confusing for students because it is very similar to prompt 9. While prompt 9 asks about similarities between math and science, prompt 10 asks students whether or not they think that the learning of math and the learning of science are similar and why. I don’t think that many students noticed this subtlety. Most of the students agreed that the learning of science and the learning of mathematics are similar but for the most part did not mention anything about learning in their reasoning. Interestingly, the 2 students who believed that the learning of science and the learning of math are not similar did give reasons having to do with learning such as: “Math is set in stone on how you do it. There is typically one or two ways to efficiently get an answer. Science is more just problem solving and figuring things out” and “Math is a more textbook and curriculum taught class rather than science which is a hands on activity.”

CHAPTER 5: DISCUSSION, CONCLUSIONS, AND RECOMMENDATIONS

This chapter provides a discussion of some of the interesting results presented in chapter 4 as well as recommendations for educators who are interested in using an interdisciplinary approach.

Research Question 1

The first research question asked what the mean response is for each of the Likert scale statements on the student surveys. The students were asked to mark the extent to which they agreed or disagreed with each statement. A response of 1 indicated that the student strongly disagreed with the statement, 2 indicated that the student disagreed with the statement, 3 indicated that the student was neutral about the statement, 4 indicated that the student agreed with the statement, and 5 indicated that the student strongly agreed with the statement.

The mean response for the first Likert scale statement was a 4. This means that, on average, the students agreed that the activity helped them see the connections between mathematics and science in the real world. One of the main goals of integrated mathematics curriculum is to help students see the connection that mathematics has to other fields and how it applies to the real world. This result shows that this goal was accomplished with the activity. The mean response for statement 13 also gives evidence that students see the connection between science and mathematics in the real world because, on average, students disagreed with the statement that mathematics and science topics do not overlap at all in the real world. Another goal of integrated mathematics/science curriculum is to help students develop their critical thinking and problem solving skills. The mean response for the sixth statement was also a 4, which shows that students felt like they were pushed to think hard and discuss with their partners to answer the questions and they had to use their critical thinking and problem solving skills.

Another interesting result was that students, on average, agreed with the statements that the math questions helped them to better understand the science questions and that the science questions made the math questions more interesting. Each of these factors is discussed as a reason for integration in much of the literature surrounding the integration of mathematics and science. Mathematics content and science content are strongly related and each discipline enriches the other when the two are integrated. The students confirmed this in the way they responded to these 2 statements.

Students agreed with the statement that they find the projects and activities that they do in their STEM Technology class interesting, evidenced by a mean response of 4.11 on statement 8. In the STEM Technology class, students work on open-ended projects revolving around technology that is used in the real world. The mean responses on statements 12, 14, and 15, which were 4.11, 3.89, and 3.5 respectively, may give insight into why the students really enjoy the class activities. The mean response for statement 12 shows that students feel that they have more opportunity to be creative in their STEM Technology class than they do in their other classes. The mean response for statement 14 shows that students are more motivated to work hard in school when they know that what they are doing has a real-world application. The mean response for statement 15 shows that, on average, the students are more engaged when technology is involved in their learning. These 3 statements directly relate to how the class is conducted so it makes sense that if the students agree with statements 12, 14, and 15 then they most likely enjoy their STEM Technology class.

Research Question 2

The second research question asked if there is a statistically significant difference between the 2 levels (above 90%, below 90%) of spring midterm course grades on any of the Likert scale responses. The only statement in which the differences in responses were statistically significant was statement 14: "I am more motivated to work hard in school when I know that what I am doing has a real-world application." The non-A students had higher mean ranks than the A students did for responses on this statement, $U = 7.5$, $p = 0.003$, $r = -0.69$, which according to Cohen (1988) is a much larger than typical effect size. This indicates that the non-A students more than the A students agreed that they are more motivated to work hard in school when they know that what are doing has real-world application. This could be because non-A students and A students are motivated differently. The A students may have more intrinsic motivation to perform well in school regardless of the content and instruction whereas non-A students may need more extrinsic motivation to work hard such as knowing that what they are doing applies to the real world.

Research Question 4

This research question asked if there are any statistically significant associations among the 15 Likert scale scores. The correlations between statement 1 and statements 4 and 5 indicate that the more that the activity helped the students recognize the connections between mathematics and science in the real world, the more they also recognized how mathematics and science enriched each other in the activity. If the students felt that the mathematics questions helped them to better understand the science questions and that the science questions made the mathematics questions more interesting, it makes sense that this activity helped them to realize the connection between mathematics and science.

The correlations between statement 7 and statements 1, 4, and 5 were some of the most important results from this study. These correlations indicate that the more the students could see the connection between mathematics and science and the more they felt that the two disciplines enriched each other in the activity, the less they thought that the activity was boring. This set of correlations provides evidence that using an integrated approach can be beneficial to students. The less engaged students are in the classroom, the less motivated they will be to participate and to put effort into learning. These results show that integrating mathematics and science is one way to provide an engaging lesson.

Statements 11's correlations with statement 10 indicates that the more they felt that their STEM Technology class was more relevant to their lives than their other classes, the more they felt that what they learn in their STEM Technology class will be more helpful in the real world than what they learn in their science class. One possible interpretation for this correlation is that students perceive things that will be helpful in the real world as being relevant to their lives. Interestingly, there was not a statistically significant correlation between feeling that the STEM Technology class was more relevant to their lives than their other classes and feeling that what they learn in their math class will be more helpful in the real world than what they learn in their STEM Technology class. Statement 11's correlation with statement 12 indicates that that the more they felt that their STEM Technology class was more relevant to their lives than their other classes, the more they felt that they had more opportunity to be creative in their STEM Technology class than in their other classes. This correlation could indicate that having more opportunities to be creative in class promotes a feeling that the material is relevant to their lives.

Connections Between Quantitative and Qualitative Findings

The 5 main themes that were discussed by many students throughout the open-ended response portion of the survey were collaboration, creativity, open-ended projects, hands-on activities, and connections between subjects and to the real world. Not surprisingly, the themes that were found in the student responses were ones that were also highly emphasized throughout the literature on integration.

Although collaboration was not addressed in the Likert scale statements, student collaboration was given as a reason for integration many times throughout the literature. An interdisciplinary approach can promote meaningful discourse and collaboration between students and help students to develop social and communication skills. While some of the students found collaboration to be challenging in their STEM Technology class, some of the same students and many additional students also claimed that group work and collaboration were among their favorite things both for the activity and for their class.

Creativity was addressed in the Likert scale statements and is also emphasized throughout the literature. I believe that this theme and the open-ended projects theme are tied very closely to one another. Many students mentioned that creativity and getting to think outside the box as well as participating in open-ended projects and taking the projects their own direction were among their favorite things about their STEM Technology class. This is one of the beautiful things about interdisciplinary curriculum. This approach gives students more freedom to be creative and suit their projects to their own interests while thinking critically and solving problems in doing so. Evidenced by the scores on the Likert scale statement about creativity and the responses on the open-ended response prompt about how their STEM Technology differs from their other classes, it is clear that students don't feel the same way in their one-subject courses.

While hands-on activities were not addressed in the Likert scale statements, discussion of this theme is worthwhile because of the amount of students who mentioned it in the open-ended response portion of the survey. Students mentioned this theme in discussing their favorite things about the activity, their favorite things about their class, and in discussing how their STEM Technology class is different from their other classes. This theme is also apparent throughout the literature on integration where it is discussed as a benefit for students. Interdisciplinary curriculum can provide students with many opportunities to engage in hands-on activities, which are clearly liked by the students according to their responses to the survey.

Perhaps the most unsurprising theme that was found in the written responses was discussion of real-world application and connections between subjects. This theme was apparent in the prompts about their favorite parts of the activity, the challenging parts of the activity, what they learned most by doing the activity, what they enjoy about their STEM Technology class, what they find challenging about their STEM Technology class, how their STEM Technology class is different than their other classes, and more. It is apparent in the written responses that students enjoy being able to see how disciplines are connected to each other and to the real world. This is also evidenced by the response to the Likert scale statement about having more motivation when real-world applications are involved.

The most interesting responses to the last 3 written response prompts were those for prompt 8: "(*Choose a, b, or c and then explain*) If I could choose, mathematics and science would be taught (a) complete separately, (b) sometimes together and sometimes separately, (c) always together because…" Most of the students answered with b and only a few answered with either a or c. This finding was interesting because of the reasons that students gave for choosing a, b, or c. Most of the students seem to understand that while integrating mathematics with science has many benefits, there are also challenges associated with it. For example, one student mentioned that math and science “go hand in hand but the pace is completely different”. This student went on to give the example that biology wouldn’t go with one certain math class. This shows that student realizes that the sequencing and scope of math and science classes can make full integration challenging. Another student mentioned that, “it is good to have an understanding of each subject so it is easier to apply them to each other”. This is also discussed in several articles about integration.

Considerations and Recommendations

While using an interdisciplinary approach to teaching is beneficial to students in numerous ways, there are several important things to consider before jumping in. For one, integration should only be used when it will result in more meaningful learning for the students in each content area that is being integrated. Integrating just for the sake of integrating may not yield the same benefits for students. If integration would be meaningful, then the topics being integrated should be grounded in the curriculum. This does not mean that every activity must directly relate to a curriculum standard but that the overall theme or goal should. I would also recommend that an educator who wants to try using an integrated approach in their classroom should start small by first trying an integrated activity. This will allow the educator to see what works well, what does not work well, how the students respond to integration before attempting to develop an entire integrated unit.

The teacher interviews provided an abundance of information important in making recommendations to other educators. One of the biggest recommendations that the teachers had for other educators is that it takes more than one teacher to implement an integrated course. Teaching an integrated course requires a tremendous amount of collaboration and is incredibly time consuming. Because this approach requires a deep level of collaboration, co-teaching will be much easier if collaborators have compatible personalities, work ethics, educational goals, and teaching philosophies. This type of approach to education requires many resources, one being administrative support. Some other resources important for using this approach are funding, equipment, and professional development. External sources of funding such as grants are often needed to be able to participate in professional development and to be able to purchase classroom supplies and equipment.

While the literature review and the teacher interviews each provided valuable information, engaging in the process of developing and implementing an integrated activity was necessary to be able to make my own recommendations for other educators. For my activity, it was extremely helpful to build off of and modify an existing activity. In implementing an integrated approach, there is no need to reinvent the wheel. There are plenty of existing resources available to get the process started. When it comes to creating or modifying an activity, it’s helpful to decide beforehand how integration is going to occur. My activity was fairly sequential in that the students were either doing math or science each day, not necessarily both. Lastly, because mathematics and science have so much content overlap the possibilities for integration are endless. For this reason, it can be difficult to stick to one topic for an activity so I would suggest starting out by picking a very narrow topic.

REFERENCES

Basista, B., & Mathews, S. (2002). Integrated science and mathematics professional development programs. *School Science and Mathematics*, *102*(7), 359-370.

Beane, J. A. (1995). Curriculum integration and the disciplines of knowledge. *Phi Delta Kappan*, 616-622.

Beane, J. (1996). On the Shoulders of Giants! The Case for Curriculum Integration. *Middle School Journal*, *28*(1), 6-11.

Berlin, D. F., & White, A. L. (1994). The Berlin-White integrated science and mathematics model. *School Science and Mathematics*, *94*(1), 2-4.

Berlin, D. F., & Lee, H. (2005). Integrating science and mathematics education: Historical analysis. *School Science and Mathematics*, *105*(1), 15-24.

Bossé, M. J., Lee, T. D., Swinson, M., & Faulconer, J. (2010). The NCTM process standards and the five Es of science: Connecting math and science. *School science and mathematics*, *110*(5), 262-276.

Bragaw, D., Bragaw, K. A., & Smith, E. (1995). Back to the Future: Toward Curriculum Integration. *Middle School Journal*, *27*(2), 39-46.

Colorado Department of Education (2009). *Colorado Academic Standards (Science)*. Retrieved from http://www.cde.state.co.us/sites/default/files/documents/coscience/documents/science_standards_adopted_2009.pdf.

Czerniak, C. M., Weber, W. B., Sandmann, A., & Ahern, J. (1999). A literature review of science and mathematics integration. *School Science and Mathematics*, *99*(8), 421-430.

Davison, D. M., Miller, K. W., & Metheny, D. L. (1995). What does integration of science and mathematics really mean?. *School science and mathematics*, *95*(5), 226-230.

Elliott, B., Oty, K., McArthur, J., & Clark, B. (2001). The effect of an interdisciplinary algebra/science course on students' problem solving skills, critical thinking skills and attitudes towards mathematics. *International Journal of Mathematical Education in Science and Technology*, *32*(6), 811-816.

Furner, J. M., & Kumar, D. D. (2007). The mathematics and science integration argument: A stand for teacher education. *Eurasia Journal of Mathematics, Science & Technology Education*, *3*(3), 185-189.

Gardner, H., & Boix-Mansilla, V. (1994). Teaching for understanding-within and across the disciplines. *Educational Leadership*, *51*, 14-14.

George, P. S. (1996). The Integrated Curriculum: A Reality Check. *Middle School Journal*, *28*(1), 12-19.

Huntley, M. A. (1998). Design and implementation of a framework for defining integrated mathematics and science education. *School Science and Mathematics*, *98*(6), 320-327.

Hurley, M. M. (2001). Reviewing integrated science and mathematics: The search for evidence and definitions from new perspectives. *School Science and Mathematics*, *101*(5), 259-268.

Koirala, H. P., & Bowman, J. K. (2003). Preparing middle level preservice teachers to integrate mathematics and science: Problems and possibilities. *School Science and Mathematics*, *103*(3), 145-154.

Lederman, N. G. and Niess, M. L. (1997), EDITORIAL. School Science and Mathematics, 97: 57–58. doi: 10.1111/j.1949-8594.1997.tb17342.x

Lonning, R. A., DeFranco, T. C., & Weinland, T. P. (1998). Development of theme-based, interdisciplinary, integrated curriculum: a theoretical model. *School Science and Mathematics*, *98*(6), 312-319.

Lonning, R. A., & DeFranco, T. C. (1997). Integration of science and mathematics: A theoretical model. *School Science and Mathematics*, *97*(4), 212-215.

Mason, T. C. (1996). Integrated curricula: Potential and problems. *Journal of teacher education*, *47*(4), 263-270.

McBride, J. W., & Silverman, F. L. (1991). Integrating elementary/middle school science and mathematics. *School Science and Mathematics*, *91*(7), 285-292.

McDonald, J., & Czerniak, C. (1994). Developing interdisciplinary units: Strategies and examples. *School Science and Mathematics*, *94*, 5-10.

Meier, S. L., Hovde, R. L., & Meier, R. L. (1996). Problem solving: Teachers' perceptions, content area models, and interdisciplinary connections. *School Science and Mathematics*, *96*(5), 230-237.

Morgan, G. A., Leech, N. L., Gloeckner, G. W., & Barrett, K. C. (2013). *IBM SPSS for Introductory Statistics: Use and Interpretation* (5th ed.). New York, NY: Taylor & Francis.

National Governors Association Center for Best Practices, & Council of Chief State School Officers (2010). *Common Core State Standards (Mathematics)*. Retrieved from http://www.corestandards.org/Math/.

Niess, M. L. (2005). Preparing teachers to teach science and mathematics with technology: Developing a technology pedagogical content knowledge. *Teaching and teacher education*, *21*(5), 509-523.

Pang, J., & Good, R. (2000). A review of the integration of science and mathematics: Implications for further research. *School Science and Mathematics*, *100*(2), 73-82.

Roebuck, K. I., & Warden, M. A. (1998). Searching for the Center on the Mathematics-Science Continuum. *School Science and Mathematics*, *98*(6), 328-333.

Roth, K. J. (1994). Second thoughts about interdisciplinary studies. *American Educator*, *18*(1), 44-48.

Stinson, K., Harkness, S. S., Meyer, H., & Stallworth, J. (2009). Mathematics and science integration: Models and characterizations. *School Science and Mathematics*, *109*(3), 153-161.

Stohlmann, M., Moore, T. J., McClelland, J., & Roehrig, G. H. (2011). Impressions of a middle grades STEM integration program. *Middle School Journal*, *43*(1), 32.

Venville, G., Wallace, J., Rennie, L. J., & Malone, J. (1998). The Integration of Science, Mathematics, and Technology in a Discipline-Based Culture. *School Science and Mathematics*, *98*(6), 294-302.

APPENDIX A: ACTIVITY WITH SELECTED STUDENT RESPONSES

Day 1

1. Familiarize yourself with the MELC (micro encapsulated liquid crystal) sheet. Does the color change when you place your finger on it? Why or why not? What happens if you place the MELC sheet on top of your hand?

-Student Response: Yes, our fingers are warmer. Only a strip changes color when we put it on top of our hands.

-Student Response: Yes, it turns dark blue where we touched. The heat seems to turn it blue. When you place it on your hand, the entire sheet turns a dark royal blue.

-Student Response: Yes, because our body temperature is different from the MELC sheet. The sheet becomes warmer (dark blue).

2. Using the pipets, place a drop of the warm water and a drop of the cool water on the MELC (do not let the two drops touch). One partner should place the drops while the other partner videotapes the drops changing colors. Type your observations about the color changes that you see.

-Student Response: Cold water: When the water touched the sheet, it turned black, and spread to about 2 mm from the water. Followed by the black, there was a ring of red. Followed by a ring of light green that turned into turquoise.

Hot water: When the water touched the sheet, it turned the sheet (that was around it) a dark blue, but soon after it faded into a turquoise. But changed into a light green, but after a couple seconds, changes back to turquoise.

-Student Response: The hot water changed the MELC the slowest while the cold water was instantaneous. After dropped, the cold water was a maroon color and it had green and blue rings around it, whereas the warm went directly to the same dark blue color we previously observed. After the warm water changed color it cooled down and became the same color as the cold water droplet.

-Student Response: The darker color represented the warmer water. The lighter colors indicated colder water.

3. Dry off the MELC, then place 2 drops of the warm water, one large and one small, on the MELC. Try not to let much time pass between placing the drops on the sheet. Again, one partner should place the drops while the other partner videotapes the drops changing colors. Compare and contrast the color changes between the small drop and the large drop (example: which one returns to the original color faster?).

-Student Response: The big drop changed color the fastest but it took longer to reach the original color. The small drop of water didn't really change color as much or as fast but cooled off sooner.

-Student Response: They both immediately turned colors to dark blue. The small drop cooled quickly to a greenish-yellow. The larger drop took longer and eventually started to turn to green around the edges.

-Student Response: Small drop: Started as a dark blue spot, then it turned to a light green. It turned red next, but changed to black with a ring of red, followed by a ring of light green. Which faded into turquoise (starting color).

Large drop: Has a big black spot in the center of drop. Then turned into blue, to a light green. Then from the center out, it turned to turquoise (starting color). Turn red from the edges to the center (rusty red). Then, turned black with the same color rings as the small drop. The small drop changed back to the originally color fist.

4. Discuss with your partner why you think that one of the drop sizes returns to the original color faster than the other drop size. Type your thoughts about this below.

-Student Response: The small drop doesn't have as much water molecules to cool as the big one does so the small one cools faster.

-Student Response: The smaller one returned to the original color faster because it has less mass to return to the temperature of the air around it.

-Student Response: With less volume, the smaller drop is able to cool faster because the heat has less surface area to go through.

5. On the sheet protector (with the ruler inside), line up a very small drop, a medium-sized drop, and a large drop next to each other using the pipet. Take a clear, close-up photo of the side view of these drops. Compare and contrast the shape of the very small drops with the shape of the large drops.

-Student Response: The larger drops had a higher dome because they had more surface tension. the smallest one was still something like a half sphere.

-Student Response: The smaller ones are more spherical compared to the larger ones. The smaller ones have less volume allowing surface tension to better keep them together compared to the larger.

6. At what diameter do you think that a drop best represents a perfect hemisphere?

-Student Response: The smaller the circle the better the hemisphere.

-Student Response: It always wants to be a circle considering water wants to take up the least amount of surface area (which a circle/ sphere accomplishes). The perfect circle stops at around a millimeter or two though.

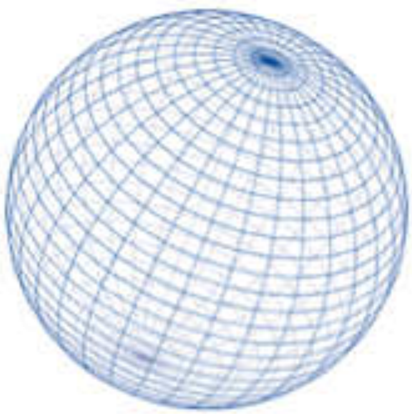
-Student Response: A diameter between 1 and 2 millimeters.

Day 2

Form 1

Volume and Surface Area of a Sphere are below (you'll need these!)

Note: In this activity, we are assuming that the drops are perfect hemispheres, although in reality they are not perfect.



$$SA = 4\pi r^2$$
$$V = \frac{4}{3}\pi r^3$$

Figure AA.1: Formulas for Surface Area and Volume of Sphere

1. Using the formula above for surface area of a sphere, come up with a formula for the surface area of a hemisphere. How did you come up with your formula?

-Student Response: Divide the formula of a sphere by two. This is because a hemisphere is half of a sphere. You also have to include the surface area of the flat part. This is added to the equation after it is divided by two.

-Student Response: SA of Hemisphere=((4πr^2)/2)+(SA of flat circular base) The hemisphere has a flat base under it that the sphere does not, so despite it being halved, it will have more surface area.

2. Using the formula above for volume of a sphere, come up with a formula for the volume of a hemisphere. How did you come up with your formula?

-Student Response: Divide it by two. A hemisphere is half of a sphere

-Student Response: We came up with V/2 because the volume of a sphere is twice as much as a hemisphere so just cut the sphere in half.

3. Surface Area to Volume ratio is a very important concept in Biology. How can we calculate this ratio?

    -Divide the volume of an object by its surface area

    -Divide the surface area of an object by its volume

    -Other

4. Will the surface area to volume ratio of a sphere be the same as the surface area to volume ratio of a hemisphere? Explain.

-Student Response: No because they are not similar. Ratio of similarity only works with similar shapes.

-Student Response: No, because the base circle is included in the hemisphere, so they are not proportional. By subtracting the base in the SA, then they are proportional.

-Student Response: No they won't be. Initially, they would, but if you add in the part of the hemisphere that is laying flat, then they're not.

5. What about if we don't include the part of the hemisphere that is laying flat as part of the surface area? Explain.

-Student Response: Yes the ratio would be the same because your just cutting everything in half.

-Student Response: They will be proportional ratios. For example, if you have SA/V of hemisphere, then by multiplying the ratio by two, you will get the ratio of sphere.

Form 2

6. Ms. Gentry will assign you and your partner to fill in a section of the Google Sheet. You need to calculate the surface area, the volume, and the surface area to volume ratio of a hemisphere for the radius that you are assigned to. You can round to 2 decimal places.

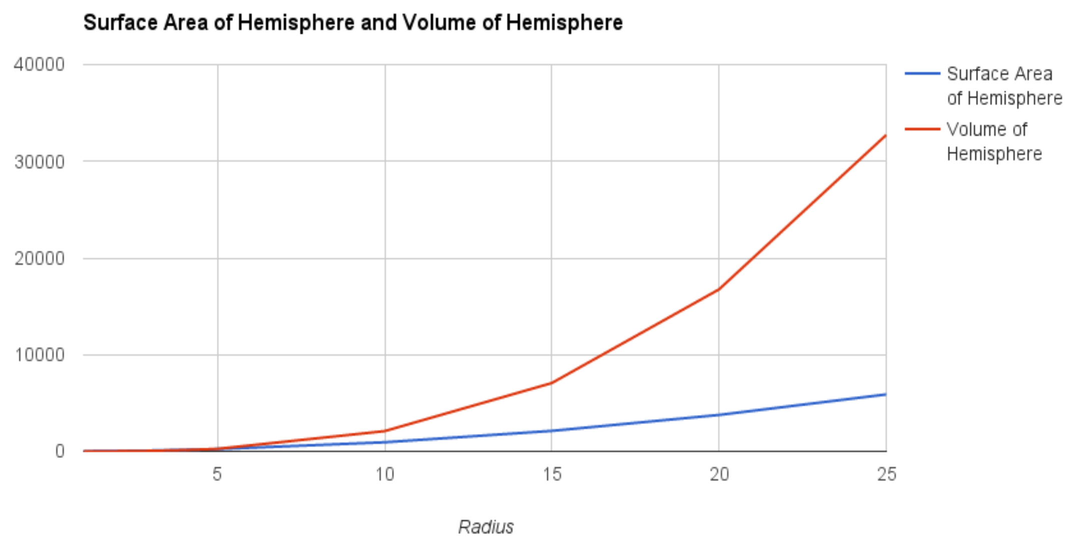


Figure AA.2: Student Constructed Graph in Google Sheets

7. As the radius increases, which increases more rapidly?

    -Surface Area

    -Volume

8. How does the surface area to volume ratio change as the hemisphere becomes larger?

-Student Response: It decreases rapidly.

-Student Response: The SA and V have an increased distance from one another. The ratio decreases.

9. If we calculate the surface area and volume of a "perfect" hemisphere, will we be underestimating or overestimating the surface area and volume of the drops we made? (It might help to look at the side view picture of the drops from yesterday!)

   -Underestimating

   -Overestimating

   -Other

10. Watch the videos that you made yesterday of the water drops on the MELC sheets. Now that you know more about the relationship between surface area to volume ratio, can you explain why the larger the drop became, the longer it took to cool? (Hint: Heat escapes from the drop through the surface and heat retention is based on the volume of the drop)

-Student Response: The smaller drop would have a larger SA/V ratio and would have more SA to volume and would cool faster because the surface area is where the heat would escape. then the large drops would have a smaller SA/V ratio and would cool slower because there would be less surface area and more volume to cool.

-Student Response: Because the larger dots it could hold more heat because the top surface is less big because it is shorter. Also so the volume is bigger so it has more heat retention.

-Student Response: The volume is greater and so is the surface area. The ratio between the two is smaller than the smaller drops though. This means that the heat takes longer to escape and due to the larger volume it holds the heat longer.

Form 3

Below are the formulas for surface area and volume of a cube and of a cylinder.

Images from (https://upload.wikimedia.org/wikipedia/commons/thumb/e/e7/Necker_cube.svg/2000px-Necker_cube.svg.png) and (https://upload.wikimedia.org/wikipedia/commons/thumb/3/36/Circular_cylinder_rh.svg/220px-Circular_cylinder_rh.svg.png).

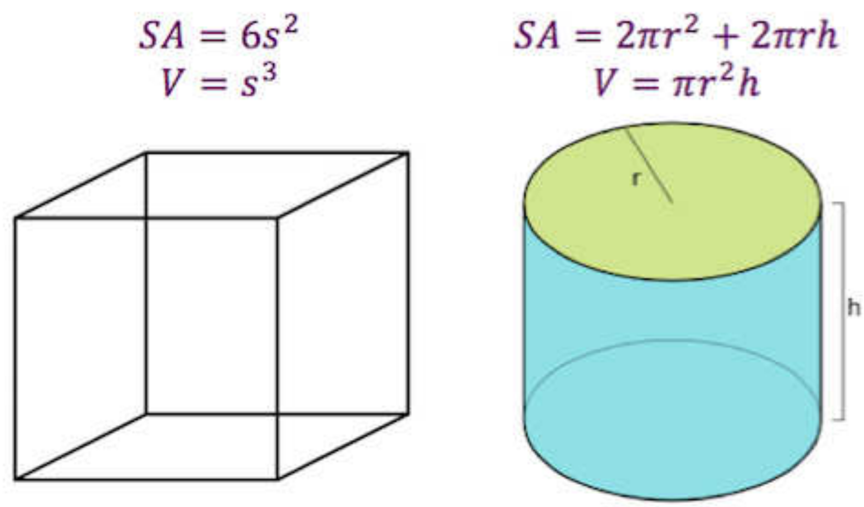


Figure AA.3: Formulas for Surface Area and Volume of Cube and Cylinder

11. We want to know if the surface area to volume ratio for different shapes behaves in the same way that it does for a sphere/hemisphere. Explore this concept with the shapes above. How does the surface area to volume ratio of the cube change as the size of the cube increases?
12. The cylinder is more complicated because it has more than one parameter to account for at the same time (radius and height) and the other shapes only had one parameter (radius or side length). Compare and contrast what you think the surface area to volume ratio would be for differently shaped cylinders (tall & skinny vs. short & fat).

13. What happens to the surface area to volume ratio if the size of a cylinder increases but the shape of it stays the same?

Day 3

Form 1

1. Answer questions a-e using the images below. Be prepared to explain your reasoning!

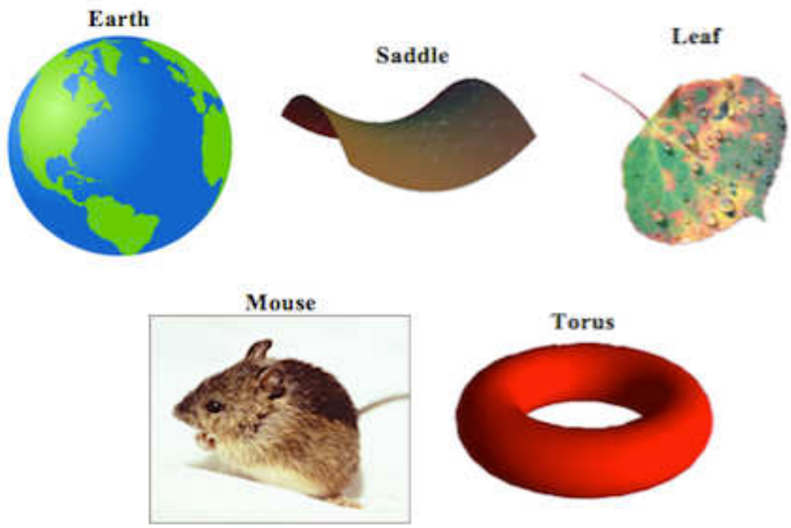


Figure AA.4: Earth, Saddle, Leaf, Mouse, Torus

a. The surface area to volume ratio of Earth would be...

-Tiny

-Pretty Small

-Medium

-Pretty Large

-Huge

-Other

b. The surface area to volume ratio of the saddle would be…

-Tiny

-Pretty Small

-Medium

-Pretty Large

-Huge

-Other

c. The surface area to volume ratio of the leaf would be...

-Tiny

-Pretty Small

-Medium

-Pretty Large

-Huge

-Other

d. The surface area to volume ratio of the mouse would be...

-Tiny

-Pretty Small

-Medium

-Pretty Large

-Huge

-Other

e. The surface area to volume ratio of the torus would be...

-Tiny

-Pretty Small

-Medium

-Pretty Large

-Huge

-Other

As we saw for spheres, cylinders, and cubes, as the size of the object increases (but the shape does not change), the surface are to volume ratio decreases. Surface area to volume ratio is very different depending on the shape and size of the object that you are dealing with. As it turns out, surface area to volume ratio is a very important topic for all living beings!

2. Brainstorm with your partner and try to think of some examples of how surface area to volume ratio plays a role in nature/Biology. Type your examples below!

-Student Response: Reptiles "sunbathe" on big rocks because they hold heat longer, due to the surface area to volume ratio.

-Student Response: Leaves. Leaves need more surface area to take in water, thus they have a larger ratio.

-Student Response: Creatures that want to stay warm but live in an environment that is not warm. Things that are trying to absorb things would want a larger surface area so they would be more able to absorb water and things, like trees. Big leafed plants having larger leaves to absorb more sunlight.

Form 2

3. Imagine that you walk outside into the snow with no gloves on. Immediately, your hands begin to feel cold. What is your immediate reaction? Are you going to stretch your fingers out or are you going to make a fist with your hand? Now imagine that not only do you not have gloves, but you also have no coat on. After a few minutes of standing outside with no coat or gloves, what position do you think you'll find yourself in?

-Student Response: You would clench your fists and hold your arms against your chest.

-Student Response: Probably in a ball because then less of my outer body is in the cold so less of my surface area is in the cold.

-Student Response: The fist will be most logical for no gloves because less surface area and more volume means that retaining heat will be easier. The same goes for no coat. The fetal position is a great choice.

4. What do you notice about the surface area to volume ratio of the ears when comparing these two rabbits? Do you think the climate that the rabbit lives in has anything to do with this? Explain.

Figure AA.5: Rabbits

-Student Response: The jack rabbit's ears have a much smaller ratio than that of the snow rabbit. Yes climate plays a role in this, the snow rabbit has smaller ears so there is less surface area for the cold to reach.

-Student Response: The large ears keep them cool in the desert because heat escapes much quicker, while in the arctic, the rabbits have smaller ears considering they need to retain heat.

-Student Response: The ears of the jackrabbit are larger because they are able to expel heat easier and faster than the snow hare who lives in cold climates and needs to retain heat. These animals have adapted to their environment with these ears.

-Student Response: The white rabbit lives in cold temperature and would rather not have a large surface area to lose heat through. The other rabbit however lives in a warmer climate and doesn't have to worry about losing heat.

5. In Florida, the average weight range for a white-tailed deer is 77-110 pounds. In Canada and the northern regions of the United States, the weight of a white-tailed deer ranges from 100-300 pounds. Try to explain this using the knowledge you've gained about surface area to volume ratio and climate.

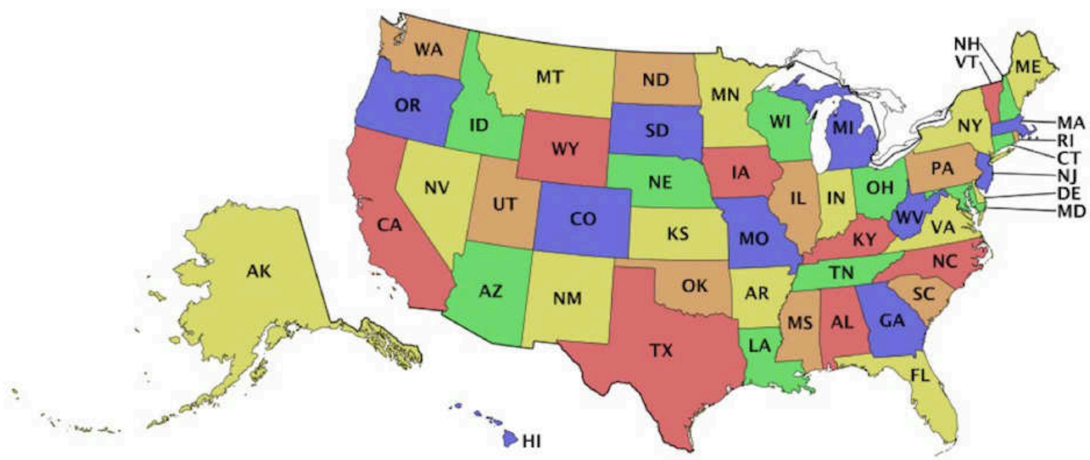


Figure AA.6: Map of the United States of America

-Student Response: The bigger the animal the smaller the surface area to volume ratio is so in Canada is it is trying to absorb all of the heat it can and keep it in.

-Student Response: The larger the animals, the better it will be at retaining heat due to its ratio of surface to volume. Since Canada is closer to the pole it is colder, and the animals must be more round to retain their heat.

-Student Response: In Florida the climate is hotter and more humid and the abundance of food there makes it so these deer don't have to stock up in fat reserves. Up in Canada these deer need to have a bigger and more fat body because of the cold and lack of food.

6. Why are the cells in our body so tiny that you need a microscope to see them? Cells are constantly interacting with their surrounding environment in order to survive. They must absorb gas and food molecule and dispose of waste products. The absorbing and disposing process occurs through the plasma membrane. Each region inside of the cell has to be served by part of the cell surface absorption/disposal system. If each the inside regions are not served adequately, the cell will not survive, so at a certain point the cell must stop growing. Try to explain this using surface area to volume ratio.

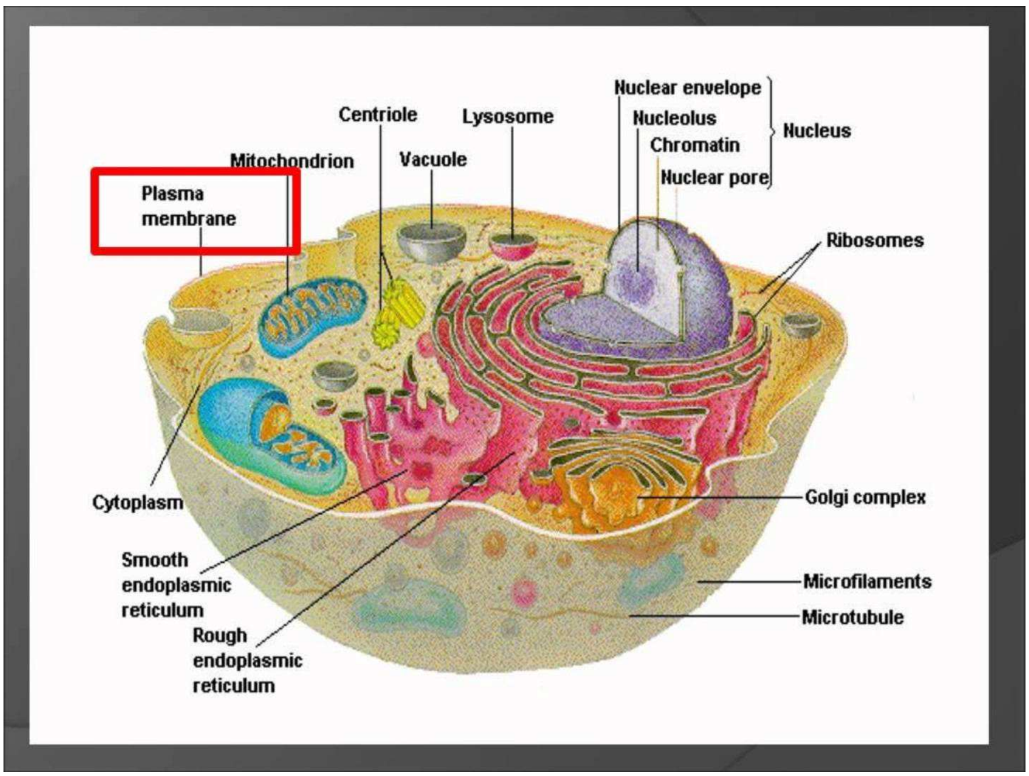


Figure AA.7: Cell Structure

Image from: https://i.ytimg.com/vi/RDPmTIyawGE/maxresdefault.jpg

-Student Response: It has to be smaller for it to continuously move. As the cell gets bigger the ratio shrinks and the amount of gas and food molecules it can retain changes.

-Student Response: They are able to move more fluidly due to their small size, and this movement can also create heat faster.

-Student Response: Cells have to stay a certain size because if they get too large, it's going to be harder for them to absorb enough nutrients, water etc to keep itself running.

-Student Response: They would prefer to have a larger surface area to absorb materials and would also try to stay smaller so that they can adequately serve it's parts because if they were spread out they would be unable to get materials, where they need them.

7. Now that you've seen a few examples, brainstorm again with your team to come up with more examples to share with the whole group! Type your examples below.

-Student Response: Animals- how living things adapt to live in certain conditions

-Student Response: Before a bear goes into hibernation, they eat more to have more mass and stay warmer.

-Student Response: Plants that want light would try to have large surface are on their leaves for sunlight and would like more surface area to absorb carbon dioxide better. Tree roots need a large surface area to absorb water and nutrients better.

APPENDIX B: STUDENT SURVEY

Student Code:

For the statements in the table below, please circle one number (1-5) which best represents your opinion: 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree.

About the activity:					
1. This activity helped me to see that mathematics and science are connected in the real world.	1	2	3	4	5
2. I prefer activities that involve only science topics without other subjects involved.	1	2	3	4	5
3. I prefer activities that involve only mathematics topics without other subjects involved.	1	2	3	4	5
4. The math questions in this activity helped me to better understand the science questions.	1	2	3	4	5
5. The science questions in this activity made the math questions more interesting.	1	2	3	4	5
6. I had to think hard to answer some of the questions in this activity.	1	2	3	4	5
7. This activity was boring.	1	2	3	4	5
About the class:					
8. I find the projects and activities that I do in this class interesting.	1	2	3	4	5
9. What I learn in my math class will be more helpful in the real world than what I learn in this class.	1	2	3	4	5
10. What I learn in this class will be more helpful in the real world than what I learn in my science class.	1	2	3	4	5
11. The things that I learn in this class are more relevant to my life than the things that I learn in my other classes.	1	2	3	4	5
12. I have the opportunity to be creative in this class more than I do in my other classes.	1	2	3	4	5
General:					
13. Mathematics and science topics do not overlap at all in the real world.	1	2	3	4	5
14. I am more motivated to work hard in school when I know that what I am doing has a real-world application.	1	2	3	4	5
15. I am more engaged when technology is involved in my learning.	1	2	3	4	5

Please finish the sentences below with 1-3 statements.

About the activity:

1. My favorite things about this activity were…

2. The things that I disliked about this activity were…

3. What I found challenging about this activity was…

4. What I learned most by doing this activity was...

About the class:

5. What I enjoy about this class is…

6. What I find challenging about this class is…

7. This class is different than my other (one-subject) classes because…

General:

8. (*Choose a, b, or c and then explain*) If I could choose, mathematics and science would be taught **(a) complete separately, (b) sometimes together and sometimes separately, (c) always together** because…

9. I think that the ways that mathematics and science are similar are…

10. (*Choose a or b and then explain)* I **(a) do think, (b) do not think** that the learning of mathematics and the learning of science are similar because…

APPENDIX C: INSTITUTIONAL REVIEW BOARD APPROVAL

From: Evelyn.Swiss@ColoState.EDU
Sent Date: Tuesday, April 05, 2016 14:24:55 PM
To: Abigail.Gentry@colostate.edu, Mary.Pilgrim@colostate.edu
Cc:
Bcc:
Subject: The following Protocol has been Approved: 16-6387
Message:

The IRB has approved your protocol referenced below:

Protocol ID: 16-6387
Principal Investigator: Pilgrim, Mary

Protocol Title: Integrated Mathematics-Science Curriculum and Instruction
Review Type: EXPEDITED
Approval Date: April 05, 2016

This is not an official letter of approval. Your approval letter is available to you in the "Event History" section of your approved protocol in eProtocol. Note that specific information regarding the approval and any conditions of approval are available below the signature line in the footer of the approval letter.

IMPORTANT REMINDER: If you will consent your participants with a signed consent document, it is your responsibility to use the consent form that has been finalized and uploaded into the consent section of eProtocol by the IRB coordinators. Failure to use the finalized consent form available to you in eProtocol is a reportable protocol violation.

If you have any questions regarding this approval, please contact:

CSU IRB: RICRO_IRB@mail.colostate.edu; 970-491-1553
Evelyn Swiss: Evelyn.Swiss@Colostate.edu ; 491-1381
Tammy Felton-Noyle: Tammy.Felton-Noyle@colostate.edu; 491-1655

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https://csu.keyusa.net/