Spring 2018

How Can a 9th Grade Math and Science Curriculum Become Integrated as Part of a Project-Based Academy?

Evan Pierson
Hamline University

HOW CAN A 9TH GRADE MATH AND SCIENCE CURRICULUM BECOME INTEGRATED AS PART OF A PROJECT-BASED ACADEMY?

By Evan Pierson

A capstone submitted in partial fulfillment of the

requirement for the degree of Master of Arts in Education

Natural Science and Environmental Education

Hamline University

Saint Paul, Minnesota

May, 2018

Primary Adviser: Susan Manikowski

Peer Reviewer: Scott Schmelzle

ACKNOWLEDGEMENTS

To C, H, & h, for their love, support, and patience they showed me as I completed this program.

To my mom and dad, for instilling a love of nature and the work ethic I needed in order to complete this program.

To my current and former students, for inspiring me to be the best possible educator I can be.

Table of Contents

CHAPTER ONE:

Introduction

The Challenge

I could tell this was different from the other initiatives I've seen come and go during my first 10 years of teaching. Perhaps it was because this time I was approached by a fellow teacher who knew how to get me riled up and excited about a new challenge or maybe it was all that time spent envisioning the academy while brainstorming ideas with my peers. But the reasons don't matter – I was hooked.

Our group of teachers divided into two separate camps, mostly to keep ourselves from biting off more than we could chew. The English and social studies teachers had a natural affinity towards each other, with literacy being on the forefront of their curriculums and learning targets and standards that were malleable and easily integrated. Math and Science both used numbers, engineering, and graphing as part of their physical science and algebra curriculums. As Science, Technology, Engineering, and Mathematics (STEM) teachers, we knew our content areas had to fit together one way or another but it wasn't as easy as it sounded and has provided me with the driving force for my capstone: "How can a 9th grade math and science curriculum become integrated as part of a project-based academy?"

In this chapter I will discuss the rationale for exploring this question by explaining my personal connection to the topic. I will start by talking about how my life experiences have fostered my passion and commitment to project-based learning. Next, I will introduce the various components of the school I work in; everything from the students and staff to the parents and community. Then I will describe the academy itself and my personal involvement with the development of it. Finally I will describe how standards in math and science for the state of Minnesota allow for a combined curriculum but also present challenges when considering a fully integrated classroom.

The Farm

For the first 18 years of my life I spent the majority of my time on a dairy farm. Countless summers were spent working with cows and preparing my projects for the county and state fairs. Being involved in 4-H taught me a lot about preparation, hard work, deadlines, and acquiring information within the context of a project. This experience surely helped me with time management and leadership, not only in school, but life in general. The responsibility of caring for a live animal for a few months every summer made this a very real experience that has shaped me into who I am today.

Another big influence in my youth was my dad, who always found a way to make things work with what he had. If we weren't fixing machinery, we were taking care of the cows, land, or infrastructure. Many times the fixes to the problems on the farm required parts that simply weren't available or wouldn't be ready in time, so making do with what we had was extremely necessary. There is no doubt that when I envision my students taking on projects such as constructing windmills made from CDs or bridges from file folders, I do it with my father in mind.

I remember helping my father construct the bunk beds my sisters used for a large part of their adolescent years (and actually is the same bed that my son currently uses). I also have vivid memories of taking apart a Mercury Cougar with him and restoring it to a factory condition, not knowing that this would be the car I would drive on my wedding day. I saw firsthand how rewarding it is when you have a practical use for items you've created or if the product of the projects you've done is worth showing off. It's projects such as these that I remember from my younger years, not definitions, spelling tests, or math problems from school and one of the reasons I'm drawn towards project-based learning.

Today I live a very similar life to the one I had growing up. My first instinct when presented with a problem is, "How can I fix it?" rather than, "Who do I need to call?" My love of project-based learning is evident in my home, where I've learned how to lay electrical circuits and design plumbing schemes while finishing my basement. There are several built-in benches and furniture in my house that have tested my ability to engineer, and while I wasn't exactly sure how they would turn out in the end, I was able to adapt to any problem I was presented along the way. I ask that students approach any project that I assign using the same mindset; that they use open mind and have flexible plans as the project unfolds.

<u>The School</u>

As a school in a second-ring suburb in the large metropolitan area in the upper Midwest, the school at which I teach is full of motivated students, staff, parents, and community. Their mission statement of "Preparing Successful Future Ready Students" is apparent on both a day-to-day basis but also throughout the whole school year. Having said that, our school has ever-changing demographics; this year more than any other year I've taught we have more students of color, a wider range of socioeconomic status, and many levels and types of students with social-emotional needs. Our vision of partnering with students, families, and community to create a culture of learning and provide the support and resources necessary to achieve at high levels has encouraged teachers to develop specialized programs and academies such as the Business Academy, MnCaps, and a STEM Academy specializing in the biomedical field. Programs like these help many of the college-bound and career-driven students who have an idea of a career path they'd eventually like to head down, but our team saw a need for students who want to develop skills needed to be lifelong learners who share a passion for collaboration, community, and citizenship.

A school demographic that consists of 86% Caucasian one might not think we have a diverse group of students. Having said that, our Hispanic and African American population is on the rise and conducting culturally responsive classrooms is something our staff is aware of and striving to achieve. Each year more and more of professional development resources and time are spent towards finding a style and type of class that work well with all students, but particularly ones of color. In my experience, students need a classroom with a perfect balance of structure to allow them to stay on track but enough freedom to allow them to be themselves culturally and emotionally.

Along with a group of students who have largely become disengaged and deal with a tremendous amount of pressure in their homes (89% of students enrolled in a higher institution in 2015), there is also a large number of students who have a place in our academy. Whether it be students who fall into a demographic where the traditional classroom model has fallen short or the pressure of being a teenager in a successful community with successful families has promoted mental health issues, the authenticity and connections that students receive in a project-based classroom allow everyone to be successful.

The Academy

In the winter of 2016 an English teacher approached me with a proposal for a "school within a school" or "teacher governed school." The idea was simple: students would be shared among four core teachers during an (essentially) open four-hour period that wouldn't be limited by bells, passing time, or other disruptions. Assessments would largely be based off projects, where inquiry and personal connection to content thrives. The grant had been written and approved and a few math and English teachers have already begun to explore schools around the country where this idea has been tried and successful. They were looking for a social studies and a science teacher who shared their passion for providing opportunities for student learning through projects and collaboration.

After I officially joined the team later in the spring and attended meetings during summer, we collectively decided it would be best to start with smaller projects within a couple of subjects and work our way from there. I worked with my colleague in the math department and began comparing units in our freshman level math and science courses. It had been five years since I'd taught freshman level science, so I was quite unfamiliar with the curriculum and skill level of freshman.

After catching up a bit on the curriculum, we decided to attend a “Project Based Learning” workshop operated by the Buck Institute. While my life experiences often pointed me towards project-based learning, it was at this workshop where I learned of the true power of project-based learning in the classroom. Students didn’t need projects just for the sake of doing projects; they needed to be presented with projects that gave them a cause or set of questions that they generated. This kind of student-led inquiry is truly when the projects become memorable and learning becomes authentic.

My math colleague and I searched our curriculums and looked for the perfect units or even partial units to integrate. It turned out that there never really was a perfect unit to bring together between our math and science curriculums; if the standards worked out, it became an issue with timing. If timing worked, than maybe standards only partially matched or didn’t match at all. As the workshop progressed, it became clear that we weren’t going to simply be able to cobble together a years worth of curriculum into projects and call it good enough, we needed approach this marriage between the two subjects with a well thought out strategic plan that was based on state standards.

The Standards

Several years ago, our ninth grade science team was given the task of dissolving earth science classes at the high school level and replacing them by integrating earth science into physical science curriculum. Given my limited background in earth science, this was a huge undertaking but it did allow me the opportunity to become familiar with the process of dissecting the standards and writing learning targets to fit our individual school's needs. Earth science standards also open up the interesting possibility for real-world application and large scale mathematical relationships in a project-based classroom.

The tricky part with our state standards is that they are currently under review in both math and science. While I may be able to get some of the units to meld together and work for our current standards, I need to remember that standards for both will be changing shortly. Insiders from my district have said that I should pay special attention to the NextGeneration set of standards for science. These standards open themselves up to math and engineering integration into science classrooms around the state. So, while it may be challenging on initial glance to mesh these two standards, NextGeneration standards might be exactly what everyone in our academy needs, teachers and students alike!

<u>The Summary</u>

Based on my prior experiences as a farm kid in the rural Midwest and my professional experience as a teacher in a suburban community in a large metropolitan area in the Upper Midwest, I've come to believe that a Math and Science integrated curriculum in a project based academy is relevant, important and necessary. Clearly my interests and skills align with a project-based model and fulfill a need within the academy at my school. Academic standards will potentially limit the scope and breadth of my capstone project, but will also challenge me as an educator at the same time.

How can a 9^{th} grade math and science curriculum become integrated as part of a project-based academy? As research shows, integrating curriculums across multiple domains can be one of the most challenging yet rewarding tasks for teachers. Adding a project-based dimension to the integrated curriculum will only increase the stakes further and make this an even more challenging capstone project. In this capstone project, I will research the implications of an integrated curriculum and project-based model and explore how these two topics in education can be combined. A final product of the capstone project will include a curriculum plan consisting of a two week unit that is designed for integration, innovation, and creativity, but most importantly, it will be a curriculum based on research and best practice.

In the following chapter, I will present a literature review that will delve into the topic of integrated curricula, primarily focusing on the 9th grade math and science curriculums. Then I will investigate the positive and negative effects of a project-based learning environment, especially in the math and science areas. Next, I will explore how integrated curriculums and project-based models can be combined through a seamless and productive process. Lastly, I will analyze how research states that integrated curriculums and project-based model may not be in the best interests for every student in every situation.

CHAPTER TWO:

Review of Literature

Introduction

"How can a 9th grade math and science curriculum become integrated as part of a project-based academy?" To look into this topic, I decided to focus my research on two main areas: a curriculum with an emphasis on integrating science and math- and project-based learning. To effectively study this question, it becomes critical to look at how these two topics get along with each other as well. Do these topics do well on their own but create obstacles when they're implemented together? Is there any research-based opposition to integrated curriculums and project based classrooms?

In this chapter, I will investigate what research says about an integrated curriculum in terms of effects on students and teachers. Next I will research how project-based learning has recently taken off in the education world and whether or not research backs up project-based learning. Then I will explore if project-based learning and integrated curriculums can coexist in a 9th grade academy setting. Finally, I will research how opposing viewpoints suggest that integration and implementation of these two topics might be unsuccessful or at the very least challenging.

<u>Inquiry in science and math</u>

The word "inquiry" has developed into one of the science teaching buzzwords of today and really goes hand-in-hand with the scientific method. Students are provided with opportunities to question, investigate, analyze, and draw conclusions about the world around them. This type of active learning allows students to create their own questions, investigations and finally draw their own conclusions based on experimental evidence (Truchan, 2010). The most powerful aspect to inquiry in the classroom is when students are able to review, conclude, and propose new questions to further enhance their understandings of scientific concepts. In essence, by incorporating inquiry into their math and science classrooms, teachers simply allow students to have the same opportunity that mathematicians and scientists have every day in their careers.

As Sahin notes, inquiry-based learning and project-based learning are interrelated; project-based learning is a type of extended inquiry that uses inquiry during each step of the learning process (Capraro, 2013). Whereas project-based learning is focused on student's creating an end product or artifact displaying their knowledge across multiple disciplines, inquiry-based tends to be a bit more restrictive and teacher directed (Capraro, 2013). Having said that, inquiry can be assimilated to traditional curriculum easier and might provide introductory teachers a good place to start with their integration process (Kanter & Konstantopoulos, 2009). Research shows that using these two formats in the classroom provides students with an opportunity for choice but also allows the teacher to adjust expectations as they are comfortable..

History of Project-based Learning

Project-based learning dates as far back to Dewey's paper "Experience and Education," where he is quoted as saying: "Education is not preparation for life; education is life itself" (Dewey, 1938, p. 239). Montessori further develops project-based learning by creating environments in which young children learn to think by themselves and, as much as possible, learn from first-hand experiences (Montessori, 1949). Humans form their education based on their previous individual experiences, which can allow them to ask questions, investigate, interact with others and reflect upon their experiences (Piaget, 1969). The foundations of constructivism, as Piaget named it, has provided both inquiry and project based learning with a solid foundation built upon research, practice, and theory.

Why Project-based Learning?

The real life application of mathematics and laboratory setting of science naturally lends themselves towards project-based learning. Learning through discovery and developing skills such as critical thinking and problem solving will prepare students for careers and problems that don't even exist today (Resnick, 1999). As previous studies have indicated, project-based learning has largely increased student's academic performance, motivation, and overall social skills in math and science classes (Holmes & Hwang, 2016; Cunningham, 2016). project-based learning has developed immensely in the past fifteen- years or so, with many researchers assigning significant words and terms relating to project-based learning such as: driving question, inquiry, collaboration, technology, and authenticity (Solomon, 2003; Larmer & Mergendollar, 2010; Cook, 2009). High school science and math classrooms in project-based learning look similar to science projects that are implemented in early education but are often integrated with content and rich in standards (Soloman, 2003; Crane, 2015). This type of learning opportunity situates students in the scientific field and allows for authentic investigations and data collection that often provides students with the most accurate view of the scientific process (Heflich, Dixon & Davis, 2001).

Project-based Learning: A Focus on Students

With an emphasis on developing authentic projects, much of the focus in the classroom falls back on the students. Teachers are able to scale back traditional teaching practices such as lecture (Geier, Blumenfeld, Marx, Krajcik, Fishman, & Soloway, 2008), homework and even predetermined labs (Munakata & Vaidya, 2015) in favor of a more student-centered approach. This approach allows teachers to become coaches or facilitators and to a certain extent allow them to engage in explorations along with the students (Munakata & Vaidya, 2015). As the classroom becomes less predictable from day-to-day for both teachers and students, stakeholders approach each day with a new set of challenges, questions, and discoveries. Moreover, teachers are able to adapt project's criteria, constraints, duration, or expectations in order to meet the needs of all student populations (Capraro, 2013). With projects still rooted in standards and course content, everyone still needs to be accountable, flexible, and show high levels of investment in the educational process (Langbeheim, 2015).

The very structure of project-based learning gives students an opportunity for voice and choice; driving questions, methodology, topics, and project design can all be given directly to the students or scaled back to meet the needs of individual students and present opportunities for growth and challenge (Larmer & Mergendollar, 2010). Students in an effectively managed project-based classroom will find success with organization, goal setting, time management, creativity, and peer-to-peer interactions (Holmes + Hwang, 2016; Munakata & Vaidya, 2015). Projects emphasize 21st century skills such as teamwork and communication skills that help them prepare for their future careers (Morgan, Moon & Baroso, 2013). The open-endedness of projects allow students to have options when considering, analyzing, and problem-solving in original, creative, and well thought out solutions (Munakata & Vaidya, 2015). Ultimately, students are allowed the freedom to interpret problems, obstacles, and criteria of their concept area and go on to form diverse solutions for well-defined outcomes (Capraro, 2013). Putting the focus back on the students through project-based learning helps increase engagement amongst students, teachers, and the entire school community.

Providing opportunities for student led inquiry in the form of projects engages all students, but especially helps students in minority or disadvantaged populations (Langbeheim, 2015). Project-based learning classrooms can have a positive effect on closing the achievement gap ,as students quickly realize that they can be their own resources. Even low academic level students will show enough motivation to intentionally seek help (Holmes & Hwang, 2016). Although some research shows that project-based learning can actually decrease minority student's attitudes towards science, the same study shows that academic achievement amongst those same students increased by a factor five times greater than to be expected from a typical group of students at that age and skill level (Kanter & Konstantopoulos, 2009). Another study suggests that, while high and middle performing students increase student achievement in math Texas Assessment of Knowledge (TAKS) assessment scores, it was the lower performing students who increased the most on the TAKS. In particular, this was true for students who are of Hispanic ethnicity and was attributed largely to their ability to communicate with peers and teachers more so in a project-based classroom than a traditional lecture intensive classroom (Han, Capraro, & Capraro, 2014). Exceptional learners (English Language Learners, students with Learning Disabilities, and students with Emotional and Behaviorial Disorders) all benefit from a project based learning environment, where exposure to content is repeated, collaboration with peers is encouraged, and obstacles such as lecturing, authenticity and a general lack of time are eliminated or reduced (Capraro, 2013). Project-based learning has the ability to create powerful and productive relationships amongst a diverse group of students (Capraro, 2013). With pressure being placed on school districts nationwide to close the achievement gap, project-based learning is a great place to start trying to accomplish that, bringing all students into the fold in the form of projects.

Challenges to Project-based Learning

While most research indicates that project-based learning largely has a positive effect on everybody involved, there are still skeptics. The largest drawback to project-based learning is also the most obvious: pursuing the open-ended questions will take more class time and more expertise in teaching (Langbeheim, 2015). If it's not timing within a class period, perhaps it's an expectation that student achievement will improve or turnaround significantly in a short period of time from school administrators or the school community. Interestingly, there are studies that show that project-based learning is actually a detriment to student learning. Teachers, specifically math teachers, have become daunted by the methodical task of creating problems that do a good job or organizing student data and assess their knowledge. Oftentimes the projects they use are not directly connected to the math curriculum but rather are projects that require a little math to be done along the way or study something very limited in it's nature of mathematics standards and curriculum, such as mathematics history (Luneeva & Zakirova, 2017).

The large expense of transitioning to a project based curriculum and negative impact on literacy it's had on students have made project based classrooms in their specific situation a negative experience (Bloom, 2016). Other frustrated teachers note that some students failed to reflect on their work or submitted only portions of their final projects while missing deadlines along the way (Crane, 2015). Even if students were motivated by the concept of a project-based classroom, they still lacked the maturity, consistency, and follow through that project-based learning classroom requires. Like many strategies in education, research shows that project-based learning might not be the best fit for everyone.

That being said, one researcher addressed the time constraints that persisted during his implementation of project based learning in an engineering course but concluded that the benefits of a student-led classroom far outweighed the drawbacks. The primary topics of his course were still being covered, while breadth was substituted for depth in his course (Kunberger, 2013). Another school administrator noted that unrealistic expectations were unfairly being placed on project-based learning and argued that the school community can't expect to see change within a year or even two from a transition to the project based classroom. The change takes time for teachers to set up appropriate projects and for students to open up to the collaborative culture that project based learning creates (Bloom, 2016). While there weren't many drawbacks to project-based learning to begin with, negatives to project-based learning were isolated to individual cases where the school community didn't give project based learning the time, resources, or opportunity it needed to flourish.

Integrating math and science

With a project based classroom established, the next important facet to the question "How can a 9th grade math and science curriculum become integrated as part of a project-based academy?" is an integrated classroom. While the ultimate goal might be to one day have all the courses at the 9th grade level completely integrated, most research points towards integration of math and science as the easiest to execute (Stinson, Harkness, Meyer, & Stallworth, 2009). These two disciplines are often described as logically connected, both by researchers and teacher organizations nationwide (Pang and Good, 2000; National Council of Teachers of Mathematics, 2000 & National Science Teachers Association, 1996). They are interrelated and similar, such that connections formed within these fields are natural and not forced (Kurt & Pehlivan, 2013). For many concepts, principles, and theories, math and science have enough in common that integrating the two subjects provides students with a more meaningful and efficient education (Berlin & White, 1994). Later, this chapter will investigate how actually connecting the two domains in the classroom is a much tougher task than it seems.

It's necessary to define what is meant as "integrated" when describing an integrated curriculum. Like project based learning, researchers and education experts have fashioned words like: interdisciplinary, multidisciplinary, thematic, integrated, connected, nested, sequenced, shared, webbed, threaded, immersed, networked, blended, unified, coordinated, and fused (Czerniak, Weber, Sandmann, 1999). With so many definitions and methods to integrating the two subjects, it's no wonder that educators become frustrated and confused when integrated curriculum is implemented. Recent definitions of integrated math and science curriculum state that all interactions between science and math objectives can be either connected within a single lesson or blended throughout the entire courses (Kiray, 2012 & Berlin and Lee, 2005). The method, degree, structure, and model of integration can vary greatly and largely depends upon the teacher that implements it (Stinson, Harkness, Meyer, & Stallworth, 2009; Berlin and Lee, 2005). Despite a lack of definition and professional development on integrated curriculums, teachers must choose an appropriate level of integration for their course. Otherwise concepts in math and science classes become trivialized and fail to enhance student understanding of important ideas (Mason, 1996). While most teachers agree that an integrated curriculum is ideal, the lack of definition has educators defining "integrated" many different ways and left many feeling ill-prepared and frustrated by the entire process of integrating (Davison, Miller, & Matheny, 1995).

<u>Benefits to Integration</u>

When implemented appropriately, there are plenty of benefits to an integrated curriculum. Most importantly, the topic of integration is approached with a high level of enthusiasm and positive attitude; not just from students but from teachers, student teachers, administration, and even communities (Berlin & White, 2012; Riordain, Johnston, & Walshe, 2015; Kosal, Lawrence & Austin, 2010). Watanabe and Huntley (1998) state that providing connections between math and science makes the topics more relevant and increases motivation in students and provides them with an opportunity to learn new skills or concepts. Interestingly one study showed that some students like certain subjects better than others, and that there is a greater chance that students can access less favored subjects through ones they might prefer (Zolnierczyk, 2016). For example, a student may prefer the real life application of science but get bogged down or drowned out by the calculations in math. Combining the two subjects allows students to master concepts they may not have an opportunity to master without the attitude, skills, or real-life application of their preferred subject. Positive attitudes might not necessarily translate to student success, however, as one study states that while teachers approached integration with a positive attitude, there were situations in which they lacked the skills and training necessary to integrate the two courses (Baskan, Alev, & Karal, 2010). Project-based learning encourages differentiation within classes as well, making it developmentally appropriate. Research shows that curriculum changes meets the individual needs of students (Capraro, 2013).

Integration, especially when combined with project-based learning, allows teachers the opportunity to provide students with solutions to real-world problems that make these two courses more personal and relevant. Content relating to personal interests and social issues encourages, supports, and nurtures student's confidence in their ability to do math and science (Berlin & White, 1994). Like project-based classrooms, the shift to more real-life problem solving and inquiry-based techniques make these two subjects more accessible to students who might otherwise not excel or have interest in a math and science.

Integrated classrooms in math and science also show signs that student achievement can be increased. Results from one experiment showed that when statistical concepts were integrated into an 8th grade science class, students scored significantly higher on their unit test; so much, in fact, that no students from the experimental group received a letter grade of an F (Judson and Sawada, 2000). Another study connected Chemistry and Mathematics in order to improve science literacy and develop critical thinking and problem-solving skills (Kosal, Lawrence & Austin, 2010). The marriage isn't specifically limited to the chemistry or physics either. A few studies integrated math with biology and earth science in order to increase engagement and applying math concepts into interdisciplinary subjects. (Clary & Wandersee, 2014). Another study showed a direct correlation between math students who were participated in an integrated curriculum (with science) and math students who were not. Those who received an integrated curriculum showed higher student achievement as in this case science provided a great context and application for mathematics (Judson & Sawada, 2000) . Regardless of age level or specific units within math or science, integrated curriculums can be successful in terms of academic achievement.

<u>Integration benefits more than just students</u>

Science and mathematics related experiences need to be more personal and relevant to student's immediate and long-term interests and needs (Berlin & White, 1994). To do this, teachers collaborate and form professional learning communities (PLCs) with members within their own subject area or perhaps even their own specific courses. Schwols and Brush Miller (2012) encourages teachers to move out of the vertical teaming and into horizontal teaming with teachers that are currently teaching the same students. Using common language, identifying concepts that are covered within both content areas, and discussing sequencing within a school year can help students perform better academically. Teachers working on both integration and project based learning can focus on central ideas of the curriculum and use it to create engaging and challenging activities in the classroom (Capraro, 2013). This type of thoughtful and intentional collaboration benefits not only the students but teachers who might not normally collaborate across content areas, establishing and improving relationships across the entire school community.

<u>Challenges to Integration</u>

Interestingly, according to research, it is teachers who show the most hesitation towards an integrated math and science curriculum. Some teachers lack confidence when dealing with integrated curriculums, both from a content and execution point of view (Valtorta & Berland, 2015) While some lack confidence, others try to integrate the two subjects when best practice for specific units might simply be to teach them independent from one another (Zolniercyzk, 2016). This type of "forced integration" makes content more confusing and can actually have the opposite effect on student learning (Mason, 1996). Most research indicates that while there are areas within specific units that allow for easy integration, educators must pick and choose integrating the two topics or risk facing one of the most daunting tasks they'll ever face (Berlin & White, 1994; Pang & Good, 2000). Teachers will need access to proper training and professional development and cross-training would become necessary. Nonetheless, many researchers believe these hurdles are more than warranted and provide many benefits for students in the years to come (Bosse, Lee, Swinson & Faulconer, 2010).

Especially at the high school level, there simply isn't a magic formula to combining math and science. The lack of an established system and precedence for integration has confused and intimidated teachers to the point where many decide not to try it. Many teachers recognize that integration is important for student success but content knowledge and skills prove to be barriers for integration, especially at the high school level (Zolniercyzk, 2016). Teachers who show the drive and enthusiasm for math and science integration may lack the experience necessary to successfully combine the two. With state and national standards changing and the general direction of education shifting every couple of years, teachers may feel as if integrating the two subjects might be only a "flash in the pan" in the field of education.

Integrating with Standards

Many school districts, mine included, now use what is called backwards design for curriculum planning. This method focuses on results and standards in order to build coherent curriculum. The book Understanding by Design lists three basic steps to the backwards design process (Wiggins & McTighe, 1998):

1. Identify desired results.
2. Determine acceptable evidence.
3. Plan learning experiences that lead students to desired results.

By organizing the design process and including standards that cut across both curriculums, this process can be taken one step further (Drake and Burns, 2004). Cutting across curriculums does more than just force students to memorize facts or answer "yes" or "no" questions, it encourages higher level thinking skills. Wiggins and McTighe call these skills "interdisciplinary concepts" and "enduring understandings" (Wiggins & McTighe, 1998). In general, Drake and Burns point out that the most commonly mentioned skills across all standards included the following (Drake & Burns, 2004):

- Research
- Scientific method-inquiry
- Problem solving
- Communication
- Design and Construction
- Presentation
- Comparison

- Prediction
- Making charts and graphs

Not surprisingly, these are skills that appear time and again in present day math and science standards. The *Next Generation of Science Standards* state that scientific content and knowledge simply isn't enough anymore and that students need to be able to demonstrate crosscutting skills and engineering practices like the ones mentioned above. Classroom instruction will involve learners by using scientific processes and crosscutting concepts in order to develop scientific concepts and understandings (Krajcik, 2013). This is particularly true within the physical science core standards, where students build on foundational ideas to explain phenomena in other disciplines (Krajcik, 2013).

Mathematics is a subject that can easily be integrated into natural science curriculums including biology, chemistry, and physics (Luneeva & Zakirova, 2017). Their research found that in general math was a subject in which project-based learning was hard to implement without also integrating outside content within the curriculum. In one instance, students with learning disabilities showed a tremendous increase on standardized test scores when participating in a project-based learning environment that intertwined science, math, and agricultural engineering (Foutz, Navarro, et al., 2011). One example shows how teachers were surprised by their lack of content knowledge about the other subject, but when they were given the time and ability to force correlations between the two subjects they were able to grow both in content knowledge of material and assistance with identifying misconceptions (Offer & Mireles, 2009). The flexibility that project-based learning and integration provides teachers enables teachers to meet mandates while leading students in their own explorations (Capraro, 2013). Bringing the 5 Es from the National Science Education Standards (NSES) and standards from the National Council of Teachers of Mathematics (NCTM) together provides many benefits for students in math and science classrooms (Boss, Lee, Swinson & Faulconer, 2010). When examining the two sets of standards, researchers have found that there is little dissimilarity between math and science and that they can be brought together with fourteen shared characteristics (Figure 1). Some specific examples of where science and math have been integrated are as follows:

- "Integrating Biology, Chemistry, and Mathematics to Evaluate Global World Problems." (Kosal, Lawrence, & Austin, 2010)

An interdisciplinary and context- driven course focused on global water issues was developed and taught at the college level. Students designed a semester-long research project, collected and analyzed data, and ultimately presented their results and conclusions to the larger community.

- "Striding Through Time: Using Dinosaur Tracks to Integrate Engineering and Math into the Science Classroom." (Clary & Wandersee, 2014).

Students investigated the relationship between a vertebrate's stride length and speed in high school Biology and Earth Science classrooms by collecting and measuring data, graphing their results, and apply them to dinosaur trackways.

While our educational system has been organized in such a way that science is only for the science classroom and math is only for the math classroom, by taking the time to examine standards from both subjects, one can see that they are much closer than they initially appear. Patterns and relationships found within sets of data bring the two subjects closer together. "Science provides mathematics with interesting problems to investigate and mathematics provides science with powerful tools to use in analyzing data" (Rutherford & Ahlgren, 1991). The beautiful and underrated aspect to science is that it is a discipline that is different from all other content areas. Math can be used as part of computations, graphing, unit conversions, and problem solving. Art and industrial technology can be used to create scientific models and in engineering. English is used in reading and writing about science. Science is everywhere and should be integrated with other disciplines in order to show real-world application.

Combining Project-based Learning & Integrated Curriculum

Combining these two approaches may take a lot of training, preparation, education, and time from teachers but research shows that both of these are effective on their own and researchers and educators alike speculate that combining the two would allow each of them to thrive even more. Interdisciplinary project-based learning would eliminate the fragmented curriculum within subject areas that traditional classrooms and allow for a more natural, deeper understanding of course concepts (Capraro, 2013).

Successful integration at the 9th grade level would help students transition to high school level, where expectations are increased, and time management and study skills are introduced. The collaborative focus to project based learning gives students every opportunity to forge new friendships and gain confidence at their new school. Establishing good study habits and a reliable group of friends early on in high school has shown to be a very important part of high school success (Hertzog and Morgan, 1998).

One way several programs have successfully melded the two formats is by giving projects an engineering focus. Students learn concepts and material better when the result of the project has a specific purpose or use (Valtorta & Berland, 2015). As a matter of fact, students gain a much broader and richer conceptual understanding when the purpose of the project is discussed and emphasized rather than content such as vocabulary or formulas (Valtorta & Berland, 2015). Giving students the opportunity to engineer projects has put coursework in perspective and created ownership amongst the students states some teachers involved in one study (Clary & Wandersee, 2014). Engineering also encourages integration of other content areas as well; there are plenty of examples incorporating technology, computer science, business, English, and industrial technology content into math and science courses (Morgan, Moon & Baroso, 2013). There are many processes and models used to integrate engineering into science and math curriculum, but regardless of the model used, engineering enhances the learning process (Morgan, Moon & Baroso, 2013).

Personal Viewpoint

There were a few limitations to both project based learning and curriculum integration I found while I conducted my research. Most of the drawbacks were centered around a lack of a developed program, time constraints, curriculum planning and a general lack of student/teacher experiences with an integrated project-based learning learning environment (Capraro, 2013). While these downsides were valid and applicable to many situations, it should be noted that they can be negated by teams of educators who communicated with each other and were supported in their schools with planning time, administrative support, and hard work from all of those involved. The opportunity for growth (academically and personally) in students and teachers involved in an integrated project-based learning environment is simply too great to pass up.

I feel as if I could be more effective in an academy setting where I'm one of a team of educators. I know I have benefitted from professional development in my school in the past and feel as though daily Professional Learning Communities meetings and peer observations would make me a much more effective teacher. While I've had the opportunity to teach several different science courses relating to physical science to a variety of different ages and academic levels of students, I will be the first to tell you I have room to grow when it comes to reading, writing, or even specific mathematical terminology and strategies. While science is a discipline that uses many other content areas within its concepts of study, many science teachers lack skills in these particular methods. For me, getting the chance to work collaboratively with a motivated and focused team of teachers is one of the most exciting parts of this endeavor.

Summary

Research shows that when project-based learning and integrated curriculum are supported, students thrive. This chapter looked at how both project-based learning and integrated curriculum are rooted in both history and research. While there are some negatives to these methods, the benefits far outweigh any drawbacks that researchers have found. Both styles of learning fit state and national math and science standards well and also my personal school situation. Combining them is certainly doable, especially when the academy is well supported and teachers are collaborative and driven.

The next chapter will describe the framework of my project, which will include the curriculum for a unit of study in an integrated science and math 9th grade course. Since this project will be rooted in a researched based framework, I will provide a rationale for what framework I chose. Next I will define the audience for who this project will be intended and describe how I will measure project effectiveness and measure student success. While the focus of the project is to complete it by the beginning of the 2018-19 school year, the short-term goal will be to implement a couple of lessons or a unit during the spring of the 2017-18 school year.

CHAPTER THREE:

Methodology

Introduction

I knew that to answer the question, "How can a 9th grade math and science curriculum become integrated as part of a project-based academy?" it was going take a lot of patience. One of the most exciting parts of coming together with my group of coworkers was to begin the process of putting the two pieces of curriculum together and actually developing projects that work with existing curriculum, standards, and course sequencing. Digging deep into our respective standards wasn't an easy task and developing original, applicable curriculum was my biggest challenge. After all, research does say that if there is any difficulty surrounding both project-based and integrated curriculum it comes in the planning and development stages.

The purpose of this chapter is provide an overview of the project; detailing the framework, audience, context, timeline, and rationale for completing this project. A few details of the project will be dictated by my specific situation, as there are parameters the state and district have set forth that make options limited. Having said that, the lack of teacher preparation programs and strategies relating to these topics makes the possibilities endless. I consider myself fortunate to be able to be in a situation where the there are few guidelines as it provides me with a freedom to plan specifically to my situation.

Project overview

The Understanding by Design framework by Wiggins and McTighe provided the structure, consistency, and level of detail that leadership in my school district was looking for. Please see Appendix A for a blank template relating to the UbD framework. Transitioning to both a project-based and fully integrated classroom was gradual, as moving too quickly might be a shock to both the students and teacher. At the beginning, there certainly were days in which the academy looked more like a traditional classroom than one with a project or integrated focus. But as we progressed through year one, projects and integration were implemented more frequently and to more depth. I started by creating a unit that was fully integrated between math and science with foundations of project-based learning. The project component to this capstone was to create this unit from start to finish, including everything from introductory activities and labs to the culminating project at the conclusion of the unit. Depending upon how the unit went, I was able to open up the curriculum even more to include more aspects of integration and project-based learning, but that will likely be a few years down the road.

Audience

The most obvious audience of this project is myself and other teachers who embarked on integration, project-based learning or a combination of the two. Since I planned to invest lots of time and resources into the project and I wanted to make this project as applicable as possible, I was able to implement this curriculum into the course I teach. I've only taught the 9th grade level twice during my ten years of experience; so physically being able to teach to that age level became imperative once this project was created. Since this was curriculum design, teachers, myself included, wanted the curriculum to be well researched, detailed, and adaptable enough for any situation. Research has shown that one of the biggest struggles to both project based learning and subject integration is the lack of clarity in preparation, resources, and training for teachers; my hope was that this project will at the very least provide teachers with specific examples of curriculum and any trials and errors that I encountered in my journey.

The most important part of my project was the students in my classroom. This Masters program has shown me countless ways to engage, interact, and encourage curiosity in my students, so I looked to the project as one last opportunity to do exactly that. Obviously, I wanted this to reach out beyond the scope of just this class and students I currently had at the time. So creating a curriculum based on standards that are about to be adopted by our state and generating a unit with future students in mind, I hoped to make this curriculum adaptable and flexible enough to withstand the test of time.

Location

Working in a large school in an outer ring suburb in the upper Midwest definitely has its perks. Students are, for the most part, driven and encouraged to pursue additional education beyond high school. While the school community has and will continue to be supported, there are certain aspects to the school that need to change. Since the school is so large, some students lacked an identity and feel as if they have no choices while in school. Their options seemed limited, as there are too many academic requirements and too many students for their opinions, issues, and voices to be heard. Although many students felt prepared for higher-level education upon graduation at my school, many lacked the critical thinking skills that are developed in integrated classrooms and communication skills that honed in a problem-based learning atmosphere. An academy that looked like "a school within a school" was one of the first ones of its kind in public education in the state.

As I stated before, minority populations in my school are growing and undoubtedly there are always a few kids who fall through the cracks and whose needs are not met. Both integrated and project-based learning classrooms showed the ability to help all students, including minority students, students who are in special education, and even the gifted/talented.

With state standards being restructured in both science and math curriculums, now was as good as a time as ever take a closer look at the standards and reorganize curriculum in my school. Course sequencing needed to be adjusted in order to fit this unit in but new standards and the schedule of the academy gave me the freedom to make it work. Given that I worked with at least one other teacher, the support, feedback, and resources were there to help me as I created and implemented this project.

<u>Timeline</u>

The project began in January 2018 with the hope for implementation during the 2018-19 school year. That provided me with enough time to gather research, dig into the standards, and develop worthwhile projects for ninth grade students. There were times during the spring of 2018 when I was be able to try out parts of my curriculum plan. The actual curriculum design was submitted via a capstone on or around May 6th. Some parts of the unit were classroom tested, others not so much.

Measuring success

According to the project-based learning workshop I attended last summer, one component that shouldn't change much in a project-based classroom is grading and assessments. While rubrics were developed to help with checkpoints throughout the project, students were still expected to take formative and summative assessments throughout the unit. Teachers wanted to give the same assessments as what they'd been giving previously or as other traditional classes simply for the fact that it was easier to understand program effectiveness and in order to compare with traditional teaching strategies and testing. Note that if there was a true integration happening in the program, the teacher shouldn't look at specific science or math portions of the tests but rather both of them combined. Students should expect to see a teacher that is continuously monitoring their progress through formative and summative assessments throughout the unit.

One of the unique aspects to a project-based learning environment is how well it tailored itself to an advisory relationship that teachers were able to establish with their students. Successful advisor relationships were built upon a strong personal connection between the teacher and student and frequent check-ins in order to report progress. The teacher became invested along with the student in the project and the responsibility of student learning became shared between the students and teacher. Once this learning culture was established, learning occurred naturally and teachers didn't feel burdened by a lack of preparation or overwhelmed with student concerns or questions. This was the exactly the type of classroom I looked forward to leading when I implemented a fully integrated, project-based classroom in an academy setting.

Summary

This chapter included a project description of my project, which allowed me to provide a framework for the curriculum design. Although I designed a curriculum for teachers, the main beneficiary of this project was students. To provide context, I also described my community, school district, coworkers, and academy itself. The timeline I described indicated I wasn't in a hurry, which allowed me to be purposeful in my planning and realistic in my expectations. As far as assessment went, I indicated that a project-based classroom worked perfectly for kind of classroom I want to lead. A classroom where relationships and communication is pivotal to the success of the program and frequent check-ins are encouraged to support both the teacher and student.

In the next chapter, I will describe how the project contributes to the educational field and share any personal reflections and findings found by me during the research, construction, and implementation of the project. Then I will reflect upon any limitations or modifications that need to be considered by any teacher considering integrating math and science curriculum. Next I describe how the project can evolve and discuss where integration and project-based learning might be headed in the future. Finally I will present any conclusions I find during this investigation; summarizing the pros, cons, and results of the project.

CHAPTER FOUR:

Conclusions

Introduction

This project came to fruition when considering “How can a 9th grade math and science curriculum become integrated as part of a project-based academy?” As a teacher I felt as if there were gaps in my students’ education, particularly when it came to the math and science courses. Math and science standards and curriculum at the 9th grade level have similarities and common language; this project addressed misconceptions between the two and intertwined them in a way that few had done before.

The purpose of this chapter is to highlight what I learned by doing this project and reflect on what kind of contributions it might have on the teaching profession. First I will share my major findings as a result of doing the project capstone. Then I will revisit the literature portion of the capstone and comment on specific sources that helped me as I created the project. After that I will consider any implications and limitations that I encountered while doing my project. Then I will discuss the potential for additional research and look at where course integration might be headed in the future. Finally I will describe how I plan to communicate my findings of this project with others in the education field and how it might be helpful to those who have a similar question or set of observations.

Major Findings

As the project has demonstrated, there are strong and specific connections that can be made across math and science curriculums. I don't think that is a surprise to many, myself included, but what did surprise me was that there weren't nearly as many connections that could be made across math and science curriculums specific to a grade level. For example, many science concepts might either be way above or below where a math student's skill level might be expected to be at and that poses additional challenges for the teacher. While some might see this as a benefit for students who are bit behind or significantly above in their math coursework and an easier way to allow for differentiation in the classroom, I found this to be particularly challenging in my project. Integration might be more successful at higher levels of education, such as calculus and physics or even at the college level. Some teachers might find more success integrating the two at an elementary level, when graphing and basic algebra are being introduced. Others may find a specific unit or two throughout the year that they choose to integrate rather than an entire course. Regardless, integration creates other avenues for teachers to do what they do best: find strategies for different styles and create the best learning environment for each student.

This capstone also showed me how a project-based learning environment can engage and motivate nearly every type of student. I saw students come alive and truly behave like scientists would: asking pertinent and challenging questions, considering variables, drawing conclusions based off concrete data and reflecting upon what they have learned. While I still believe there is some value in traditional formative assessments such as quizzes and tests, a project-based learning environment allows students to show learning through different means and, in my opinion, shows more student growth in learning than any multiple choice test could ever do.

On a personal level, as someone who hasn't written a research paper since high school and doesn't necessarily do a lot of leisure or professional writing, I looked at the writing of this capstone as a huge challenge. In showing that I'm capable of organizing a detailed and comprehensive capstone, I look at this as an area where I experienced a large amount of personal and professional growth throughout the past nine months.

Review of Literature

While searching, reading, analyzing, and sorting through the literature, I found a general consensus that both integrated and project-based classrooms had a positive impact on student engagement and achievement. My project confirmed these findings as students ended our integrated unit with enthusiasm while completing their projects and willingly taking their unit assessments with confidence. A quick survey of test scores shows that students averaged 3-4% higher on this unit test than any other unit test they've taken thus far during the school year.

As stated above, course integration is a difficult process and one that is unique to each and every situation. Although I never quite found literature that was completely similar to mine, I felt that the studies that provided as much detail as possible made it easier to draw parallels to my project and were the most helpful.

One source laid out a detailed plan integrating math and science with motion but didn't use the same curriculum design as I did (Rordin, Johnston, & Walsh, 2016). Others offered studies that showed how math and science are be related but units of study were a bit different (Harvey, 2012 & Kosal, Lawrence & Austin, 2010). Some helped with templates, standards, and curriculum design (Wiggins & McTighe, 1998; Krajcik, 2013). A very thorough and comprehensive piece of literature I found in my research was a text that contained a plethora of information on both project-based learning and math and science integration (Capraro, 2013). Some chapters within this text focused on doing both at the same time, which was exactly the same format as I what I did in my project. Finally, a source found in Hamline's Bush Memorial Library was the most helpful and applicable to my situation. Although the capstone was a thesis, Trucan's study had similar framework, age level, courses, and even geography as what I did in my project capstone (Trucan).

Several times during the capstone practicum course my professor made the point that school districts nationwide are constantly rolling out new initiatives and developing innovative programs. With all of this literature available to us as educators, we would be fools to not use this as we develop and create new programs, locally or nationally. As I found with my capstone project, more often than not, research doesn't lie.

Implications and Limitations

By nature, both integrated and project-based learning require longer chunks of time set aside for collaboration between students and teachers. Depending upon the situation, this might mean that existing schedules would need to be adjusted to accommodate for collaboration. It also might mean that face-to-face meetings are longer but less frequent, which makes class time even more valuable. I wasn't allowed to change the schedule during my project, so I didn't have this specific issue but at a larger school any change to the bell schedule is always met with resistance from some. Aside from the bell schedule, other logistical issues such as class scheduling, physical space, and marketing of the program might arise, but only on a case-by-case basis.

On a larger scale, a shift in the education system needs to occur. An integrated, project-based classroom is not what a traditional classroom has looked like in the past and some would view changes such as these as a waste of time, money, and resources. One could make this argument about a lot of innovative ideas in education but the truth in the matter is that the students we have in the classroom today are far different than students the past, even as little as five or ten years ago.

Future research

As momentum continues to build surrounding project-based classrooms, the hope is that it will be met with the same levels of excitement that my students showed during their projects. Literature shows that project-based learning engages and motivates students, which results in higher academic achievement from most demographics of students. Future research involving project-based learning might continue to look at specific content areas and mixing in other strategies, such as an integrated curriculum, and see how different combinations can further increase engagement and achievement.

Integration between math and science was a logical place to start looking at a combined curriculum but further research involving integration between all courses might give some interesting results. Combining science with other content areas, such as English, social studies, culinary arts, and physical education would give students more options in course selection, even if done on a smaller scale.

Communicating Benefits to Profession

I've found in my ten prior years of teaching that the most effective communicators in a school are the students themselves. Getting them excited about projects or course content trickles into other classrooms and soon other staff members are asking questions seeking that kind of energy in their own. Soon district leadership such as principals and superintendents were visiting my classroom, which was a bit scary at first but I can't think of a better way to communicate than to get leadership believing what is actually happening in the classroom.

I also found that in my project an integrated and project-based classroom not only encourages collaboration between students but also between teachers. The kind of conversations I had in the two weeks during this unit were unlike any other I'd had in my ten prior years of teaching. These were conversations I was having outside of my department and with teachers who had the same or similar set of students.

Summary

This chapter highlighted some of my findings from the capstone and described how I plan to use it for professional growth. Although there were limitations in how I created the project, there is a plethora of literature available describing various studies and as teachers we are used to adapting things for our own situations. Possibilities are endless for both of these topics and they really can be adapted to many situations in future research. The growth I experienced while completing this capstone has motivated me to help others out in the profession and use this as a way to contribute to the education field formally and informally.

As I look back to the day the coworker approached me about an academy where teachers collaborate with each other in order to create integrated, project-based classrooms, I never knew the journey that it would take me on. I approached this capstone like I ask my students to approach their learning: with an open and curious mind that is always striving to get better. Now I see the fruits of my labor and wait for the next adventure to walk through my door… as an educator you just never know when or how that's going to happen.

APPENDIX A

Understanding by Design Planning Format

Plan for Instruction

TEACHER:	DATE(s):
CLASS:	UNIT:

Brief Overview of the Unit:

Information from UbD Stage 1: Desired Results

Content Standards:	
Essential Learnings:	

Differentiated Instruction needed to ensure all learners have access to this learning

Modifications	Accomodations

	The Teacher will…	The Student will…
W Where are we going? What is expected?		
H How will we hook the students?		
E How will we equip students for expected performances?		
R How will we rethink or revise?		

E How will students self-evaluate and reflect their learning?		
T How will we tailor learning to varied needs, interests, and learning styles?		
O How will we organize the sequence of learning during the lesson?		

Plans for after this learning/competency is complete: *What will the students do if they finish early?*

Information from UbD Stage 3 - Learning Plan, Experiences, Instruction and Learning Activities:
Consider the **WHERETO** elements

Information from Stage 2: Evidence
Sufficient and Revealing Evidence of Understanding: Briefly explain if and how it will be used.

Informal Check:	
Quiz/Test:	
Performance Task/Project:	

Resources Used/Materials Needed: Websites, books, video, etc.

Type of Resource(s):	Name of Resource(s):

APPENDIX B

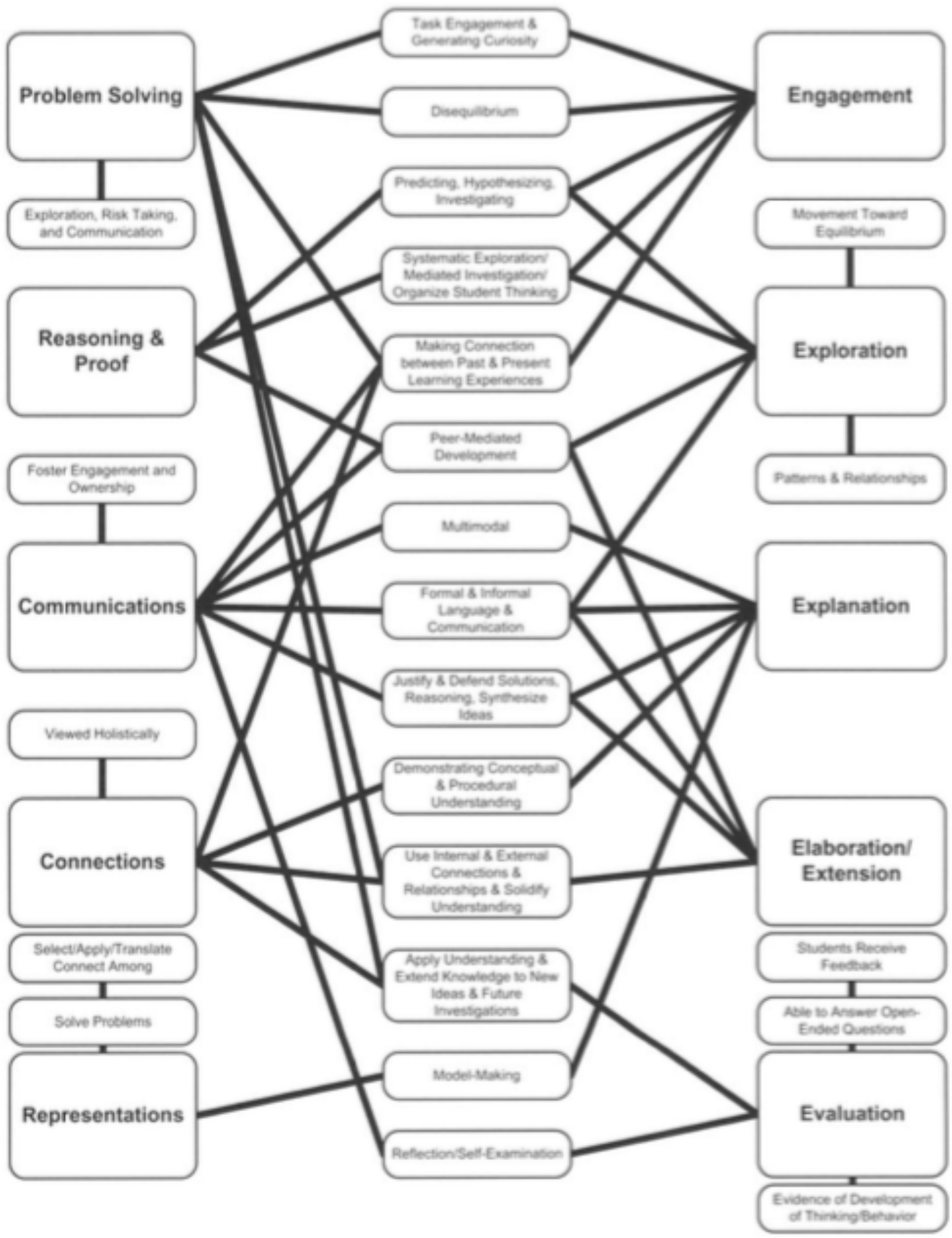

Figure 1: Characteristics among learning processes from mathematics and science education based on discovered characteristics among them. (Boss, Lee, Swinson & Faulconer, 2010)

References

Başkan, Z., Alev, N., & Karal, I.S. (2010). Physics and mathematics teachers' ideas about topics that could be related or integrated. Procedia Social and Behavioral Sciences, 2, 1558-1562.

Berlin, D. F. 1., & White, A. L. 1. (2012). A longitudinal look at attitudes and perceptions related to the integration of mathematics, science, and technology education. *School Science & Mathematics, 112*(1), 20-30. doi:10.1111/j.1949-8594.2011.00111.x

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

Berlin, D. F., & White, A. L. (1994). The Berlin-White integrated science and mathematics model. *School Science & Mathematics, 94*, 2-4. doi:10.1111/j.1949-8594.1994.tb12280.x

Bloom A. (2016). Project-based learning holds back poor pupils. *TES: Times Educational Supplement,* (5222), 8-9.

Boss, 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.

Capraro, R. M. (2013). In Capraro M. M., Morgan J. (Eds.), *STEM project-based learning: An integrated science, technology, engineering, and mathematics*

(STEM) approach (2nd ed ed.). Rotterdam: Rotterdam : Sense Publishers. doi:10.1007/978-94-6209-143-6

Clary, R., & Wandersee, J. (2014). Striding through time. *Science Teacher, 81*(5), 45-51.

Cook, K. (2009). A suggested project-based evolution unit for high school: Teaching content through application.*American Biology Teacher, 71*(2), 95-98.

Crane, E. L. (2015). *Project-based learning in the secondary chemistry classroom* (M.S.). Available from ProQuest Dissertations & Theses Global. (1680510122).

Czerniak, C. M., Weber, W. B.,Jr, & Sandmann, A. (1999). A literature review of science and mathematics integration. *School Science & Mathematics, 99*(8), 421-430. doi:10.1111/j.1949-8594.1999.tb17504.x

Davison, D. M., Miller, K. W., & Metheny, D. L. (1995). What does integration of science and mathematics really mean? *School Science & Mathematics, 95*, 226-230. doi:10.1111/j.1949-8594.1995.tb15771.x

Dewey, J. (1938). *Experience and education*. New York: Macmillan.

Drake, S., Burns, R., & Association for Supervision and, Curriculum Development. (2004). *Meeting standards through integrated curriculum* Association for Supervision and Curriculum Development.

Foutz, T., Navarro, M., Hill, R. B., Thompson, S. A., Miller, K., & Riddleberger, D. (2011). Using the discipline of agricultural engineering to integrate math and science. *Journal of STEM Education: Innovations and Research, 12*(1-2), 24-32.

Geier, R., Blumenfeld, P. C., Marx, R. W., Krajcik, J. S., Fishman, B., Soloway, E., & Clay-Chambers, J. (2008). Standardized test outcomes for students engaged in inquiry-based science curricula in the context of urban reform. *Journal of Research in Science Teaching, 45*(8), 922-939.

Han, S., Capraro, R., & Capraro, M. (2015). How science, technology, engineering, and mathematics (stem) project-based learning (PBL) affects high, middle, and low achievers differently: The impact of student factors on achievement. *International Journal of Science & Mathematics Education, 13*(5), 1089-1113. doi:10.1007/s10763-014-9526-0

Heflich, D. A., Dixon, J. K., & Davis, K. S. (2001). Taking it to the field: The authentic integration of mathematics and technology in inquiry-based science instruction. *Journal of Computers in Mathematics & Science Teaching, 20*(1), 99-112.

Hertzog, C. J., & Morgan, P. L. (1998). Breaking the barriers between middle school and high school: Developing a transition team for student success. *NASSP Bulletin, 82*(597), 94-98. doi:10.1177/019263659808259716

Holmes, V., & Hwang, Y. (2016). Exploring the effects of project-based learning in secondary mathematics education. *Journal of Educational Research, 109*(5), 449-463. doi:10.1080/00220671.2014.979911

Judson, E., & Sawada, D. (2000). Examining the effects of a reformed junior high school science class on students' math achievement. *School Science and Mathematics, 100*(8), 419-25.

Kanter, D. E., & Konstantopoulos, S. (2010). The impact of a project-based science curriculum on minority student achievement, attitudes, and careers: The effects of teacher content and pedagogical content knowledge and inquiry-based practices. *Science Education, 94*(5), 855-887. doi:10.1002/sce.20391

Kiray, S. A. (2012). *A new model for the integration of science and mathematics: The balance model.* ().Online Submission.

Kosal, E., Lawrence, C., & Austin, R. (2010). Integrating biology, chemistry, and mathematics to evaluate global water problems. *Journal of College Science Teaching, 40*(1), 41-47.

Krajcik, J. (2013). The next generation science standards: A focus on physical science. *Science Teacher, 80*(3), 27-37.

Kunberger, T. (2013). Revising a design course from a lecture approach to a project-based learning approach. *European Journal of Engineering Education, 38*(3), 254-267.

Kurt, K., & Pehlivan, M. (2013). Integrated programs for science and mathematics: Review of related literature. *Online Submission,* Retrieved from http://search.ebscohost.com/login.aspx?direct=true&db=eric&AN=ED543277&site=ehost-live

Langbeheim, E. (2015). A project-based course on newton's laws for talented junior high-school students. *Physics Education, 50*(4), 410-415.

Larmer, J., & Mergendoller, J. R. (2010). 7 essentials for project-based learning. *Educational Leadership, 68*(2), 34-37.

Luneeva, O. L., & Zakirova, V. G. (2017). Integration of mathematical and natural-science knowledge in school students' project-based activity. *EURASIA Journal of Mathematics, Science & Technology Education, 13*(7), 2821-2840.

Mason, T. C. (1996). Integrated curricula: Potential and problems. *Journal of Teacher Education, 47*, 263-270. doi:10.1177/0022487196474004

Montessori, M. (2016). *The absorbent mind*

Munakata, M., & Vaidya, A. (2015). Using project- and theme-based learning to encourage creativity in science.*Journal of College Science Teaching, 45*(2), 48-53.

Offer, J., & Mireles, S. V. (2009). Mix it up: Teachers' beliefs on mixing mathematics and science. *School Science and Mathematics, 109*(3), 146-152.

Pang, J., & Good, R. G. (2000). A review of the integration of science and mathematics: Implications for further research. *School Science & Mathematics, 100*(2), 73-82. doi:10.1111/j.1949-8594.2000.tb17239.x

Piaget, J., & Inhelder, B. (1969). *The psychology of the child*.

Rordin, M. N., Johnston, J., & Walshe, G. (2016). *Making mathematics and science integration happen: Key aspects of practice*.

Rutherford, F. J., & Ahlgren, A. (1990). *Science for all Americans*. New York: Oxford University Press.

Schwols, A., & Miller, K. B. (2012). Identifying mathematics content and integrating it into science instruction. *Science Scope, 36*(1), 48-52.

Solomon, G. (2003). Project-based learning: A primer. *Technology & Learning, 23*(9), 20-30.

Stinson, K., Harkness, S. S., Meyer, H., & Stallworth, J. (2009). Mathematics and science integration: Models and characterizations. *School Science & Mathematics, 109*(3), 153-161. doi:10.1111/j.1949-8594.2009.tb17951.x

Truchan, K. (2010). *Effects of integrated instruction on the achievement of freshman math and science students*

Valtorta, C. G., & Berland, L. K. (2015). Math, science, and engineering integration in a high school engineering course: A qualitative study. *Journal of Pre-College Engineering Education Research, 5*(1), 15-29.

Watanabe, T., & Huntley, M. A. (1998). Connecting mathematics and science in undergraduate teacher education programs: Faculty voices from the maryland collaborative for teacher preparation. *School Science and Mathematics, 98*(1), 19-25.

Wiggins, G. P., McTighe, J., Kiernan, L. J., Frost, F., & Association for Supervision and Curriculum Development. (1998). *Understanding by design*. Alexandria, Va: Association for Supervision and Curriculum Development.

Zolnierczyk, J. A. (2016). *Perspectives of teachers regarding the integration of mathematics and science at the secondary school level* (M.Ed.). Available from ProQuest Dissertations & Theses Global. (1826829177).