Fall 2017

Exploring Benefits And Pedagogical Considerations For Integrating Quantitative Literacy In Science At The Middle Level

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Plan B Project

Submitted in partial fulfillment of the requirements
for the degree of Masters in Science in Natural Science/Mathematics
in the Science and Mathematics Teaching Center
of the University of Wyoming 2017

Laramie, Wyoming

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Abstract

Integrative practices between mathematics and science are critical and essential for students when approaching real-world problems and applications. This literature review explored the possible benefits and considerations for integrating quantitative literacy into the middle level science classroom. Explorations included understanding the standards for mathematics and science, identifying connections, and comparing and contrasting the learning cycle for science and the process standards for mathematics. In researching the standards and the learning processes, the underlying mechanisms and the intricate relationship between mathematics and science was revealed. Included in the literature review is an example of how to integrate quantitative literacy into science. The example steps outside of common integrative practices involving measurement and probability and identifies the applications for algebraic calculations in a biology laboratory. The research on this topic was not exhausted. The findings for the research that was explored concluded that there are benefits to integrating quantitative literacy into science. The research indicated that science is utilized to demonstrate real-life, authentic examples of mathematical concepts, and that mathematics is used as the quantifiable application to solve and analyze scientific phenomena. The research concluded that a benefit of integration is that science and mathematics provide context and relevancy to each other's respective content. This context and relevancy helps students identify and experience real-world applications and use concepts explored in both science and mathematics.

Acknowledgements

Many thanks and gratitude to the faculty and staff of the Science and Math Teaching Center along with Coe Library who helped with the contribution and support of this Plan B Project. I want to take the time to say thank you to the many people that helped me, most notably my Master's committee members Alan Buss, Naomi Ward, and chair Linda Hutchison. A special thank you to Linda Hutchison for the extensive time and effort that went into helping me revise and refine this body of work. I would also like to acknowledge Ana Houseal for her help and support in narrowing the scope and sequence of my Plan B project that provided me with a concentrated focus. In addition, I would like to thank my peers in the Mathematics cohort; I have greatly appreciated the unwavering support and collaboration you have provided during my time in this program with you, thank you.

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Chapter 1

Introduction

Background And Purpose

Best teaching practices are a driving force in education. Improving them is a continual focus for educators, administrators, and school board members along with many other invested partners in education. Among the many instructional strategies and approaches that are applied in the classroom, integration of two content areas or more is one that is utilized. This literature review will specifically focus on integrating quantitative or mathematical literacy skills into the middle level science classroom.

There are many definitions circulating in the literature regarding quantitative literacy; the working definition that will be used in this literature review is provided below:

> Mathematical literacy is an individual's capacity to identify and understand the role that mathematics plays in the world, to make well-founded mathematical judgments, and to engage in mathematics in ways that meet the needs of that individual to be a constructive, concerned, and reflective citizen. "Mathematical literacy" is used here to indicate the ability to put mathematical knowledge and skills to use rather than just mastering them within a school curriculum. (Programme for International Student Assessment, 2003, p. 20).

Quantitative literacy can be found throughout scientific fields and necessitates the need for specific mathematical skills (Mayes, Peterson, & Bonilla, 2013). For instance, the studies of Environmental Science involve the examination of different ecological systems and related components including the impact of human dynamics (Mayes et al., 2013). This involves taking a study of macroscopic principles and tracing the relationship to its microscopic counterparts (Mayes et al., 2013). In order to fully understand the depth of the principles at the macroscopic level, there has to be an integral quantitative literal understanding of the chemistry and physics involved (Mayes et al., 2013). This leads to an understanding of the underlying foundation of the relationships found within these larger environmental systems (Mayes et al., 2013). In 1989, Shoemaker defined integration as “providing instruction that cuts across subject matter lines, bringing together various curricular aspects into meaningful association that focuses on broad areas of study” (Douville, Pugalee, and Wallace, 2003, p. 388-389).

Berlin (1989) reported students in the United States are not measuring up in the fields of mathematics and science in comparison with their peers in other countries. As a response, during the educational reform that took place in the 1980s, different curriculum models were developed to integrate mathematics and science. The objective was to improve student test scores in both mathematics and science by integrating the two contents, in order to increase student comprehension and understanding (Berlin, 1989). The educational reform went a different direction, and the new curriculum models did not progress any further. Two curriculum programs that were developed but not adopted are GEMS (Great Explorations in Mathematics and Science) and AIMS (Activities to Integrate Mathematics and Science). The goal of the curriculum models was for students to be immersed in and experience real-world applications. Even though these curricula were not adopted into schools, integration remains an opportunity for educators to demonstrate the relevant and applicable nature that mathematics brings to scientific concepts.

Mathematics and science are two systems of thought that work in tandem (Douville et al., 2003). Mathematical concepts explain phenomena in science, which is one of many fields that put mathematical concepts into practice. In addition to science, quantitative literacy is apparent across all subject areas, including examples of "logic and reasoning in language and communication; ratio and rhythm in music; scale, proportion, and geometry in art; recognition of patterns in history and political science; and assertions in philosophy and classics" (Steen, 1999; Owusu-Ansah, Chew, & McDaniel, 2006, p.3). Mathematics is used to quantify scientific concepts and explain themes and patterns numerically (Douville et al., 2003). Science, in turn, demonstrates the relevancy of mathematical thinking and illustrates the utilization of mathematical concepts (Douville et al., 2003).

There are countless analyses to be found in the literature regarding the relationship between mathematics and science. The research addressed the idea that integrating quantitative literacy into science does serve a purpose to assist students in mastering these concepts. The integrative process is applicable and necessary when searching for real world applications and authentic solutions. "The ability to think quantitatively is essential for citizens of a democracy, for it allows them to make informed decisions at home, in the workplace, and on complicated national and international issues that impact their local communities" (Mayes, Peterson, & Bonilla, 2013, p.4).

Statement Of Problem

Conventionally, in the classroom, content areas are taught separately (Wicklein and Schell, 1995). These disciplines, where one concept builds off of another, like mathematics and science, are segregated and explored in isolation. Wicklein and Schell (1995) explain that with this independent teaching approach students can struggle to see and simulate the connection and synthesis of new ideas when faced with an authentic challenge. In conjunction with disciplines being taught separately, students may miss opportunities to identify the links and applications between them. Collectively, students have been conditioned to receive content instruction in isolation. In consequence, students may not have received the necessary practice to combine and synthesize ideas and subjects to create an appropriate solution when presented with higher-level problems.

Students need continual opportunities to take the concepts they have learned in mathematics and apply them in science, reassembling the pieces into a larger whole to solve a realistic problem (Wicklein and Schell, 1995). This integrative approach demonstrates the relationship of subject matters and how each are used to solve a corresponding objective.

Objectives

This literature study set out to explore benefits and pedagogical considerations for integrating quantitative literacy into science at the middle school level. Several focal points were examined, which surveyed the multitude of benefits and the underlying mechanisms for integrating mathematical language into science. Key components of the mathematics and science standards are presented to highlight the opportunities to integrate quantitative literacy into the middle level science classroom. The focal points include examples of ways to integrate the two contents in addition to possible reasons why teachers may not integrate mathematics and science. Reasons include a professed lack of knowledge, lack of awareness of possible benefits, and/or lack of support for implementation.

The analysis of the literature examined the culture that has been established in the classroom where contents are separated and taught individually (Wicklein and Schell, 1995). This educational structure does serve a purpose and has its' benefits. This format, however, may not adequately prepare students to conceptualize higher-level ideas. It does not fully allow for students to collaborate and synthesize a resolution to a given problem that simulates a real-world challenge (Wicklein and Schell, 1995).

Statement Of Purpose

The purpose of this research was to explore the pedagogical considerations and benefits of integrating quantitative literacy into science and how this integration enhances the learning, mastery of concepts, and deepening of comprehension levels. The exploration included the underlying mechanisms of the interconnectedness of mathematics and science that allows for connections to be made across content. The research investigated the opportunities that cross-curricular teaching provides for higher-level assemblies of the information and support of real-world experiences. Examinations included the possible deterrents to integrating content such as the perceived inabilities of teachers to integrate the enriching content they do not primarily teach. Also included, was the lack of professional development needed to support the organization and conceptualization of integrative practices (Stinson, Harkness, Meyer, & Stallworth, 2009).

Research Question

What are benefits and pedagogical considerations for integrating quantitative literacy into science at the middle level?

Significance

The significance of this research is to enable teachers to inform their students about the myriad of benefits and applications of quantitative literacy and science integration. Through integration, students can examine the relevance of a given concept through the application of another content. Ultimately, the hope is that readers will take away the reasons why integration of quantitative literacy is important, an understanding that integration is coherent in nature, and the necessity of integration when exploring mathematics and science in meaningful ways.

Chapter 2

Literature Review

History And Culture Of Integration

Subject integration as an instructional practice dates back to the 1890s (Brinegar & Bishop, 2011). It emerged at this time as a way to grow and improve upon instructional strategies (Brinegar & Bishop, 2011). The reasoning for incorporating this strategy has not changed in the past 125 years. The goal of integrating content is to connect related themes and to apply and synthesize the concepts in an authentic manner to provide a deeper meaning of the concepts. However, over the past several decades, integration has not been a priority as an instructional practice due to the increased focus on student achievement, standardized assessments, and accountability, especially in mathematics and reading (Berlin, 1989).

A Push For Curriculum Integration

James A. Beane (1995), who was an advocate for curriculum integration in the 1990s, discussed in his writings that when integrating content, students have opportunities to meld what they know with what they are learning. Students are able to connect themes to construct an authentic resolution. Beane stated “since life itself does not know the boundaries of compartments of what we call disciplines of knowledge, such a context uses knowledge in ways that are integrated” (Beane, 1995, p. 616). Beane’s statement coincides with Sherrod, Dwyer, and Narayan’s (2009) viewpoint that the boundary between mathematics and science is indistinguishable. Beane argues that students require a knowledge base in order to further compound related ideas, which enable students to construct an authentic resolution (Beane, 1995). Baumgartner, Biga, Bledsoe, Dawson, Grammer, Howard, and Snyder (2015) relate to this argument by explaining that students need practice identifying compounded and related ideas between mathematics and science. Beane (1996) explains that anyone, who is an advocate and pushes for integration, is following in the footsteps of pioneers in this field including John Dewey and L. Thomas Hopkins. The efforts for integration began to make a heavy imprint during the early 1900s especially during the 30s and 40s (Beane, 1996). Beane (1996) further identified Dewey and Hopkins as examples of innovators who have written papers that served as a voice for the need of integration. The essence of integration incorporates thematic units of study where the ideas are centered on an issue or problem and invite creative problem solving and resolutions from more than one content area (Beane 1996).

In the interest of clarity, Beane (1996) provides an informative definition where he expands on this idea of what integration is:

> The idea of curriculum integration involves four dimensions. First, the curriculum is organized around problems and issues that are of personal and social significance in the real world, usually identified through collaborative planning by teachers and students. Second, learning experiences related to the organizing center are planned so as to integrate pertinent knowledge in the context of the organizing centers without regard for subject area lines. Third, knowledge is developed and used to address the organizing center currently under study rather than to prepare for some later test or grade level, or to accumulate specific facts or skills

> from some state or district list. Finally, emphasis is placed on substantive projects and other activities that involve real application of knowledge, thus increasing the possibility for young people to integrate curriculum experiences into their schemes of meaning and to experience the democratic process of problem solving. (Beane, 1996. p. 6).

History Of Science Education

The history of formal science education in school dates back to the 1800s. Secondary science was reserved for the elite and individuals of high social standing (Chiappetta, 2008). At that time instructional practices in science were much more basic and science itself was used more for references and fact checking. The primary strategy was the didactic approach, which is a questioning strategy to illicit ideas from students. This strategy is also sometimes referred to as the Socratic method; it is discussion-based where the teacher asks questions, and the students answer in a continual dialogue format in which critical thinking is the focus. Over time, the method by which science is taught has evolved. In the beginning of science education, the didactic approach was a commonly used method, but in more recent science education, science inquiry is more commonly used. Inquiry focuses on a student's ability to investigate a phenomenon and to make inferences in the process (Karsai and Kampis, 2010). To make inferences, students take what they have previously understood, and they combine it with incoming knowledge to develop a new understanding about the concept they are investigating.

Dewey's Argument For An Increased Focus On Science Processes

Since the beginning of science education in a school setting, science was always regarded as a large body of facts to dispense to students. The focus was to deliver factual knowledge that was relevant to a specialist. For example, the scientific details, that a biologist or a chemist would deem important to know and be able to utilize within their respective disciplines, were taught and memorized, thus making science a factual rather than an integrated experience. John L. Rudolph wrote a piece about John Dewey's beliefs on the utilization of science as a method for learning versus a body of facts (Rudolph, 2014). The article reflects on the concerns that Dewey had about the approach used to teach science and the product that it yielded in terms of the information gained by students. His concern was that high-level content knowledge was neither purposeful nor meaningful to someone who did not intend to use that knowledge in such a manner as a specialist might. Dewey's intent was to advocate for the appropriate knowledge base that students would receive in science class. His argument concentrated on how the focus of science education should revolve around the method by which science is approached. It should be viewed as a discipline versus a body of facts to be referenced as needed. His point was that one of the distinguishing elements of science is that it can be used to explore and explain natural phenomena.

Dewey explained that by understanding the nature and process of the scientific approach, students would gain much more, and their intended focus did not have to be directed towards a specific discipline. Comprehending, science as a process enables students to move from a lower level of recalling facts to a higher-level of learning, where students can analyze and synthesize concepts. The point was that in day-to-day living, one's ability to perform a job or task relies on their ability to analyze a problem, consider the options, formulate a plan, and resolve the issue. Dewey's case was that the natures of performing a job, especially ones that have an engineering aspect to it, mimic the design process.

The design process includes different steps within a cycle that is a scientific process used to solve a problem or design a prototype. Many occupations, especially ones connected to a science discipline, utilize this process. There can be various steps but in general the procedure in the design process includes identifying the problem/need, asking questions, collecting data, brainstorming ideas, developing possible solutions, test idea/model, and analyze results (Chicago Architecture Foundation, 2012-2016). After the concluding step of analysis, the problem is resolved or professionals depending on their need or purpose may revisit the cycle. The cycle is revisited in order to improve their design or to come up with an enhanced resolution. The design process is one that has evolved into a cultural method used in many engineering, architectural and science based disciplines today. The foci of Dewey's argument is that this method of problem solving requires science based skills in order to succeed in a given work/task force and is not solely accomplished by the use of scientific facts (Rudolph, 2014).

Current Science Education- Development Of The Next Generation Science Standards

The foundation of understanding science education is to first explore the standards and science literacy efforts that have been put in place to drive science education. The Next Generation Science Standards (NGSS, 2013) were developed in an effort to mimic the unified goal of Common Core State Standards for reading and mathematics in addition to developing a structure for science education that incorporates goals for 21st century learners (NRC, 2012). Rich (2010) explains that this idea of 21st century learning includes the expectation of "core competencies such as collaboration, digital literacy, critical thinking, and problem solving" (para.1). Some of the driving forces to develop the NGSS were to improve the achievement levels of U.S. students in not only science but mathematics as well (NGSS, 2013).

Our nation's workforce has continued to evolve more towards a technologically driven force (NRC, 2012). It is a workforce where the emphasis is on the ability to innovate and come up with scientifically and mathematically based resolutions. To adapt to this growing culture, there was an expressed need to develop standards that focused on scientific and technological literacy with an emphasis on engineering practices and crosscutting concepts like mathematics and computational thinking (NRC, 2012). There were several organizations and hundreds of individuals that worked on the creation and development of a framework for science education; most notably this included the National Research Council (NRC), Achieve Inc., the American Association for the Advancement of Science (AAAS), and the National Science Teachers Association (NSTA) (NRC, 2012). The individuals who met as a committee and developed this framework and criteria for science education established three areas of focus: Scientific and Engineering Practices, Crosscutting Concepts, and Disciplinary Core Ideas.

The standards of these foci are included in the following sections along with the mathematics standards. These standards have been included and teased apart to provide a survey of all the different strands of mathematics and science. The depths to which mathematical and scientific ideas can be cross-correlated are complex and multifaceted. The standards are delineated for the reader in an effort to recognize the many different avenues and possibilities for connecting mathematical and scientific principles.

Scientific And Engineering Practices

Scientific and Engineering Practices concentrate on the design process and the skills necessary for asking questions, conducting research, and building models and prototypes. Scientific and Engineering Practices focus on the scientific processes and applications for conducting an experiment. They engage in the process of making observations, asking questions, and formulating an argument that is substantiated by lines of evidence. Students will demonstrate their mastery of these skills and depth of knowledge by their ability to analyze and interpret various forms of data (NRC, 2012).

Crosscutting Concepts

Crosscutting Concepts focus on the concepts that are transverse and apparent throughout the different scientific disciplines. Ideas such as quantity, energy, patterns, cause and effect relationships, structure and function, and stability and change are not exclusive to any one field of science. Rather, these concepts can be explored in any given discipline in science. For example, systems and system models are crosscutting concepts and can be explored in all of life, earth, space, physical, and chemical sciences; they are not restricted to any one of those given practices (NRC, 2012).

Disciplinary Core Ideas

Disciplinary Core Ideas are constructed as follows: Physical Sciences, Life Sciences, Earth and Space Sciences, and Engineering, Technology, and Applications of Science (NRC, 2012). The Physical Sciences include the study of physics and chemistry where the focus is on identifying what matter is and how it behaves at the microscopic and macroscopic levels. The focus is to explore matter in motion, the forces that act upon it, and the proponents that determine its physical and chemical behavior. Even though energy is a crosscutting concept, the mechanisms of energy itself are explored purposefully in the physical sciences because they explain the characteristics and behaviors of molecules (NRC, 2012).

Life Sciences focus on the study of life and how organisms interact with the biotic and abiotic factors in its surrounding area. Further studies include the relationship between biotic and abiotic factors present in ecosystems and biomes. This field studies the criteria for life and the intricacies of these processes by which live organisms pass on their traits to the next generation. The history and diversity of life is also explored and how it has changed and continues to change over time (NRC, 2012).

Earth and Space Sciences include the study of the structure and systems of Earth and Space. It focuses on the relationship between astronomical objects and our planet, including how those relationships can affect, impact and influence our daily lives and the future implications on our planet (NRC, 2012).

Engineering, Technology and Application of Science focus on how general science concepts are utilized and applied within engineering and technology. The variety of engineering fields and the focal points of these disciplines enable students to learn and understand the impact and developments caused by human interaction on this planet (NRC, 2012).

National Council For Teachers Of Mathematics Education

The National Council of Teachers of Mathematics (NCTM, 2016) outlines a set of content standards and a set of process standards. The content standards encompass the five disciplines of mathematics which summarize what concepts students should be able to learn and comprehend; these include Numbers and Operations, Algebraic Thinking, Geometry, Measurement, and Data Analysis and Probability (NCTM, 2016).

Numbers And Operations

Numbers and Operations in the K-12 continuum are for students to gain a conceptual understanding of what numbers are and what they represent. This further progresses into the different representation of numbers, i.e. fractions, decimals, and percentages. After the foundational understanding of what numbers are and their various forms has been cemented, students then have to be able to fluently work and perform numerical operations (NCTM, 2016).

Algebraic Thinking

Algebraic Thinking is the ability to decode a collective statement of numbers and symbols in order to understand and apply it to another statement or in another context. This skill is paramount in mathematical ability because it signals a major digression from foundational learning of mathematics into the application of it (NCTM, 2016). Algebraic thinking is the level of mathematics in which a statement comprised of a number, variable or word codes for a certain action to which another action is determined by the completion of the initial task (NCTM, 2016).

Geometric Thinking

Geometric thinking focuses on spatial relationships that are connected and dictated by axioms and theorems. Students first need to understand the relationship and structure of geometric shapes and postulates; the mathematical formulas will follow more naturally if the conceptual understanding is founded first (NCTM, 2016). Geometry is considered to be abstract in nature due to the ability required to analyze and reason spatially with objects and configurations and then support it with a mathematical proof. This abstract quality provides countless opportunities for students to grow in their abilities to reason and justify their mathematical thinking and communication (NCTM, 2016).

Measurement

Measurement is the area of mathematics that is essential to many of life's daily practices because of the commonality and utilization of it (NCTM, 2016). Measurement is vastly transverse between higher level and lower level mathematics, because it serves as an opportunity to practice both basic and intangible levels of mathematics. At the basic level students can practice fundamental operations with measurement, and at the higher level the utilization is abstract when applying engineering and architectural practices (NCTM, 2016). Possibly, Measurement and Data Analysis and Probability are the areas in mathematics that have had the most crossover into a science classroom in terms of efforts and applications of integration (Douville, Pugalee, & Wallace, 2003).

Data Analysis And Probability

Data Analysis and Probability is often referred to or considered to be statistical applications and practices. Data Analysis and Probability revolves around the discipline of collecting, organizing, analyzing and communicating data and the conclusions derived from it (NCTM, 2016). The focus of statistical applications is for students to learn the various methods used to analyze the data. In conjunction with summarizing the conclusions, common mathematical statements and ideas are used, for example measures of center: mean, median, and mode (NCTM, 2016).

The process standards describe the contexts in which students should be able to demonstrate the standards and utilize relative information, which are Problem Solving, Reasoning and Proof, Communication, Connections, and Representations (NCTM, 2016). For instance, the process standard that involves making connections describes the integrative nature of mathematics and that the discipline lends itself to rationalizing how certain phenomena occur, by means of mathematical reasoning and justification of the representation and relationship between numbers (NCTM, 2016).

Underlying Mechanisms For Why Integrating Mathematics Into Science Works

The utilization of mathematics in science is the process by which science phenomena are explained. Science provides the context where mathematical formulas and algorithms can be applied in a manner that is conceptually expressed.

5E Learning Cycle Of Science

The philosophy for unveiling scientific phenomena follows five phases in which science is purposefully taught. The five phases are to allow the saturation of meaningful learning; this is called the 5E learning cycle. The five phases are: engage, explore, explain, elaborate, and evaluate. Ideally, in any learning cycle or unit that is taught in the science classroom, these five phases are presented in the order they were listed (Bosse, Lee, Swinson, & Faulconer, 2010). These phases can be broken up and segmented out either in chunks collectively or individually based on a particular concept being taught. Each of these phases is meant to provide a meaningful learning experience where the transfer of knowledge makes significant and consequential connections, which may not have occurred in any other presentation of the material.

The introductory phase of the 5E learning cycle begins with some kind of event or situation where students engage in a scientific occurrence (Bosse et al., 2010). Students are able to experience and observe first hand the physical or conceptual manifestation of the scientific process at hand. After engaging in the experience, students are given the opportunity to explore with hands-on interactions as they begin to formulate hypotheses that can be tested and inquired through question and answer strategies. Once students have observed, tested hypotheses and identified the various key components working in the process, students begin to develop concrete explanations to the phenomena they witnessed. Students will next elaborate and build onto scientific concepts. They will explore the concepts deeper, extending their personal knowledge and connections to be made. This cycle concludes by students being evaluated in a formal setting or conducting a self-evaluation through reflection of the experience (Bosse et al., 2010). There is a metacognitive process in the last phase where students assess what they have learned and identify how that information was formed and how they came to that understanding. Bosse et al. (2010) found that it is possible to relate this learning cycle with the parallel principles established for mathematics.

NCTM Learning Principles-
The Process Standards

The mathematic learning principles mimic the conceptualization experienced in the 5E learning cycle for science. The NCTM (2016) Principles and Standards for School Mathematics have delineated five process standards that serve as learning principles for mathematics; they are the expectations for students to meet and exceed from pre-kindergarten through 12th grade. The five learning principles for mathematics are: problem solving, reasoning and proof, communication, connections, and representations. Problem solving is the process of making inferences and analyzing the information to determine the connecting points in order to synthesize a deeper understanding of the information. Reasoning and proof is identifying themes, patterns, and the underlying mechanisms which explain why mathematical concepts and relationships work. Communication is analysis, reflection, and evaluation of ideas to help build and deepen the meaning of a mathematical concept. Connections are the ability to recognize, apply and intertwine thematic ideas in mathematics; ideas that serve as the foundation for students to further build comprehension. Representation is the display of one's own mathematical thinking through records, data, and written expression in order to communicate mastery of the concept.

Connecting The Learning Cycles
For Mathematics And Science

There is more than one method to combine the learning goals for each; the following combinations are one example of arrangements that can be made with the learning cycles. *Figure 1.1* displays the layout of the independent learning/processing principles and the description of fusing them together.

Figure 1.1

Example of layout for figures 1.2 – 1.6

Mathematics	**Science**
• Process Standard	• Learning Cycle Principle
Fused Mathematics and Science concepts.	

Problem Solving and *Engaging* (figure 1.2) are both stages where students are expected to struggle with the information and make inferences based on previous knowledge and the incoming concept to develop new learning. The brain is being introduced to a new idea or a component of a new idea, and students will explore it to formulate a new coherent understanding of the information (Bosse et al., 2010). The similarities with problem solving and engaging are that students take new/challenging information and fuse it with their previous understanding in efforts to make sense of the incoming information, how to process it and determine what to do with it. The difference is that with problem solving using mathematical ideas, students cognitively assess what known and unknown components (variables/values) they have in order to solve the problem, whereas with engaging in a scientific demonstration/experiment, students generally observe and experience a tangible production of a scientific concept. They physically interact as opposed to cognitively assess and analyze a problem/scenario.

Figure 1.2

Problem Solving and Engaging

Problem Solving	**Engaging**
• Making inferences • Identifying connecting points to synthesize a deeper understanding of the information	• Experience and observation of a scientific process
Students work through and explore the information, make inferences based on previous knowledge with the incoming concept to develop new learning.	

Reasoning and Proof and *Exploring* (figure 1.3) is about identifying the themes and underlying mechanisms that define the concept. The goal of these stages is to comprehend and relate connecting ideas and establish these relationships cognitively (Bosse et al., 2010). The similarities with reasoning and proof and exploring are that students analyze and attempt to identify interconnected and underlying themes between concepts and establish a relationship between them. The differences are that reasoning and proof is usually a concrete application of the numbers that involves deductive reasoning. Deductive reasoning is when students form a conclusion based on what they already know and have determined to be true. For instance, geometric proofs are generally constructed using deductive reasoning (http://www.livescience.com/21569-deduction-vs-induction.html). With exploration in science, the discipline is more abstract and utilizes inductive reasoning. Inductive reasoning is when students make a generalized conclusion based on a concept/phenomena that was experienced and/or observed.

Figure 1.3

Reasoning and Proof and Exploring

Reasoning and Proof	**Exploring**
• Recognizing themes and patterns • Identifying the underlying mechanisms for how connections and relationships are made	• Explorations are made with hands on interactions • Developing questions and hypotheses
Students identify the themes and underlying mechanisms that define the concept.	

Communicating and *Explaining* (figure 1.4) focuses on analyzing, reflecting, and evaluating ideas to then further develop them in order to deepen a student's understanding. It is important to clarify ideas and themes in order to help reinforce one's thinking and synthesize the learning of new concepts (Bosse et al., 2010). The similarities with communicating and explaining are that students assign meaning to what they are learning and find explicit ways of conveying and expressing their understanding. They also investigate and assess their personal understanding along with discussing it with others who are involved in their learning. The differences are that when students communicate their quantitative literacy, it is based off of theorems and proofs that are determined and accepted to be true. For example, with the inequality of $4 < x + 3$ students will determine that to hold that statement true the value inserted for x, when added to three, must be greater than the value of four. On the contrary, with explanations in science, it is common that students will experience the same observation or demonstration in science class but will interpret it differently than their peers. Therefore, their personal understanding and explanation may differ.

Figure 1.4

Communicating and Explaining

Communicating	**Explaining**
• Analyze, reflect and evaluate ideas to build and deepen concepts	• Develop individual and collaborative concrete explanations for what they observed and experienced
Students focus on analyzing, reflecting, and evaluating ideas to further develop them to deepen understanding.	

Connections and *Elaborations* (figure 1.5) are contingent on being able to find how ideas are interconnected and then form a cohesive whole with the information and its' related themes. These two stages are the points within the learning cycles in which students go deeper in the content and go beyond new learning into the complexities of the discipline (Bosse et al., 2010). The similarities with connections and elaborations are finding how concepts are related and linked to one other in conjunction with the patterns and themes found amongst and between concepts. These ideas can be different in that connections specifically focus on recognizing and applying correlated objectives and themes. Elaborating takes it one step further where relationships are identified and established as a foundation to further the learning and comprehension of the concept as a whole to build from that point on.

Figure 1.5

Connections and Elaborations

Connections	**Elaborations**
• Recognize, apply and intertwine	• Build onto the concept to deepen

thematic and related ideas	their understanding • Extending personal knowledge and connections between concepts being made
The goal is for students to find how ideas are interconnected to form a cohesive body of knowledge and its related themes.	

Representing and *Evaluating* (figure 1.6) extend past the comprehension level into the ability to communicate one's own mastery of the concept. This can be done through records, data, and written expression. The distinguishing characteristic with representing and evaluating is to be able to display one's own personal mathematical thinking in a coherent manner (Bosse et al., 2010). Not only is it critical that at this stage the learning is communicated but also how it was learned. It is the process of metacognition and identifying "How did I come to understand this?" that is vital to conclude the learning cycle so that a new learning cycle can begin with a new concept to help put pieces together for the larger whole (Bosse et al., 2010). This includes showing that the mathematic and science learning cycles can be paired together, showing the commonalities of thought processes, and showing the learning progressions that occur. This demonstrates the underlying mechanisms of how integration works to incorporate these two contents cohesively (Bosse et al., 2010). The similarities with representing and evaluating are that students find individual ways to express and signify their thinking and learning. These ideas can be different in that the evaluation process delves deep into the reflection process that the students engage in during their learning. It is essential that students identify the metacognition process that took place through the learning experience to assess their mastery of the skill, whereas with mathematical representation of a student's learning, this can be communicated with data, tables, graphs, written expression, and other methods. The mathematical communication with quantitative values is concrete and absolute. For example, if a student is displaying their understanding of inputs and outputs, they will demonstrate that $f(4)$ for the given function $f(x) = 3x - 2$, the output is ten. The output is not based on a student's interpretation of determining the output of a function; it is the student adhering to a set of rules as opposed to the evaluation process throughout the learning cycle in science. A student's understanding is generally based on their interpretation of the phenomena being discussed. This will build onto previous understandings that were made, which will serve as a foundation for future knowledge acquisition.

Figure 1.6

Representing and Evaluating

Representing	**Evaluating**
• Display of one's own mathematical thinking through records, data, and written expression to communicate mastery	• Evaluation and reflection of experience and process • Explore thinking and understand how they developed their thoughts and personal understanding throughout the cycle
Students move past the comprehension level into the ability to communicate one's own mastery with the concept to others, either with verbal or written expression.	

Integrating Quantitative Literacy At The Middle Level

This writer, thus far, has explored the mechanics by which the disciplines of mathematics and science are learned and understood as a knowledge base. Beane (1995) explained in his advocacy for integration "those on the front edges of a discipline know that disciplinary boundaries are fluid and often connect with other disciplines" (p. 616).

By traversing those boundaries, students can see how content areas are impacted by one another, which supports the efforts in connecting related disciplines.

Students need to make sense of what they are learning and need facts and key ideas to be given context through integration. Context helps to provide meaning to what students are learning (Samson, 2014). On the contrary, it is unnatural for students to approach a real-world problem and immediately separate out all of the disciplines as they strategize a solution. The mathematics is not distinctly teased out from the science in their metacognition and vice versa (Beane, 1991). Beane (1991) explained this to us and reminded us that this approach to real-world problems is not innate, and should not be the same approach that is used when constructing/selecting the curriculum for middle school.

The transition for early adolescents being moved from a K-8 setting into a formal junior high specific to their age group was established in the early 1900s (Beane, 1991). Beane describes the movement in that "the junior high school was intended to be a junior version of high school, the same program adapted to be more suitable for early adolescents" (Beane, 1991, p. 10). During the mid-1900s there was an insistent push to create thematic learning units for middle level students that were experience based and focused on authentic resolutions (Beane, 1991). Regardless of the efforts to reform middle level curriculum programs to a more integrative construct, the subject-centered approach remained the primary methodology (Beane, 1991).

At the developmental stage of adolescents during the time of middle school, they are mentally devising questions and inquiries regarding how the world around them is constructed and how it operates (Beane, 1991). Beane suggests that the developmental stage at the middle level is appropriate for interdisciplinary themes and projects because these types of lessons help to satisfy student inquiries about the world and general human interaction and help to identify “self and social meaning” (Beane, 1991, p. 11). The kinds of questions students are developing at this time can in part be answered or addressed by real-world problem based activities that incorporate and cross-correlate multiple subjects (Beane, 1991).

Benefits Of Integrating Quantitative Literacy Into Science

The integration of mathematics at the middle level enhances and exposes the relevancy of mathematical ideas in science (Sherrod, Dwyer, & Narayan, 2009). The application of quantitative literacy in science is inherent and not designated by clear boundaries (Sherrod et al., 2009). The uses of mathematical concepts are immersed in such a way that the boundaries of where mathematics ends and science begins are not discernable (Sherrod et al., 2009). Everyday life activities require the intrinsic use of mathematics and science, including such things as navigating a map, analyzing the stock market, and determining a monthly budget (Sherrod et al., 2009). Sherrod et al. (2009) characterizes the beneficial relationship between mathematics and science:

> The scientific process of observation and data collection is incomplete without the use of mathematics to analyze data and quantitatively reveal relationships in order to draw conclusions. When mathematics is incorporated into a science lesson, the two disciplines complement each other in such a way that the learning of both science and mathematics is enhanced. (p. 248).

If students are to be expected to utilize mathematics in order to come up with a resolution to a real-world based problem, then students must be given opportunities to practice mathematics outside of their scheduled mathematics class (Baumgartner, Biga, Bledsoe, Dawson, Grammer, Howard, & Snyder, 2015). “Students with greater math confidence are those who are provided opportunities to build and practice their skills” (Tariq & Durrani, 2012; Baumgartner, et al., 2015, p. 265). Students need opportunities to blend mathematics and science and exposure to situations that require this blend.

Scientific inquiry necessitates a scientific environment that provides opportunities to assess intangible mathematical concepts. This type of practice allows for the construction and proof of hypotheses and authentication of computational examples in changed conditions. The representation of measurable physical processes is the basis for mathematical modeling, which informs conclusions and further research (NCTM, 2000; Sokolowski, Yalvac, & Loving, 2011).

This relationship between mathematics and science is multi-dimensional and inherently embedded within certain scientific fields, such as physics (Uhden, Karam, Pietrocola, & Pospiech, 2011). Mathematics is fundamental to the depiction of physical science and the underlying principles that establish the field (Uhden, et al., 2011). The relationship of mathematics to science is complementary when explaining and analyzing figures which represent physical outputs (Lee, Chauvot, Vowell, Culpepper & Plankis, 2013). The inherent nature of calculus is indivisible from the analysis of movement (Boyer, 1949; Uhden, et al., 2011). Vector analysis, which is the mathematical component of magnitude and direction, was shaped by the mathematical development of electromagnetism (Crowe, 1967; Uhden, et al., 2011). Mathematics in science is utilized as a problem solving mechanism as well as a method to communicate foundational components of physics (Uhden, et al., 2011). One of the fundamentals of problem solving in physical science are differential equations (Poincare, 1958; Uhden, et al., 2011). Fourier analysis, which is the deconstruction and examination of waveforms by the use of mathematical functions, is used to investigate wave dynamics and heat exchange (Davis and Hersh, 1981; Uhden, et al., 2011). Since mathematics can be viewed as a central component of physics “mathematical skills are a prerequisite for the learning of physics” (Uhden, Karam, Pietrocola, & Pospiech, 2011, p. 486).

Educators can use the connection points between mathematics and science to efficiently cover overlapping core concepts between the two classes to ensure that all curricula are covered during the school year (Coulter, 2004). Lee, Chauvot, Vowell, Culpepper and Plankis (2013) suggest that when presenting the connection points between the two contents, it is essential for the educator to understand the intricacies and depth of the primary content they teach, either be it mathematics or science. This is recommended so that the educator knows the appropriate and necessary areas to blend the respective concepts.

By using connections to link mathematics and science by means of quantitative integration, this will support and increase student learning (Coulter, 2004). “As you bring out the mathematical dimensions of a science investigation or add a scientific context in which a math concept is used, you are deepening students' understanding of the intended curriculum focus" (Coulter, 2004, p. 1). With this focus of integrating quantitative literacy into science and the interconnected relationship between the two core areas, student understanding of one core idea is dependent on their understanding of the other core idea (Schwols & Miller, 2012). "The mathematics concepts taught in the Common Core are critical for students' understanding of science" (Schwols & Miller, 2012, p.49). Examinations have identified the improvement in student achievement in mathematics and reading as a result of strategies used to integrate the two (Berry, Daughtrey, and Wieder, 2009; Schwols & Miller, 2012).

Students may struggle to understand and solve problems and activities because they struggle to recognize the context or the underlying meaning of the problem (Frykholm & Glasson, 2005; Furner & Kumar, 2007). A benefit of integrating mathematics and science concepts and components by connecting corresponding ideas is that it extends the learning and helps to provide context (Furner & Kumar, 2007).

> Integrating mathematics and science in the schools has become a central issue by such organizations as School Science and Mathematics Association (SSMA), the National Council of Teachers of Mathematics (NCTM), the American Association for the Advancement of Science (AAAS), and the National Research Council (NRC). These organizations strongly support the integration of math and science, which is reflected in the recommended national standards documents, such as *National Science*

Education Standards (NRC, 1996) and the NCTM *Standards* (1989 & 2000). NCTM (2000) makes "Connections" one of its process standards and advocates the use of integrating subjects like mathematics and science (Furner & Kumar, 2007, p.185).

Example Of Integrating Quantitative Literacy Into Science

A biology laboratory used the testing of abiotic factors on phytoplankton population growth as a platform to integrate quantitative literacy (Baumgartner, et al., 2015). The lab required the following quantitative measures to be researched and determined which then required specific mathematical skills (Baumgartner, et al., 2015):

- Population growth equation model in efforts to calculate potential growth
- Calculating the carrying capacity for the population
    - Adding and subtracting collected data through collecting phytoplankton samples in water and using Erlenmeyer flasks to measure and evaluate the change to sustain reliable sample values
    - Estimating values from droplet samples of phytoplankton it would be in droplets on a microscope slide and estimating the approximate number of phytoplankton in any given water droplet
    - Computing averages and percentages through extrapolating the number of phytoplankton in a drop of water then averaging the number in a given drop and using the scale to estimate the amount in a full beaker

- Using scale factor to account for the magnification applied while using a microscope to view the microscopic organisms
- Using dimensional analysis to convert units of data collection and analysis into millimeters for measuring
- Graphing collected and analyzed data in order to understand how to structure and label each axis correctly with the appropriate frequency intervals of each unit (i.e. population on the Y-axis and the time on the X-axis).
- Using algebraic expressions and equations to determine the rate of change in the population
  - $N_2 - N_1$ = absolute change in population = G_1 (absolute change in population from the first to second week)
  - G_1/N_1 = rate of change (r)
  - ($r * N_2$) = absolute change (G_2) (subscripts indicate the change and correlation of absolute and expected change from week to week, i.e. a subscript of (1) refers to values for week one and a subscript of (2) represents the expected values for week two and an estimated change in values from week one to week two)
  - $G_2 + N_2$ = prediction of third weeks population (N_3)

With the opportunity to incorporate quantitative literacy outside of a mathematics class, the goal was set to support and grow the confidence students had with utilizing and calculating mathematical concepts (Baumgartner, et al., 2015). Students reportedly responded well to the integration of quantitative literacy (Baumgartner, et al., 2015). One student commented that it was one of their favorite labs because it involved mathematics, which was different from the "mindless memorization" (Baumgartner, et al., 2015, p. 271).

Even though students enjoyed the mathematical application of this lab, the key to "success with this aspect of the lab requires prior opportunities for students to practice basic mathematical skills such as calculating averages and percentages" (Baumgartner, et al., 2015, p. 270). Another key component to keep in mind when integrating this kind of quantitative application into science, is that there was a "step-by-step" modeling of the formulas and procedures posted on the board for students to follow and reference (Baumgartner, et al., 2015). Analyzing student feedback for this lab activity reflected that more than one-fourth of the students experienced personal growth in their mathematical capabilities, and overall this lab supported the application and practice of fundamental mathematic abilities (Baumgartner, et al., 2015).

Pedagogical Strategies For Integration

There are pedagogical strategies to consider when integrating quantitative literacy into science to support and enhance the learning (Wenner, Baer, Manduca, Macdonald, Patterson, & Savina, 2009). These ideas are based on experiences with integrating quantitative literacy into geoscience coursework. Mathematical context is essential to the quantitative application of integrated material to help showcase the cultural relevancy to what they are learning and exploring (Wenner, et al., 2009). Lee et al. (2013) suggest as a pedagogical consideration to not view integration of quantitative literacy from a co-taught perspective, but to approach both contents separately creating various avenues in which to insert the other content. An example that Lee et al. (2013) provide shows students exploring the processes of diffusion and osmosis while they could be concurrently studying proportional reasoning.

Multiple representations are essential when integrating quantitative literacy into geoscience courses. Students need multiple opportunities to make connections and analyze the information for both mathematical and scientific ideas (Wenner, et al., 2009). Different ways to represent the information in a mathematical setting include but are not limited to verbal, numerical, graphical, and algebraic (Wenner, et al., 2009).

Technology supports can enhance the learning of mathematics. An electronic device, either a computer or a graphing calculator, are able to display certain functions or mathematical representations that can be difficult or challenging by hand (Wenner, et al., 2009). Dede (2011) and Smaldino (2011) both add that not only is student engagement an important byproduct when using technology, but also the abilities that technology provides can result in the extension of learning. "When research-based instructional strategies are combined with appropriate and innovate technology applications, learning happens" (Kelly & Kennedy-Shaffer, 2011; Kurz, 2011; Puckett, Shea, & Hansen, 2011; Smaldino, 2011, p. 2).

Facilitating cooperative learning groups is important because they give students the opportunity to communicate their personal understanding of the concept and allow them to explain it as they share with their peers (Dees 1991; Davidson et al. 2001; Wenner, et al., 2009). Reports show that the majority of students respond constructively when working collaboratively in a mathematical setting (Wenner, et al., 2009).

Complex mathematical problems are valuable because they give students the opportunity to practice decomposing and deconstructing a concept. When facilitating complex mathematical problems for students, it is imperative to understand that students need time over the course of a few class periods to work it out. Reflection is a fundamental skill when it comes to the application of mathematical problem solving (Wenner, et al., 2009). Some complex mathematic problems can essentially be broken up into several single components, requiring the utilization of numerous different procedures to implement and apply (Wenner, et al., 2009). Geoscientists can pursue different methods of utilizing the pedagogical benefits of revisiting quantitative applications over the course of several days (Wenner, et al., 2009).

Challenges To Integration

For decades, it had been discussed that the integration of mathematics and science serves a purpose in assisting students to master the concepts in these subjects and apply them in an authentic manner. While some teachers choose to utilize integrative applications (Stinson et al. 2009), some teachers require additional support and information. These concerns need to be addressed to provide a full understanding of all the possible reasons why educators may choose not to integrate mathematics and science. Stinson et al. (2009) discuss results gathered from a study of integrative practices conducted by middle school mathematics and science teachers. The findings show that limited content knowledge in complementary subject areas could serve as a hindrance. Also, Stinson et al. (2009) illustrate how an educator’s perceived inability to teach a possible corresponding field can serve as a deterrent for integration. Stinson et al. (2009) further elaborate on the expressed need for professional development for teacher preparedness and capacity for conceptualization with regard to integration. It was shown that teachers need clear guidelines as to what comprises integrative practices. Clearly there is a need for professional development opportunities to train and help alleviate deterrents for teachers.

Chapter 3

Discussion

The goal of the literature review was to explore and identify some of the benefits and pedagogical considerations for integrating quantitative literacy into the middle level science classroom. By exploring the benefits and considerations, the underlying mechanisms that connect mathematics and science became evident (Bosse et al., 2010). Science is used to explain natural phenomena that occur in our daily lives and universe (Bosse et al., 2010). Scientific concepts serve as the frame or the parameters to explain these natural phenomena (Bosse et al., 2010). Mathematics can be used to exemplify and demonstrate the scientific processes (Sherrod et al., 2009). To make a comparative analogy, mathematics is to science as human tissue is to the skeletal system.

Mathematics and science are both platforms to solve problems. Mathematics is based in numbers leading to abstract concepts to explain why *and* how things work (Bosse et al., 2010). It applies deductive reasoning (Bosse et al., 2010). Science observes real-life phenomena and theorizes the cause or correlation (Bosse et al., 2010). Inductive reasoning is used to explain the theories (Bosse et al., 2010). Different levels of reasoning may be applied, but they are both unique in that they offer something to the other where the sum is greater than the individual parts. Students are able to do more with science and mathematics combined than they can separately (Sherrod et al., 2009).

The literature explained that there are no clear-cut boundaries between mathematics and science (Sherrod et al., 2009). In fact, both traverse each other's content boundaries consistently during the exploration of either area. The literature in physical science demonstrates the deep-rooted and essential relationship between mathematics and physics

(Uhden, et al., 2011). A student can only superficially explore physical science concepts until they need mathematics to deepen their understanding (Uhden, et al., 2011). When the connected relationships of mathematics and science are brought forward to help explore and explain the other, this promotes student learning and deepens understanding (Sherrod et al., 2009). Integrating quantitative literacy into science enriches the learning for both contents and provides meaningful context (Samson, 2014).

Connections For Personal Practice

The inspiration and motivation to explore the literature on benefits and considerations of quantitative literacy was to further develop my depth of knowledge on the topic. The expectations of my role as a mathematics/science instructor in a gifted program require me to incorporate mathematics and science concepts in a cohesive and interdisciplinary fashion.

In the past, students became apprehensive when I would introduce units or lessons that were thematic and incorporated more than a single subject. Some students struggled to recognize the connection between mathematics and science, being unaware of the relationship that existed between the two contents. This caused students to be reluctant to participate and engage in the interdisciplinary units and led me to research the literature on the benefits of quantitative literacy in science. I wanted to build an arsenal of reasons to incorporate mathematics into science and science into mathematics.

When I started the research for this literature review, I was already aware of the existing relationship between quantitative literacy and science and knew there was a place for integration of the two. What I was unaware of was the intricacies and complexity of the relationship and benefits of quantitative literacy in science. I wanted to explore further in depth the complexity and dependency of that relationship.

Overall, the research revealed different options and varieties for ways to integrate quantitative literacy. The research highlighted the extent of the overlap of the two contents and the importance of both components when exploring either of the two areas (Uhden, et al., 2011). In addition, the research expounded on the necessity of interweaving the two contents in order to fully support and enhance the learning of students (Sherrod et al., 2009).

By researching this topic, I was able to explore the evolution of science education over the past two hundred years and how it evolved from a fact-based, single-focus approach to a multi-dimensional application of the discipline (Chiappetta, 2008). Within this development, researchers have depicted the strong ties between mathematics and science and the significance and relevancy of this relationship (Uhden, et al., 2011). Understanding this relationship as an instructor of integrated activities helps when implementing these activities for students who are struggling to identify the connections.

Suggestions For Further Exploration Of My Practice Utilizing The Research

The research provided great insight and examples of how to employ the integration of quantitative literacy into science (Baumgartner, et al., 2015). When embarking on this new application of knowledge, it is helpful to ease students into the new environment of learning that is being created. In my classroom, there are some gifted children who do not adjust to change easily or quickly. Therefore, integrating gradually, in small measures, gives them the needed flexibility and adjustment time to adapt to a different learning atmosphere in the classroom.

There are many areas in science in which mathematics can be highlighted, extracted and brought forth to integrate quantitative literacy (Sherrod et al., 2009). At the middle school where I teach, the science standards are structured so that students at each grade level explore all three areas of science: Life, Earth and Space, and Physical. In sixth grade, students learn the introductory concepts for each area; seventh graders learn the intermediate level concepts, and eighth graders learn the advanced concepts. With each grade level exploring all areas in science each school year, a broad array of various mathematical concepts can be identified and utilized within science.

Given that certain areas of science lend themselves quite readily to mathematical connections and exploration, such as Earth and Space and Physical Science, students will have many opportunities throughout middle school to integrate quantitative literacy into their science class. There is certainly mathematic-related content in Life Science. The mathematical connections with Earth and Space and Physical Science are clearly apparent and are an excellent starting point for both teachers and students who lack experience integrating quantitative literacy into science. Students need individual practice identifying the mathematics that is embedded in a science concept (Baumgartner, et al., 2015).

Limitations Of The Research

The first limitation was finding precise representations and explanations of integrative applications. Integration is a term that may be used to describe an instructional strategy that is not an accurate use of the term. It is often, when practices such as interdisciplinary, cross-curricular, and thematic units are being referenced, that the term integration is used interchangeably or as a catchall for other practices that have components similar to integration. With the interchanging of the terms, I found myself referencing articles and research that did not accurately reflect the use of integration. This was limiting because the portrayal of integration tended to be superficial or mechanical and and/or did not necessarily support or contribute to the topic of this literature review.

The second limitation that I encountered was articles and research, which were pertinent to my topic, but were written over twenty years ago. These older articles, though relevant and contributed to the research of the literature review, were outdated. This brings me to my third limitation. Since No Child Left Behind (NCLB) passed in the early 2000s, there has been a possible shift in educational research. As I conducted my research and collaborated with others on my findings, or sometimes the lack thereof, we discussed the possible impact and effects of this bill on the release of research on integration of mathematics and science curricula. With the advent of NCLB, the focus of research on "best educational practices" shifted. The emphasis was not on mathematics and science integration, which led to the lack of articles available to support research on this topic.

Recommendations For Future Research

Possible actions that future researchers could focus on as a result of this literature review are to present examples and opportunities for integration at the novice level. The research conducted for this literature review indicated that the lack of conceptualization and lack of experience was a possible reason as to why educators may choose not to integrate. If teachers are given simple and small places to start with integration, it will not feel as overwhelming. Teachers who are just beginning the process of integrating quantitative literacy into science need to see the evident places where they can highlight the mathematics. There are many peer-reviewed journals that present an overview of a lesson where integration of quantitative literacy into science occurred. I think what might be additionally helpful is if researchers surveyed the three areas of science: Life, Earth and Space, and Physical and generated a list of the different middle level mathematics and literary terms that can be highlighted and emphasized during exploration of those disciplines. For some middle level science educators, they are simply unaware of the many opportunities to tie in those mathematical concepts. It would be useful for educators to have an inventory of mathematical concepts that is itemized by the degree of difficulty. An educator's experience with connecting and linking concepts from different core areas could be the basis for entering at their appropriate level of novice, intermediate, or advanced.

If I were to explore this topic further I would focus on the underlying mechanisms that link mathematics and science. The connections between these two conceptual arenas help to explain their relationship and why these two integrate with one another. The underlying mechanisms between mathematics and science became apparent while researching the benefits and considerations for integration. The research on this topic alone was abundant and sufficient enough to explore it in isolation or as a primary focus.

Conclusion

Due to the immense amount of literature on this topic, not all research on this subject matter was explored. The literature that was investigated in regards to the pedagogical considerations and benefits of integrating quantitative literacy showed that there are benefits and items to consider when integrating quantitative literacy into science

(Beane, 1996). The literature states how the natural composition of one subject matter, either mathematics or science, is relevant and necessary when studying the other (Schwols & Miller, 2012).

The research indicated that the utilization, of mathematics and science in a combined curriculum, enhanced and supported the understanding of authentic real-world solutions (Beane, 1995). Realistic problems give students an opportunity to observe and experience how the two contents come together in real-life scenarios and further a student's understanding of the use and application of the concepts both on an individual level and an interdisciplinary level (Beane, 1995). The literature details the underlying components that make the relationship between mathematics and science strong and historically intertwined (Uhden, et al., 2011). As educators, it is as important to prepare students for their future as it is imperative that students understand and identify this historical connection and apply it towards new discoveries (Baumgartner, et al., 2015).

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