

The Journal of Mathematics and Science:

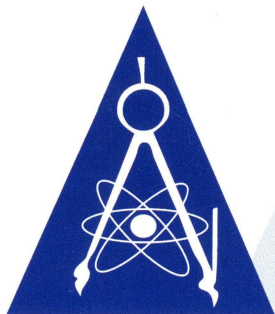
COLLABORATIVE EXPLORATIONS

Volume 13, Spring 2013

PART I: SPECIAL ISSUE

Scientific Inquiry and the Nature of Science

PART II: REGULAR JOURNAL FEATURES



Virginia Mathematics and Science Coalition

The Journal of Mathematics and Science:

COLLABORATIVE EXPLORATIONS

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PART I: SPECIAL ISSUE

Scientific Inquiry and the Nature of Science

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The Journal of Mathematics and Science:
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SPECIAL ISSUE
Scientific Inquiry and the Nature of Science

**Coordinating Editor
for this Special Issue**

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the National Science Foundation

Coordinating Editor's Remarks

The Virginia Mathematics and Science Coalition appointed a task force to study how inquiry-based teaching and explicit nature of science instruction will improve student learning in science. In 2010, the Coalition endorsed the “Scientific Inquiry and the Nature of Science Task Force Report.” The Report provides working definitions for both scientific inquiry and the nature of science, describes the rationale for teaching about these important aspects of science, and outlines how scientific inquiry and the nature of science may be effectively addressed in K-12 classrooms. This Report is available here and on the Coalition website (www.vamsc.org).

Numerous national reports from the *National Science Education Standards* (National Research Council, 1996) to *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (National Research Council, 2012) call for inquiry-based science teaching and learning. This Special Issue on Scientific Inquiry and the Nature of Science in *The Journal of Mathematics and Science: Collaborative Explorations* describes creative instructional approaches for inquiry in the science classroom and practical help for teachers as they conduct inquiry-based teaching and learning.

Teaching students to inquire, think critically, and understand the nature of science are among the most important things we do as science teachers. The ability to inquire, using logical reasoning and critical analysis, is a crucial skill for all citizens. This Special Issue explores inquiry-based teaching strategies and classroom activities that help students develop the skills needed for the twenty-first century.

The Report and these articles address the following questions: How do you define inquiry? What are essential features and principles of inquiry? Are there different kinds or levels of inquiry? How do learners engage in scientifically-oriented questions of public significance and—utilizing available community resources—give priority to evidence in responding to questions, formulate explanations based on evidence, connect explanations to scientific knowledge, and communicate and justify explanations with their peers and the larger public domain? What evidence is there of successful teaching of science inquiry skills and of students having been successful in learning these skills?

The articles are practical applications of inquiry, reviews of literature, theoretical, and policy oriented. Inquiry activities, the theoretical base, student responses, challenges faced, methods of research, research outcomes, and lessons learned are described. We believe that the publication in this Special Issue on Scientific Inquiry and the Nature of Science in *The Journal of Mathematics and Science: Collaborative Explorations* of refereed papers describing work in progress and preliminary research findings will have great value to the field.

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EXECUTIVE SUMMARY—TEACHING ABOUT SCIENTIFIC INQUIRY AND THE NATURE OF SCIENCE

VIRGINIA MATHEMATICS AND SCIENCE COALITION
TASK FORCE
May 11, 2010

Science education reform efforts emphasize teaching science for all Americans, and identify scientific literacy as a principal goal of science education. However, developing scientific literacy requires a broader view of science that includes three principal components: the knowledge of science, the methods of science, and the nature of science.

- **Scientific knowledge** includes all of the scientific facts, definitions, laws, theories, and concepts we commonly associate with science instruction.
- The **methods of science** refer to the varied procedures that scientists use to generate scientific knowledge.
- The **nature of science** depicts science as an important way to understand and explain what we experience in the natural world, and acknowledges the values and beliefs inherent to the development of scientific knowledge.

Since scientific knowledge is thoroughly covered in the *Virginia Science Standards of Learning* (Virginia Department of Education, 2010) and *Curriculum Framework for the Virginia Standards of Learning* (Virginia Department of Education), the purpose of this Task Force Report is to more clearly define **scientific inquiry** as a **method of science** and the **nature of science**.

The *National Science Education Standards* (NRC, 1996) provide guidelines for what students need to understand about and engage in **scientific inquiry**. Note that there are two facets to scientific inquiry. First, students should be able to understand about the nature of scientific inquiry as well as the attitudes and abilities they should develop by actively engaging in inquiry. Inquiry also refers to the instructional approaches that enable teachers to teach science concepts through inquiry. When evaluating whether an activity involves students in scientific inquiry, two questions are relevant:

- 1) Does the activity include a research question?

2) Do students engage in data analysis to answer the research question?

Effective science teaching also requires teaching about the **nature of science**. Research has provided a clear picture of the appropriate aspects of the nature of science which should be taught in the K-12 setting:

- 1) Scientific knowledge is empirically based.
- 2) Scientific knowledge is both reliable and tentative.
- 3) Scientific knowledge is the product of observation and inference.
- 4) Scientific knowledge is the product of creative thinking.
- 5) Scientific laws and theories are different kinds of knowledge.
- 6) Scientists use many methods to develop knowledge.
- 7) Scientific knowledge is, to a degree, subjective.

Providing an accurate understanding of the nature of science helps students identify the strengths and limitations of scientific knowledge, develop accurate views of how science differs from other ways of knowing, and helps students delineate the types of questions science can and cannot answer. Research indicates that effective nature of science instruction is explicit, set within a meaningful context, and linked to relevant process skills. Furthermore, teaching the **nature of science** and **inquiry** in tandem with **scientific knowledge** encourages students to develop scientific habits of mind that will enable them to be effective decision-makers beyond the classroom.

SCIENTIFIC INQUIRY AND THE NATURE OF SCIENCE TASK FORCE REPORT

VIRGINIA MATHEMATICS AND SCIENCE COALITION
TASK FORCE

PREFACE

Charge from VMSC — On October 6, 2009, the Virginia Mathematics and Science Coalition directed the science committee to establish a task force to write a report to present to local education agencies (LEA), Department of Education (DOE), Board of Education (BOE), and policymakers on how inquiry-based teaching and explicit nature of science instruction will improve student learning in science. This Report includes, but is not limited to, what scientific inquiry and the nature of science are, why teach them, and how to teach them effectively.

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TEACHING ABOUT SCIENTIFIC INQUIRY AND THE NATURE OF SCIENCE: TOWARD A MORE COMPLETE VIEW OF SCIENCE

Science education reform efforts emphasize teaching science for all Americans, and identify scientific literacy as a principal goal of science education [1, 2]. Scientific literacy has been defined in many ways, but generally refers to the ability to read and understand media accounts of science and scientific issues [3]. Additionally, scientific literacy involves the ability to make informed decisions on socio-scientific issues. Ultimately, scientific literacy addresses the need for citizens to actively participate in a technologically advanced democracy [4].

Achieving scientific literacy requires more than teaching and learning science as a body of knowledge. Rather, developing scientific literacy requires a broader view of science that includes three principal components: the knowledge of science, the methods of science, and the nature of science (see Figure 1). **Scientific knowledge**, the most familiar component of scientific literacy, includes all of the scientific facts, definitions, laws, theories, and concepts we commonly associate with science instruction. The **methods of science** refer to the varied procedures that scientists use to generate scientific knowledge. While these methods can be very complex, K-12 science instruction typically focuses on the more basic inquiry skills, including observing, inferring, predicting, measuring, and experimenting. Additionally, scientific inquiry refers to a specific instructional approach in which students answer research questions through data analysis. The **nature of science** is the most abstract and least familiar of the three components of scientific literacy. The nature of science addresses the characteristics of scientific knowledge itself and is perhaps easier described than defined. It depicts science as an important way to understand and explain what we experience in the natural world, and acknowledges the values and beliefs inherent to the development of scientific knowledge [5]. These three essential components of scientific literacy are highly interrelated and K-12 science instruction should reflect the synergy that exists among scientific knowledge, methods of science, and the nature of science. Finally, a basic understanding of mathematics and the nature of mathematics is one additional, necessary component to develop scientific literacy among students [6].

The Virginia *Science Standards of Learning* address each of the three principal components of scientific literacy [7]. The majority of standards in each content area focus on scientific knowledge. Science methods and process skills are primarily addressed in *SOL X.1* of

each content area or grade level. These methods and process skills in combination with scientific knowledge are used to perform scientific inquiry, where students investigate aspects of the world around them and use their observations to construct reasonable explanations. *Standards of Learning X.1* also briefly refers to the nature of science. However, to understand more specifically what should be taught about the nature of science, one must refer to the *Curriculum Framework for the Virginia Standards of Learning* [8].

The purpose of this Task Force Report is to provide working definitions for both scientific inquiry and the nature of science, describe the rationale for teaching about these important aspects of science, and outline how scientific inquiry and the nature of science may be effectively addressed in K-12 classrooms.

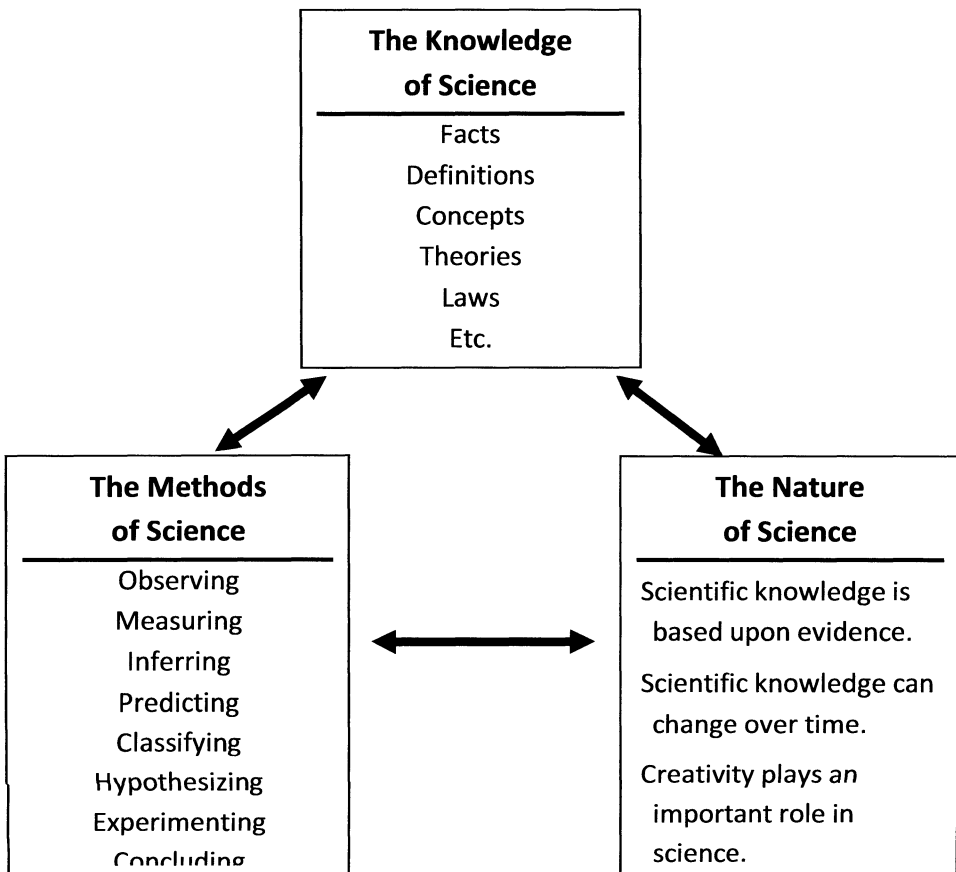


Figure 1. Three components of scientific literacy.

What Is Scientific Inquiry and Why Teach It?

Inquiry is at the heart of the scientific enterprise and, as such, demands a prominent position in science teaching and learning. The *National Science Education Standards (NSES)* refer to two important aspects of inquiry that are important to science instruction:

Scientific inquiry refers to the ways in which scientists study the natural world and propose explanations based on evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world [2].

Engaging students in scientific inquiry is an important component of science instruction that helps students develop scientific literacy and provides them with the opportunity to practice important science process skills in addition to critical thinking and problem solving skills. Furthermore, research suggests that engaging students in scientific inquiry can lead to achievement gains in science content understanding, and critical thinking and problem solving skills [9].

The *NSES* describe both the essential understandings students should have about inquiry and the essential abilities necessary for students to do scientific inquiry [2]. According to the *NSES*, students should understand the following:

- scientists use many methods to conduct a wide variety of investigations;
- scientists rely on technology and mathematics; and,
- scientific explanations must be logically consistent, abide by rules of evidence, be open to questions and modification, and be consistent with current scientific knowledge [2].

In order to engage in scientific inquiry, the *NSES* propose that students should do the following:

- design and conduct scientific investigations;
- use technology and mathematics;
- formulate and offer explanations using logic and evidence; and,
- communicate and defend a scientific argument [2].

One way to think about inquiry is of a coin with two distinct sides. On one side is the content that students need to learn, including what students should be able to understand about the

nature of scientific inquiry, as well as the attitudes and abilities they should develop by actively engaging in inquiry. Standard X.1 of the Virginia *Science Standards of Learning* focuses on this aspect of inquiry [7]. On the other side of the coin are the teaching approaches and learning strategies that enable teachers to teach science concepts through inquiry. While it is very important for teachers to be familiar with and incorporate Standard 1 in their instruction, they also need practical strategies for evaluating curriculum materials that are inquiry oriented and strategies for revising those that are not. Therefore, at its core, inquiry instruction can be defined simply as “an active learning process in which students answer a research question through data analysis” [10].

Teaching Scientific Inquiry

Far too often, teachers equate inquiry instruction with hands-on activities. While inquiry instruction is student-centered in that students are actively engaged, not all hands-on activities promote inquiry. Conversely, not all inquiry activities must be hands-on. It is possible for students to engage in inquiry through analyzing existing data, without the need for hands-on data collection. Many teachers believe that, in order for students to engage in inquiry-oriented activities, they must design investigations and carry them out on their own. This perception is too narrow. Students cannot be expected to design and carry out valid investigations without substantial support and instruction. Therefore, teachers should scaffold inquiry instruction to enable students to develop their inquiry abilities and understandings to the point where they can confidently design and conduct their own investigations from start to finish [11]. Further, instructional objectives should play a significant role in the design of an inquiry-based activity for a particular lesson. Luft, Bell, and Gess-Newsome provide content-specific examples of inquiry lessons that provide varied levels of support by teachers and are appropriately aligned with instructional objectives [12]. In some lessons, it might be best for students to learn a science concept inductively through inquiry-based experiences. For other lessons, the focus may be on developing specific inquiry skills, such as measuring and using lab equipment to collect data.

Is It Inquiry? — The primary question to consider when determining whether an activity is inquiry-based is: Are students answering a scientific question through data analysis? Many worthwhile hands-on activities traditionally performed in science classrooms do not involve students in these essential components of inquiry. For example, constructing a model of the atom, organizing a leaf collection, or building a soda-bottle water rocket can all be excellent instructional activities. However, unless these activities involve research questions and the opportunity to analyze data, they do not qualify as inquiry activities.

Thus, when evaluating whether an activity involves students in scientific inquiry, the first question for teachers to ask is: Does the activity include a research question? Specifically, does the activity include a research question that can be answered through a scientific investigation? Appropriate research questions include the following examples:

- Does the moon rise and set at the same time every night?
- How does concentration influence the rate of a particular reaction?
- What effect does the intensity of light have on plant growth?

Each of these questions can be answered through analysis of observational or experimental data. Note that scientific questions may be posed by the teacher or students, depending on the specific goals of the lesson and abilities of the students.

The second critical question in evaluating whether an activity supports inquiry is: Do students engage in data analysis to answer the research question? Activities in which students are simply gathering information from secondary sources via the Internet or library research are not inquiry activities. Students must analyze data themselves. Note, however, that students do not necessarily need to collect their own data in order to satisfy this condition. Data can be presented by the teacher to students for analysis or obtained from other sources, such as the Internet or a simulation. At the heart of this question is “Are students doing their *own* data analysis to draw conclusions and answer the research question?” It is essential to note that activities engaging students in pure observation may be inquiry-based if they meet the above criteria. It is not necessary for students to design and carry out *experiments* in order to do inquiry.

Scaffolding Inquiry Activities — When considering activities that fit the two conditions for inquiry, it is important to realize that not all inquiry activities are equivalent. Herron identified four levels of openness for inquiry in science activities [13]. Based partly on Herron’s work, Rezba, Auldridge, and Rhea developed a four-level model of inquiry instruction, which was subsequently modified by Bell, Smetana, and Binns [10, 14]. This model of inquiry instruction illustrates how inquiry-based activities can range from highly teacher-directed to highly student-directed, based on the amount of information provided to the student (see Figure 2).


		How much information is given to the student?		
		Question?	Methods?	Solution?
Teacher-Directed  Student-Directed	Level of Inquiry			
	1- Confirmation	✓	✓	✓
	2- Structured	✓	✓	
	3- Guided	✓		
	4- Open			

Figure 2. Four-level model of inquiry [10].

Level 1 and Level 2 activities are characterized as “low level” inquiry activities. They are often referred to as “cookbook labs,” in that the procedure is typically laid out for students in a step-by-step sequence. Level 1 inquiry activities provide students with the research question and the method through which the research question can be answered. Additionally, the expected answer to the research question is known in advance. In these activities, students are confirming what is already known. Level 2 inquiry activities, referred to as structured inquiry, are those in which students are given a research question and the prescribed procedure, but the answer to the research question is not known in advance. Note that a Level 1 activity can easily be changed to a Level 2 activity by changing when students do the activity with respect to instruction. For example, if students are taught a concept that provides them with the expected results of an inquiry activity before they perform it, the activity would be considered a Level 1. However, if the inquiry activity is completed prior to learning the concept such that students do not know the expected outcome, it would be considered a Level 2 activity.

Level 3 and Level 4 inquiry activities are characterized as “high level” inquiry activities, as they require significant cognitive demand on the part of the student. In Level 3 inquiry activities, students are presented with a teacher-posed research question, but students devise their own methods and solutions to answer the question. In this “guided inquiry,” students practice research design. A Level 1 or Level 2 inquiry activity can be transformed into a Level 3 activity by having students develop their own, teacher-approved method to answer the research question.

Level 4 inquiry activities are those in which students are responsible for choosing the research question, designing their own procedure for answering the question, and developing their own solutions to the research question. Only after students have completed activities at the first three levels are they prepared to tackle the open inquiry of Level 4.

By varying the amount of information provided to students, teachers can scaffold inquiry activities for their students over the course of the academic year. Teachers can model the process of scientific inquiry for students by beginning the year with Level 1 and Level 2 activities, eventually introducing Level 3 activities and Level 4 activities. By gradually transferring the amount of ownership and responsibility of inquiry activities to students, teachers can reduce the support provided to students during inquiry instruction to the point where students are ready to successfully design and conduct their own scientific investigations [10]. Appendix A provides a list of resources for inquiry activities, including examples of inquiry activities at each of these levels.

What Is the Nature of Science?

Understanding and actively engaging in scientific inquiry is only part of the picture when it comes to developing scientific literacy. Equally important is an understanding of the nature of science, or “science as a way of knowing.” The nature of science has been defined in a variety of ways, and these definitions are hotly debated among philosophers and sociologists of science [15]. Some science educators have defined the nature of science as “the values and assumptions inherent to the development of scientific knowledge” [16]. One assumption central to the scientific enterprise is that the universe is knowable. Many of the assumptions and values related to the scientific endeavor are too abstract and esoteric to be meaningful to K-12 students [17]. Therefore, the major science education organizations have delineated the nature of science concepts that should be addressed in K-12 classrooms [1, 2, 18]. These documents paint a consistent picture of the nature of science that is most appropriate for developing scientific literacy among students, and there is little debate over these key components of the nature of science appropriate for K-12 instruction [19, 20]. The following is a brief description of seven key characteristics of the nature of science.

- 1) **Scientific knowledge is empirically based**—“Empirical” refers to knowledge claims based upon observations of the natural world. While some scientific ideas are theoretical and are derived from logic and reasoning, all scientific ideas must

ultimately conform to observational or experimental data. Empirical evidence, in the form of quantitative and qualitative data, forms the foundation for scientific knowledge.

- 2) **Scientific knowledge is both reliable and tentative**—Scientific knowledge should not be viewed as absolute, but tentative and revisionary. For example, many scientific ideas have remained largely unchanged over long periods of time; however, scientific knowledge can change in light of new evidence and new ways of thinking. New scientific ideas are subject to skepticism, especially if they challenge well-established scientific ideas. Once generally accepted by the scientific community, scientific knowledge is durable. Therefore, it is reasonable to have confidence in scientific knowledge while still recognizing that new evidence may result in changes in the future. Related to the tentative nature of science is the idea that regardless of the amount of empirical evidence supporting a scientific idea (even a law), it is impossible to prove that the idea holds for every instance and under every condition. Einstein’s modifications to the well-established Newtonian Laws are a classic case in point. Thus, “Truth” in the absolute sense lies outside the scope of science [21]. Scientific laws do not provide absolutely true generalizations; rather, they hold under very specific conditions [22, 23]. Scientific laws are our best attempts to describe patterns and principles observed in the natural world. As human constructs, these laws should not be viewed as infallible. Rather, they provide useful generalizations for describing and predicting behavior under specific circumstances.
- 3) **Scientific knowledge is the product of observation and inference**—Scientific knowledge is developed from a combination of both observations and inferences. Observations are made from information gathered with the five senses, often augmented with technology. Inferences are logical interpretations derived from a combination of observation and prior knowledge. Together, they form the basis of all scientific ideas. An example of the interplay of observation and inference is the manner in which we determine the distances to stars. Stars are so far away that only a relatively small fraction of star distances can be measured through direct observation and the application of geometry. For the rest of the stars and other distant celestial objects, a complex combination of observations and

inferences must be employed (see Murphy and Bell, 2005 for a more complete description of how astronomers determine distances to stars) [24].

- 4) **Scientific knowledge is the product of creative thinking**—Scientists do not rely solely on logic and rationality. In fact, creativity is a major source of inspiration and innovation in science. Scientists often use creative methods and procedures throughout investigations, bound only by the limitation that they must be able to justify their approaches to the satisfaction of their peers. Within the limits of peer review, creativity permeates the ways scientists design their investigations, how they choose appropriate tools and models to gather data, and how they analyze and interpret their results. Creativity is clearly evident in Darwin's synthesis of the theory of natural selection from a wide variety of data and ideas, including observations from his voyage on the *H.M.S. Beagle*, his understanding of the geologic principles of Lyell, and even Malthus' theory of populations. Although known as a careful and methodical observer, Darwin's recognized genius stems from his creative work of synthesizing a powerful scientific explanation from a variety of sources and clues.

- 5) **Scientific laws and theories are different kinds of scientific knowledge**—A scientific law is a description of a generalized relationship or pattern, based on many observations. Scientific laws describe *what* happens in the natural world and are often (but not always) expressed in mathematical terms. Scientific laws are simply descriptive—they provide no explanation for why a phenomenon occurs. For example, under relatively normal conditions, close to room temperature and pressure, Boyle's law describes the relationship between the pressure and volume of a gas. Boyle's law states that at constant temperature, the pressure of a gas is inversely proportional to its volume. The law expresses a relationship that describes *what* happens under specific conditions, but offers no explanation for *why* it happens. Explanations for why this relationship exists require theory. Scientific theories are well-supported explanations for scientific phenomena. Theories offer explanations for *why* a phenomenon occurs. For example, the kinetic molecular theory explains the relationship expressed by Boyle's law in terms of the inherent motion of the molecular particles that make up gases. Scientific theories and laws are similar in that both require substantial evidence before they are generally accepted by scientists. Additionally, either

can change with new evidence. However, since theories and laws constitute two different types of scientific knowledge, one cannot change into the other.

- 6) **Scientists use many methods to develop scientific knowledge**—There exists no single “scientific method” used by all scientists. Rather, scientists use a variety of approaches to develop and test ideas, and to answer research questions. These include descriptive studies, experimentation, correlation, epidemiological studies, and serendipitous discovery. What many refer to as the “the scientific method” (testing a hypothesis through controlling and manipulating variables) is really a basic description of how *experiments* are done. As such, it should be seen as an important way, but not the only way, that scientists conduct investigations, as scientists can make meaning of the natural world using a variety of methodologies.

- 7) **Science is a social activity that possesses inherent subjectivity**—Science is a human endeavor and, as such, it is open to subjectivity. For example, the scientific questions considered worth pursuing, the observations that count as data, and even the conclusions drawn by scientists are influenced to some extent by subjective factors. Such factors as the existing scientific knowledge, social and cultural contexts, external funding sources, and the researchers’ experiences and expectations can influence how they collect and analyze data, and how they draw conclusions from these data. While subjectivity cannot be totally removed from scientific endeavors, scientists strive to increase objectivity through peer review and other self-checking mechanisms.

These seven tenets of the nature of science present a more appropriate view of scientific knowledge and address the major misconceptions about science documented by science educators [19, 25]. Taken as a whole, they serve as reminders that a principal strength of scientific knowledge is that it can change as needed and is required to better fit existing data. However, it is important to realize that change in science is not arbitrary. Scientific knowledge changes only as a result of further inquiry, debate, collaboration, and evidence. Thus, changes in science move our understandings toward important “truths” about the natural world. Although these truths should not be viewed as absolute or final, they are among the most reliable that we have at any given point in time. No other means of inquiry has proven more successful or trustworthy. One

need only consider the advances in science-related fields, such as medicine, agriculture, and engineering, for verification that science works.

Why Teach the Nature of Science?

Science educators and researchers have presented a variety of rationales for teaching about the nature of science. Perhaps the most straightforward justification is that an accurate understanding of the nature of science helps students identify the strengths and limitations of scientific knowledge, develop accurate views of how science differs from other ways of knowing, and helps students delineate the types of questions science can and cannot answer [26]. Additionally, research suggests that teaching students the nature of science can enhance their content knowledge and increase student achievement [27-29]. Furthermore, an appropriate understanding of the nature of science is essential to understanding the relationship between science and religion, the controversy over “creation science” and “intelligent design,” and the essential differences between scientific and non-scientific disciplines [30]. Additionally, teaching the nature of science helps increase awareness of the influence of scientific knowledge on society [31-33]. Research also indicates that teaching the nature of science may increase student interest in science by making instruction more engaging and meaningful [32, 33]. Most importantly, developing appropriate conceptions of the nature of science is cited as a critical aspect of scientific literacy and, as such, is central to national standards documents and the *SOL* [1, 2]. Examples of the *SOL* that address each of the seven aspects of the nature of science presented in the previous section are included in see Appendix B.

Effective Nature of Science Instruction

Science instruction should help students develop meaningful understandings about the foundational and somewhat abstract concepts that constitute the nature of science. Research indicates that explicitly teaching students the nature of science, allowing students to experience the nature of science in a meaningful context, and linking the nature of science to process skills instruction are three specific ways educators can make instruction about the nature of science effective and engaging for students.

A large body of research indicates that the most effective way to teach nature of science concepts is through explicit instruction [15, 34, 35]. Explicit refers to making the nature of science a specific goal of instruction, with lesson objectives, activities, and assessments all including specific aspects of the nature of science when it is appropriate to do so. While nature of science instruction should be explicit, this does not mean that it must be didactic. Students are

not likely to glean a meaningful understanding of the nature of science merely from having someone tell them that science is empirically based or that theories cannot become laws. Rather, particular aspects of the nature of science should be illustrated to students within the context of inquiry activities, exploration of socio-scientific issues, and discussions of key episodes in science history. Learning in a meaningful context can help students assimilate the abstract elements of the nature of science more deeply than memorizing a list of the key concepts.

Engaging students in hands-on science activities alone will not likely lead them to appropriate understandings of the nature of science and the scientific enterprise [34]. Rather, students must engage in purposive discussion and reflection about the nature of science in order to learn about the nature of science:

Learning about the nature of science requires explicit discussion and reflection on the characteristics of scientific knowledge and the scientific enterprise—activities students are not apt to engage in on their own, even when conducting experiments. Students need someone to guide them through the process of learning *about* science as they *do* science [26].

Thus, effective nature of science instruction requires students both to engage in science and to reflect on what they learned about the scientific enterprise. To this end, linking nature of science concepts to process skills instruction has been shown to be effective [36]. In this approach, students learn about the nature of science and the scientific enterprise as they develop the skills necessary to do science. The teacher explicitly links nature of science concepts to activity-based lessons incorporating science process skills, such as observing, inferring, predicting, measuring, and classifying. Bell provides dozens of activities that utilize this process skills-based approach to nature of science instruction [26]. Additional resources for teaching the nature of science are provided in Appendix A.

Research has demonstrated that effective nature of science instruction does not come naturally for most teachers. Some confuse teaching the nature of science with inquiry and process skills [17]. Others do not consider the nature of science to be a necessary component of the science curriculum [37, 38]. Still others may possess the same misconceptions about science as their students [15]. Including the nature of science in the Virginia *Science Standards of Learning* is an important first step toward legitimizing nature of science instruction and delineating what teachers should teach [7]. However, knowing what to teach and actually

teaching it are not the same. Implementing nature of science instruction requires specific professional development that includes instruction on what the nature of science is and how to teach it, as well as support for teachers as they begin to integrate the nature of science into their own instruction [37, 39, 40].

Conclusion

Science is more than a body of knowledge and a way of developing and validating that knowledge. Science is a social activity that reflects human values, including curiosity, creativity, integrity, and skepticism. Developing scientific literacy requires meaningful, engaging instruction that integrates the knowledge of science, the methods of science, and the nature of science. Scientific inquiry as both content and as a process for learning provides opportunities for students to develop inquiry skills, use critical thinking, and deepen their understanding of science content. Furthermore, research strongly supports our experience that students enjoy the challenges of scientific inquiry when given appropriate support, and that they are enthusiastic participants in learning about the nature of science and how we know what we know. Teaching the nature of science and inquiry encourages students to develop scientific habits of mind that will enable them to be effective decision makers beyond the classroom.

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Appendix A
Teaching Resources for Inquiry and Nature of Science
Resources for Teaching Inquiry

Books:

- Cothron, J., Giese, R., & Rezba, R. (2006). *Students and Research: Practical Strategies for Science Classrooms and Competitions*. Dubuque: Kendall/Hunt.
- Llewellyn., D. (2005). *Teaching high school science through inquiry: A case study approach*. Arlington: National Science Teachers Association Press.
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- Smithenry, D. & Gallagher-Bolos, J. (2009). *Whole-class inquiry*. Arlington: National Science Teachers Association Press.

Articles:

- Banchi, H. & Bell, R. (2008). The many levels of inquiry. *Science and Children*, 46(2), 26-29.
- Brown, P. & Friedrichsen, P. (2006). JELL-O and detergents: A successful inquiry recipe. *The Science Teacher*, 73(5), 30-33.
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- Quinlan, K., & Sterling, D. R. (2006). Inquiry-based investigation on the Internet: Sound and the human ear. *Science Scope* 29(4), 26-29.

Resources for Teaching the Nature of Science

Books:

- Bell, R.L. (2008). *Teaching the nature of science through process skills: Activities for grades 3-8*. New York: Allyn & Bacon/Longman.

Articles:

- Kim, B. & McKinney, M. (2007). Teaching the nature of science through the concept of living. *Science Scope*, 31(3), 20-25.
- Metz, S. (Ed.) (2004). The history and nature of science. *The Science Teacher*, 71(9).
- Nargund, V., Rogers, M. (2009). That is not where that element goes ... Ah, the nature of science. *Science Scope*, 33(2), 22-29.
- Reeves, C., Chessin, D., & Chambless, M. (2007). Nurturing the nature of science. *The Science Teacher*, 74(8), 31-35.
- Sterling, D. R. (2009). From Aristotle to today: Making the history and nature of science relevant. *Science Scope* 32(5), 30-35.

Websites:

- Evolution and the Nature of Science Institutes. <http://www.indiana.edu/~ensiweb/>
- Understanding Science: How science really works. <http://undsci.berkeley.edu/index.php>

Appendix B
Nature of Science in the *Virginia Standards of Learning Curriculum Framework*

NOS Tenet	<i>SOL/Curriculum Framework Examples</i>
Scientific knowledge is empirically based.	<p>K.1 Observation is an important way to learn about the world. Through observation one can learn to compare, contrast, and note similarities and differences.</p> <p>4.1 Accurate observations and evidence are necessary to draw realistic and plausible conclusions.</p> <p>BIO.1 The analysis of evidence and data is essential in order to make sense of the content of science.</p>
Scientific knowledge is tentative.	<p>PS.1 The analysis of data from a systematic investigation may provide the researcher with a basis to reach a reasonable conclusion. Conclusions should not go beyond the evidence that supports them. Additional scientific research may yield new information that affects previous conclusions.</p> <p>BIO.2 The scientific establishment sometimes rejects new ideas, and new discoveries often spring from unexpected findings.</p> <p>CH.1 Constant reevaluation in the light of new data is essential to keeping scientific knowledge current. In this fashion, all forms of scientific knowledge remain flexible and may be revised as new data and new ways of looking at existing data become available.</p>
Scientific knowledge is the product of observation and inference.	<p>4.1 An <i>inference</i> is a conclusion based on evidence about events that have already occurred. Accurate observations and evidence are necessary to draw realistic and plausible conclusions.</p> <p>4.1 To communicate an observation accurately, one must provide a clear description of exactly what is observed and nothing more. Those conducting investigations need to understand the difference between <i>what is seen</i> and what inferences, conclusions, or interpretations can be drawn from the observation.</p>

	<p>5.1 Scientific conclusions are based both on verifiable observations (science is empirical) and on inferences.</p>
<p>Scientific knowledge is the product of creative thinking.</p>	<p>PS.1 Scientists rely on creativity and imagination during all stages of their investigations.</p> <p>PH.3 Science is a human endeavor relying on human qualities, such as reasoning, insight, energy, skill, and creativity as well as intellectual honesty, tolerance of ambiguity, skepticism, and openness to new ideas.</p>
<p>Scientific laws and theories are different kinds of scientific knowledge.</p>	<p>ES.1 <i>Scientific laws</i> are generalizations of observational data that describe patterns and relationships. Laws may change as new data become available.</p> <p>ES.1 <i>Scientific theories</i> are systematic sets of concepts that offer explanations for observed patterns in nature. Theories provide frameworks for relating data and guiding future research. Theories may change as new data become available.</p>
<p>Scientists use many methods to develop scientific knowledge.</p>	<p>LS.1 Investigations can be classified as <i>observational</i> (descriptive), <i>studies</i> (intended to generate hypotheses), or <i>experimental studies</i> (intended to test hypotheses).</p> <p>LS.1 Experimental studies sometimes follow a sequence of steps known as the Scientific Method: stating the problem, forming a hypothesis, testing the hypothesis, recording and analyzing data, stating a conclusion. However, there is no single scientific method. Science requires different abilities and procedures depending on such factors as the field of study and type of investigation.</p> <p>PS.1 Different kinds of problems and questions require differing approaches and research. Scientific methodology almost always begins with a question, is based on observation and evidence, and requires logic and reasoning. Not all systematic investigations are experimental.</p>
<p>Scientific knowledge is subjective and culturally influenced.</p>	<p>PS.1 Investigation not only involves the careful application of systematic (scientific) methodology, but also includes the review and analysis of prior research related to the topic. Numerous sources of information are available from print and electronic sources, and the researcher needs to judge the authority and credibility of the sources.</p> <p>BIO.1 It is typical for scientists to disagree with one another about the interpretation of evidence or a theory being considered. This is partly a</p>

	<p>result of the unique background (social, educational, etc.) that individual scientists bring to their research. Because of this inherent subjectivity, scientific inquiry involves evaluating the results and conclusions proposed by other scientists.</p>
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SCIENTIFIC ARGUMENTATION AS A FOUNDATION FOR THE DESIGN OF INQUIRY-BASED SCIENCE INSTRUCTION

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Abstract

Despite the attention that inquiry has received in science education research and policy, a coherent means for implementing inquiry in the classroom has been missing [1]. In recent research, scientific argumentation has received increasing attention for its role in science and in science education [2]. In this article, we propose that organizing a unit of instruction around building a scientific argument can bring inquiry practices together in the classroom in a coherent way. We outline a framework for argumentation, focusing on arguments that are central to science—arguments for the best explanation. We then use this framework as the basis for a set of design principles for developing a sequence of inquiry-based learning activities that support students in the construction of a scientific argument. We show that careful analysis of the argument that students are expected to build provides designers with a foundation for selecting resources and designing supports for scientific inquiry. Furthermore, we show that creating multiple opportunities for students to critique and refine their explanations through evidence-based argumentation fosters opportunities for critical thinking, while building science knowledge and knowledge of the nature of science.

Introduction

Science education plays a critical role in preparing students for multiple aspects of their future lives: thinking logically and critically, making decisions involving scientific information both personally and as active citizens and, for some, making science a vocation [3, 4]. In order to educate students with these goals in mind, a special emphasis has been placed on students' learning through scientific inquiry. Learning through inquiry involves the skills needed to ask questions, generate data, interpret evidence from first-hand investigations and from text, and make evidence-based explanations [5]. Enacted well, inquiry demands critical thinking to identify assumptions and to weigh alternative explanations, which requires an understanding of the nature of science [5, 6].

The ongoing challenge for educators lies in designing instruction that accomplishes what are sometimes competing goals. Science instruction must authentically engage students in the multiple components of science inquiry in a coherent way [7]. At the same time, it must support students' developing understanding of accepted science content and scientific ways of knowing

[8]. In recent years, there has been increasing attention paid to the role that argumentation plays in science and the role it could play in science education [2, 9-11]. We argue that instruction should be designed to support students in building a scientific argument for an explanation of a carefully selected phenomenon. Working toward better explanations through argumentation creates coherent opportunities for students to engage in multiple aspects of scientific inquiry while building science knowledge. Science knowledge has been described as a social construction that is the result of the inquiry process and communication with the scientific community, that is, through the process of argumentation [12]. By participating in argumentation, students are provided with a context and a rationale for the process skills of inquiry. In addition, due to the nature of argumentation, students necessarily practice the critical thinking skills that are vital to inquiry, as they need to evaluate evidence and critique alternative explanations. As students engage in the process of critique, reasoning based on evidence and communicating and justifying explanations play a central role, emphasizing key aspects of the nature of science.

In this article, we propose a set of design principles for using scientific argumentation as a focus for the backward design of inquiry-based science learning activities, grounded in the theoretical and empirical literature on argumentation and science education [13]. In the first part of this article, we will outline a conceptual framework for thinking about important aspects of argumentation across disciplines, and then narrow the focus to argumentation in science. We will concentrate on a type of argumentation that is central to science, argumentation for the best explanation, and outline the general structure of an argument for a particular explanation. In the second part of the article, we will map this structure to a set of principles for designing a sequence of inquiry-based learning activities that build toward students constructing a scientific argument.

The Nature of Argumentation across Disciplines—Argumentation Is a Dialogue about Alternative Positions within a Particular Community

Argumentation and argumentation in science have been studied in multiple ways from a variety of theoretical perspectives [14, 15]. As the subject of ongoing study and development, there is not a consensus definition of argumentation across scholarly communities. In this article, we draw from several theoretical perspectives to construct a definition of argumentation that is consistent with arguments in science research, and affords opportunities for argumentation to serve as a tool for students to engage in joint knowledge construction and critical thinking as they conduct science inquiry activities.

We define argumentation in general as the process of communal dialogue that determines the merits of alternative positions in relation to the available information marshaled in support of each position. There are two important aspects of argumentation to be examined. The first is the structure of argumentation that allows a particular position to be supported, examined, and critiqued. The second is the social nature of argumentation, which pertains to the characteristics of argumentation that arise from its taking place through interaction between people.

The Structure of Argumentation

Defining argumentation as a dialogic process presents an immediate challenge—where can it be said that an argument starts, and where does it end? Whether for the purposes of study or instruction, we need to identify a bounded unit that can be constructed and examined on its own. We propose a unit that has utility for thinking about argumentation: a line of argument.

A line of argument consists of several interrelated components: a *claim*, the position taken in relation to a particular topic, question, or issue; the *grounds*, the information submitted as support for the claim; and, the *justification*,¹ the rationale for how or why the grounds provide support for the claim [16]. A line of argument can also, but does not need to, include a *rebuttal*, an acknowledgment of possible exceptions to the claim. A *counterargument* is a line of argument that establishes a competing claim to one previously established, with corresponding grounds and justification. In the interest of a manageable level of complexity, we will limit our focus to claims, grounds, and justification. Figure 1 is a diagrammatic representation of the basic components of a line of argument and their relations to each other. The grounds lead to the claim, and their relation is supported by the justification.

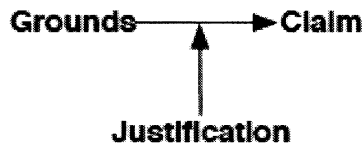


Figure 1. Diagrammatic representation of a line of argument.

¹ While Toulmin generally refers to this component of argument as “warrant,” he describes its function as one of justification. Given that *justification* is likely to be a more widely understood term, we have employed it here.

A simple example of a line of argument might be as follows: I *claim* that smoking should be made illegal on the *grounds* that smokers are more likely to die of cancer than non-smokers, death by cancer has multiple negative impacts, and laws should prevent negative outcomes. My *justification* for the grounds supporting my claim is that my claim is consistent with the grounds that I offer: a law banning smoking would prevent negative outcomes—death and its repercussions. I also offer a *rebuttal* to acknowledge a possible exception. If denying people their freedom of choice in deciding whether or not to smoke is determined to be a greater negative outcome, then smoking should not be made illegal.

The Social Nature of Argumentation

The second aspect of argumentation that we submit as important to consider for the purposes of design is the social nature of argumentation; i.e., the fact that argumentation occurs through interaction between people. Without at least one person to take a position, and at least one other to evaluate and/or contest it, there can be no argumentation. This does not suggest that an individual cannot engage in argumentation alone. However, the focus for and criteria applied in evaluating a given line of argument do not exist a priori, but are derived from the standards of particular communities, and thus are social in origin. In developing a line of argument, a scientist does so with a specific audience in mind. This social nature has multiple important implications for how argumentation is conducted.

Argumentation Depends on Socially Established Criteria

To be productive, it is not enough for argumentation simply to take place between people. It must take place between members of a particular community—a community that has implicit or explicit collective criteria for what is worth arguing about, and how a case intended to support a particular position is established and evaluated [15]. Without these collective criteria, participants could be left arguing about apples and oranges, and proposing positions that are not comparable, based on support that is not considered mutually acceptable.

The criteria for argumentation within a community can be subdivided based on their application to the various structural components of a line of argument: claim, grounds, and justification. First, criteria are required for what constitutes an appropriate claim to argue about within the community, as well as what makes one claim superior to another (given equivalent support). For example, in the scientific community it is appropriate to make a claim about the best way to explain how a particular natural phenomenon occurs (e.g., the lengthy process that creates fragile cave formations), but not a claim about how people should be required to behave

in relation to that phenomenon (e.g., human access to the caves should be restricted). Argumentation regarding claims about whether to restrict human access might take place within a political policy community.

Second, criteria are required to determine what counts as legitimate grounds (the information submitted to support a position), as some kinds of information may not be admissible at all. For example, personal beliefs or decrees by persons in positions of political or religious authority are never admissible as grounds in argumentation in natural science. Another set of criteria is used to evaluate what counts as more or less credible information to support a position. In other words, once information is determined to be admissible, its quality still must be evaluated. For example, in science, recorded measurements that were collected through imprecise or unreliable methods might be admissible in form, but considered of low quality and unlikely to be credible.

Finally, if an appropriate claim is made, and the grounds are determined to be legitimate and acceptably credible, another set of criteria is used to evaluate the justification of the relative merits of the claim in relation to the following: 1) the grounds that are offered, and 2) any other information that is available and determined to be relevant. This set includes both criteria used to evaluate a line of argument by itself (e.g., whether its grounds reasonably support its claim), and criteria used to evaluate two lines of argument in relation to each other in order to determine which is superior. For example, if a line of argument proposes and supports a particular explanation with data, that explanation may reasonably account for all of the data submitted as grounds for that line of argument. However, it may ultimately be judged inferior to a counterargument proposing another explanation that accounts for the same data, as well as additional data for which the first explanation cannot account.

The Nature of Argumentation in Science—Scientific Argumentation Is Used to Develop Increasingly Better Explanations for the Workings of the Natural World

As previously stated, the goals of argumentation depend on the goals of the community that is engaging in it, and it can focus on any of an array of contested or contestable outcomes. These outcomes could include an individual's guilt or innocence, the policy that would most benefit a society, or the best decision or course of action [16, 17]. In science and science education, the primary focus of argumentation is to develop, consider, and determine the best of a

proposed set of alternative explanations that account for observable phenomena in the natural world [2, 3, 18]. An *explanation* in science is a causal story that describes how or why a particular phenomenon comes to be or behave as it does. What makes an explanation distinct from a line of argument is that by itself, an explanation does not require support or justification. It is through argumentation that an explanation's quality, its ability to account for the phenomenon in a satisfactory manner, is determined [2]. In this section, we will outline and describe the components of an argument for an explanation in science, drawing on the elements of the conceptual framework established in the previous section. Wherever possible, we will illustrate these components by drawing from a single example of a seminal argument in science: Watson and Crick's postulation of the molecular structure of DNA [19, 20].

The Anatomy of an Argument for an Explanation in Science

The Question about the *Explanandum* — Implicitly or explicitly, any argument begins with a question about which of multiple possible positions (which themselves may not yet have been articulated) is the best one. In science, the central arguments are motivated by a question about some aspect of the natural world, and the best explanation for it [2]. For example, in their research, Watson and Crick were immediately arguing for a particular answer to the question, "How are the molecules that make up DNA arranged?" This was part of a larger ongoing line of inquiry into the question, "Why do successive generations of organisms have similar characteristics?" This initial question is the clearest link between scientific argumentation and inquiry. If inquiry is the process of asking and investigating a question [6], then a line of argument is the end product of those investigations, a tentative but supported explanation that seeks to answer that question.

The focus of the question is the *explanandum*, the phenomenon that is to be explained. The most important characteristic of the *explanandum* in scientific argumentation is that it is not in doubt within the community engaging in argument [2]. At the time of Watson and Crick's publications, the scientific community did not disagree that DNA existed, or that characteristics reappeared in successive generations. The explanation for the phenomenon, the account of how or why it happens the way it does, is what is uncertain and therefore is subject to argumentation. The question that is to be answered through argumentation is therefore slightly different than the question about the mechanism underlying the phenomenon itself. For Watson and Crick, that question would be, "What is the best explanation for how the molecules that make up DNA are arranged?"

The Claim: The Superiority of a Particular Explanation — A line of argument includes a claim, a tentative position that is taken and supported. In argumentation around a scientific explanation, the claim consists of two components: the explanation itself, which must be explicitly stated, and the position that the explanation provided is the best account available for the *explanandum*. Watson and Crick explicitly suggested their structure was a better alternative to others already proposed by colleagues, which consisted of three strands, or situated the bases on the outside of the strand, and which they described as “unsatisfactory” [20].

All explanations for phenomena are efforts to develop a more coherent causal story describing the mechanisms that result in the phenomenon as it is observed. Telling this story requires the creation or use of a cast of protagonists, entities with particular characteristics that interact with one another to bring about the *explanandum* as it exists [21]. These protagonists range from the observably material, such as a rolling ball, to the purely conceptual, such as the kinetic energy of the ball as it rolls. What science requires of these entities, regardless of whether they are ever observed, is that they have the same characteristics and behavior across the explanations in which they play a role [21]. While energy is never directly observable, it can be quantified across the contexts between which it is transferred, and that quantity remains ever the same [22].

Crick and Watson use van der Waals forces (weak intermolecular forces) as protagonists in multiple parts of their explanation of the structure of DNA [19]. The van der Waals forces account for why a particular configuration is or is not possible, depending on whether or not it violates the distance that the weak repelling forces between molecules would permit. While these forces and the molecules that give rise to them are not directly observable, they are important conceptual actors in the explanation, and the explanation depends on their consistent behavior in permitting only limited proximity. In their discussion, Crick and Watson foreshadowed the use of DNA with the structure they suggest as a protagonist in future explanations of the replication of genetic material, explanations that depend on the complementary strands that they proposed.

Science is replete with these conceptual actors—gravity, electrons, energy, tectonic plate boundaries, charge, fields, spherical planetoids—which may not have directly observable material existence, but which play critical and consistent roles in explanations of what we can observe. Moreover, while many explanatory protagonists have maintained their utility and presence in scientific explanations, others have come and gone. Phlogiston, once thought by many scientists to play a critical role in combustion, has since vanished from their explanations. Moreover,

Michelson and Morley showed that the luminiferous ether was an unnecessary protagonist in explaining the propagation of light [23].

The way that Watson and Crick's explanation suggests a causal mechanism for the reproduction of genetic material illustrates another important aspect of explanations: progress toward causality. Braaten and Windschitl provided a useful analysis of the forms of explanation in science based on scholarship in the philosophy of science, and offer a framework for working toward increasingly causal explanations in a science education setting that provides initial criteria for evaluating the quality of claims [24]. In general, scientific explanations should work toward an increasingly complete causal story for the mechanisms that lead to the *explanandum* as it is observed. To do so, they should use unobservable or theoretical protagonists and powerful science ideas (e.g., kinetic molecular theory) to account for the observable event. In progressing toward this level of causality, explanations may describe patterns in observable variables, or propose relations between variables without addressing underlying mechanisms or incorporating unseen protagonists. The authors acknowledge that there is a range of forms and standards for explanation across the scientific disciplines and the scholarship that has examined them. However, based on their work with students and pre-service teachers, they advocate and report initial success with a framework for explanation that presses for a progression from description of observable patterns toward the explication of increasingly unified underlying causes for observable phenomena.

The Grounds: Data and Existing Science Ideas — A line of argument also includes grounds, the information used to support the claim. Where scientific arguments are concerned, we will refer to grounds as *evidence*. In scientific argumentation, evidence includes some combination of new data, previously existing data, and existing science ideas. Data are systematic and recorded observations or measurements of some aspect of the natural world [3]. A line of argument may include new data that was gathered for the purpose of constructing the proposed explanation, and/or existing data; i.e., data that is not being used as part of an argument for the *explanandum* for the first time. Evidence also includes existing science ideas, which are themselves condensed representations of previously gathered data.

Research on both the nature of science and in science education support this perspective of ideas as evidence originally derived from data. In his analysis of the elements that distinguish the modern scientific culture, Latour advocates a shift in focus away from changes in ways of thinking or economic infrastructure [25]. Instead, he emphasizes the developments in the means

by which symbolic inscriptions are produced based on empirical study, reproduced, compared, discarded or compiled, and synthesized. He follows the process of “the transformation of rats and chemicals into paper,” and the process by which the resulting inscriptions are taken up and reproduced by scientific colleagues. His description provides a clear picture of how the representation of a science idea is the end product of this process of inscriptional distillation that began with the recording of empirical data. Similarly, in their development of the Evidence-Based Reasoning framework for science education, Brown, Furtak, Timms, Nagashima, and Wilson draw on Duschl to show how students analyze and interpret specific data to develop rules, more general statements that can be applied to other relevant circumstances though argument [26, 27]. In the next section, we draw on their framework for developing and applying rules in defining reasoning in scientific argumentation.

In their argument for the double-helical structure of DNA, Crick and Watson employ two kinds of evidence [19]. They use existing data, such as the x-ray images of DNA produced by their colleagues and the ratios of the four bases in samples of DNA from different organisms [28]. They also use existing ideas, such as the 3-dimensional structure of adenine, as inferred by Broomhead through calculations using measurements of x-ray reflection through crystalline samples of adenine hydrochloride [29]. They coordinate this evidence to strategically build a line of argument for the structure they propose as the best in relation to alternatives that have been or might be proposed.

As we stated previously, information provided as grounds is subject to evaluation by the audience to determine whether it is legitimate and credible, and therefore acceptable as grounds to support a position. In order for the audience to evaluate data, the presenter must provide sufficient information about the methods by which it was gathered (e.g., what specifically was observed or measured, what methods were used to achieve validity and reliability, and how any records depict or represent what was observed). In order for the audience to evaluate science ideas, they need information about the source of the ideas and how they were developed. If the ideas are drawn from sources outside the immediate experience of the audience and are subject to question, the audience will require more information about the source of the ideas. This could include either a description of the process of inference from more direct observation by which they were constructed, or some assurance that the people who developed them used methods that would be considered acceptable by the audience (e.g., in science, the audience of a peer-reviewed journal relies on these assurances). For example, Crick and Watson do not describe the methods Broomhead used to infer the molecular structure of adenine, but provide sufficient reference

information that a skeptical reader could obtain a description of those methods from the original work [19]. Some ideas, however, are so well established within a given community that they are used as a taken-as-given fact. Crick and Watson repeatedly use density as an idea to support their arguments about the structure of DNA, but never define it [19]. They reasonably assume that their audience likewise accepts and understands density as an established fact.

Reasoning: Connecting Data, Ideas, and Explanation — Establishing the connections between the data, the ideas, and the explanation (or some component of it) requires one of several kinds of reasoning, which is the presumption of particular conclusions based on the relevant grounds. Reasoning can be further subdivided into generalization and application: generalization is the construction of a general rule based on analysis and interpretation of a set of specific instances (data), while application uses that general rule to draw a conclusion about a specific circumstance determined to be relevant [26]. Each form of reasoning can involve one of several kinds of general rules: patterns, the consistent occurrence or variation of some observable characteristic; causal relationships, the identification of a causal link between two variable factors; or, causal mechanisms, a description of the means by which one factor affects another.

As a simple example, Crick and Watson reason that because a) tests for the presence of adenine in DNA have been positive and b) that adenine in samples of adenine hydrochloride has been inferred to have a particular structure, then the adenine found in DNA must also have that structure [19]. Their argument for the structure of DNA involving the pairing of specific bases (i.e., adenine and thymine) is in part dependent on this reasoning being valid. Table 1 summarizes these different forms of reasoning, and provides a brief example in a single context (the relationship between latitude and average temperature) to illustrate each.

Table 1
Types of Reasoning with Examples

	Pattern	Causal Relationship	Causal Mechanism
Generalizing	<p>Inferring that a pattern more generally holds true, based on a specific set of instances.</p> <p><i>E.g., Average temperatures are high in Mexico City, medium in Kansas City, and low in Winnipeg; therefore, temperatures are lower further north from the equator.</i></p>	<p>Inferring that factors are causally related, based on a correlation or a single aspect of disagreement (a controlled comparison).</p> <p><i>E.g., Average temperatures are lower in locations where the Earth is more steeply curved; therefore, temperature is causally related to the Earth's curve.</i></p>	<p>Inferring an underlying mechanism for an identified causal relationship.</p> <p><i>E.g., Average temperatures are lower in locations where the Earth is more steeply curved; the greater distribution of direct sunlight in steeper areas results in less energy input and lower average temperatures.</i></p>
Applying	<p>Inferring that a general pattern extends to a specific relevant instance or context.</p> <p><i>E.g., Vancouver is further north than San Francisco, and temperatures are lower further north from the equator; therefore Vancouver has lower average temperatures than San Francisco.</i></p>	<p>Inferring the presence of a known associated causal factor, based on the presence of the other.</p> <p><i>E.g., Reykjavic has low average temperatures, and temperature is causally related to the Earth's curve; therefore, Reykjavic is at a steeply curved location on the Earth.</i></p>	<p>Inferring initial conditions, processes, or results, based on the implications of a particular mechanism.</p> <p><i>E.g., Minneapolis is in a location that is more steeply curved during February compared with July, and more steeply curved areas receive less direct sunlight; therefore, Minneapolis is colder in February.</i></p>

Like the other components of a scientific argument, the reasoning that is presented is subject to critique by the audience. Generalization and application are each critiqued by different criteria. Generalization is examined for whether the rule that was inferred from specific data is plausible, based on the following: a) the number of specific instances examined (i.e., the sample size); b) the similarity between the specific instances and the categories included in the rule (e.g., generalizing a rule about all mammals based on the study of rats); and, c) the existence of plausible alternative rules that might be generalized from the same instances. Application is examined for whether the rule that was used can be described in the following ways: a) relevant to the specific instance to which it was applied; b) was applied in a way that draws valid conclusions based on the rule; and, c) is accurate, in that it is consistent with accepted science ideas.

Justification: Making a Case for the Superiority of the Explanation Based on the Grounds — Finally, a line of argument in science must provide justification for its claim that the explanation it provides is superior to any alternatives, based on the socially established criteria specific to the scientific community. These criteria can be usefully represented as critical questions that can be asked about a given argument for an explanation, and asked about the following: a) the argument in relation to other information that could be included as evidence for or against the explanation, b) alternative explanations that could be proposed, or c) counterarguments that have been made to support an alternative explanation [30]. Explicit justification included in the argument would take the form of responses to these questions.

While there are no doubt a variety of criteria that might be considered, we will focus on three that we suggest are central to science, and useful for science instruction. The first criterion is refutation, an aspect of science emphasized by philosopher of science Karl Popper, and represented as the critical question, “Is there evidence (data or ideas) that conflicts with the explanation?” [31] The second is coherence, which is similar to the emphasis placed by philosophers of science on unification—the capacity of a scientific explanation to unify a range of related observations or ideas [32]. It is represented by the critical question, “How consistent is the explanation with available relevant data and accepted science ideas?” Coherence includes validity, whether the reasoning employed generalizes or applies rules in appropriate ways, and completeness, the degree to which the explanation accounts for all data or ideas that could be considered relevant. The third is causal depth: “How does the explanation further develop the causal storyline by adding elements to or relationships between the factors that underlie the phenomenon?” [24] Providing examples of all three criteria, Watson and Crick justify their claim that their explanation is superior to their colleagues’ for the following reasons: 1a) it has greater causal depth—it provides a clear mechanism that holds the structure together, while their colleagues’ does not; 1b) it is more nearly complete—it is consistent with existing ideas about the repelling forces of negative charges; and, 2) it is not refutable—it does not conflict with ideas about the limits of van der Waals distances [20].²

It is difficult to visualize the multiple components and interrelations we’ve described. The diagram below (see Figure 2) is a representation of a portion of Watson and Crick’s argument, in order to illustrate the specific components and their relations to each other in this

² The numbering scheme reflects the numbers included by the authors, but we sub-divide their first point as reflective of two criteria.

example. Given the complexity of the argument the authors presented, we had to simplify our descriptions of some of the evidence and relevant ideas, but we believe the essence of the argument is intact. Their reasoning is represented by the arrows connecting the evidence and the sub-components of the explanation.

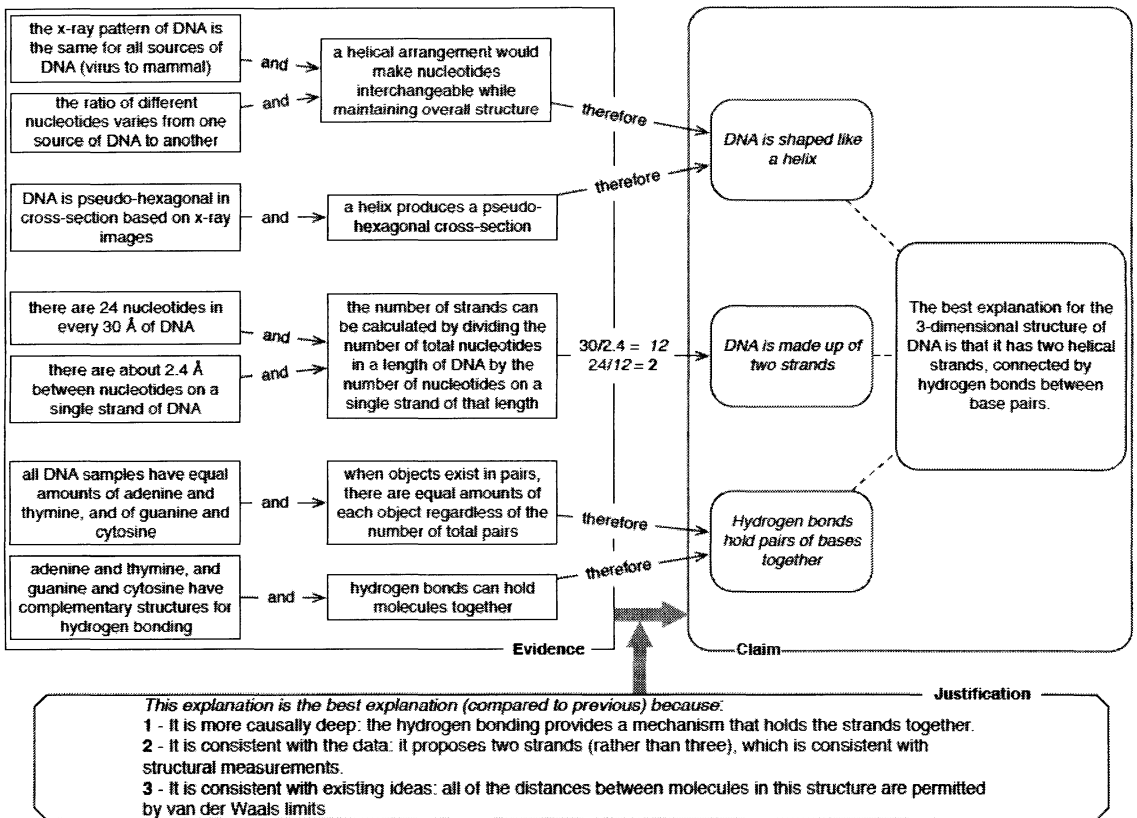


Figure 2.
Diagrammatic representation of a portion of Watson and Crick's argument.

The Implications of Science Argumentation for the Design of Inquiry Activities

If constructing better explanations for phenomena is the primary goal of scientific inquiry, and argumentation around alternative explanations is the means by which scientists work toward better explanations, then supporting students in arriving at better explanations through argumentation should be a high-priority goal of inquiry-based science education. Using the features of argumentation described thus far, we propose a set of design principles to guide curriculum developers and teachers in their creation of inquiry-based science learning activities that will strategically engage students in argumentation toward causal explanations. We will illustrate these principles by developing a single example drawn from our grade 6 earth science unit focused on the major factors that influence regional climate. A preview of the principles and their alignment with the features we've described is outlined in Table 2.

Designers Should Organize Science Inquiry Learning Activities around Developing Increasingly Better Explanations of an Intentionally Selected Focal Phenomenon

First, to align with the primary work of science, a significant portion of *students' science learning and activity should be organized around developing better explanations of a launching focal and puzzling phenomenon and/or class of phenomena*. This approach provides a specific *explanandum* that can serve as the focus of students' investigative activities and learning [33]. For example, in our curriculum, we use photographs and narrative to introduce students to the Atacama Desert, a region in South America, as presenting a puzzle. It is literally the driest place on Earth, receiving no annual rainfall, but is not far from the Amazon jungle, one of the world's wettest places. How is it that the two regions can be so close to one another, yet have such drastically different climates?

While scientists can spend entire careers focused on constructing knowledge of a relatively narrow set of phenomena, science education aims to develop students' integrated understanding of the more general, broadly applicable ideas in science [3]. In learning to explain the Atacama Desert, it is our goal that students develop more broadly applicable ideas about ocean currents, prevailing winds, differential heating, evaporation and condensation, local topography, and their relations to regional climate. If the puzzling phenomenon provides a focus for students' learning, the guiding question provides the broader outer bounds.

Table 2

Alignment of the Core Features of Science Argumentation and Corresponding Design Principles for Science Inquiry Activities

Feature of Science Argumentation	Design Principles
Argumentation in science is in response to a question about an <i>explanandum</i>	Students' science learning and activity should be organized around their developing increasingly better explanations of a launching focal and puzzling phenomenon and/or class of phenomena.
A line of argument makes a claim for a particular explanation of the <i>explanandum</i>	<p>Designers should construct and analyze a target explanation for the <i>explanandum</i> that is appropriate to what is expected of students at that grade level.</p> <p>The guiding question / <i>explanandum</i> / target explanation should require core science ideas, align with grade-level content standards, and connect with students' experience.</p>
A line of argument uses data and ideas as evidence in support of the explanation	<p>Designers should determine the data related to the <i>explanandum</i> that students will need in order to construct the target explanation, and provide them as students can identify them as necessary.</p> <p>For each of the rules and the protagonists that were identified in analyzing the explanation, designers should identify the sources of evidence—both first-hand experiences and texts—that will provide a basis for students to infer the relevant rules, and understand the characteristics of the protagonists.</p>
A line of argument requires reasoning that connect the evidence to the explanation	Designers should identify the kinds of reasoning students will need to use in constructing rules and the target explanation, and create scaffolds to support their developing thinking.
<p>A line of argument provides justification for the claim of the superiority of the explanation, based on:</p> <ul style="list-style-type: none"> • Absence of refuting evidence 	<p>Students should be provided with opportunities during the unit to consider and critique multiple explanations (of the focal phenomenon, or as part of sub-investigations) for their relative merits in relation to each other.</p> <p>Learning activities should be sequenced in order to help students develop explanations with increasing causal depth.</p>

<ul style="list-style-type: none"> • Coherence of explanation with available data and ideas • Causal depth of explanation 	
Argumentation is a dialogic process	Designers should provide students with periodic opportunities to engage in more and less formally structured argumentation over the course of the unit in order to work toward increasingly better explanations.
Argumentation uses socially defined criteria to evaluate the merits of evidence, explanations, and lines of argument	<p>Designers should provide students with opportunities and support for evaluating the quality of information that might be used as evidence.</p> <p>Designers should provide students with opportunities during the unit to consider and critique multiple explanations for their relative merits in relation to each other, either of the focal phenomenon, or as part of sub-investigations.</p>

The guiding question is a question posed in student-accessible language that guides their inquiry into the mechanisms underlying the larger class of phenomena represented by the focal puzzling phenomenon. In the case of the Atacama Desert, an appropriate guiding question is “Why do different places have different weather patterns?”

It can be easy for someone, teacher or curriculum designer, who is familiar with the ideas underlying a phenomenon to move quickly to incorporating those ideas into questions or discussion. We advocate introducing and incorporating those ideas slowly and cautiously, in a kind of “slow reveal” of the explanation and its protagonists. If students do not already have a command of the relevant underlying ideas (e.g., the role of currents in climate), the initial focus should be on what is observable and most familiar (e.g., precipitation, experienced humidity). Just as scientists begin only with their pre-existing ideas and the observable characteristics and patterns relevant to a phenomenon, so should students. This ensures that students are not being expected to take up ideas that are unfamiliar to them before they have the opportunity to construct those ideas using appropriate resources. When students are incorporating these ideas into their explanations, they have sources and shared knowledge to draw on as they do so.

Selecting an appropriate puzzling phenomenon and associated guiding question requires careful thought. *The guiding question, explanandum, and corresponding explanation should*

require core science ideas, align with grade-level content standards, and connect with students' experience. The phenomenon should be something that requires the use of powerful science ideas to adequately explain, ideas that provide a foundation for future learning, or can be applied to a variety of contexts. The science content required in the explanation should also be aligned with local and/or national science content standards so that students learn required content in the process of developing explanations through argument.

The phenomenon should also be selected to serve as a source of motivation to learn. It should connect to authentic experiences or questions in students' everyday lives, such that they can reasonably be expected to already have some ideas about and investment in it. Alternately, it should be presentable in a classroom setting using first-hand experience or secondary documentation, and be sufficiently potentially puzzling, creating cognitive dissonance for students [34]. The Atacama Desert by itself (or deserts more generally) is not particularly familiar to students, but photographs of it and the Amazon rainforest can provide some sense of their striking contrast, and students can help to "populate" the class of phenomena by providing their own examples of and questions about places with different weather patterns. In selecting and developing a puzzling phenomenon, designers should ask themselves the following question: "How can the phenomenon be directly or indirectly presented to provide students with sufficient information to support their understanding of the context and motivation to seek an explanation for it?"

The focal phenomenon not only provides a focus for instruction, it affords an initial opportunity for assessment. After students are introduced to the phenomenon for the first time, they should be invited to explain it as best they are able based on their incoming ideas, creating representations of their explanations. These representations generate records of the prior knowledge that students see as relevant to the focal phenomenon, and can also provide impetus and material for subsequent investigation and argumentation. For example, in their initial explanations of the Atacama, students might variously attribute the difference in precipitation as due to differences in local winds, or differences in temperature. These initial ideas could be the impetus for seeking data that would support one position or the other, and create an opportunity for students to engage in argument around their respective positions.

Organizing instruction and learning around questions about a focal phenomenon and a related class of phenomena aligns it with authentic science inquiry. Inquiry is initiated by asking questions, and in science it is asking questions about the workings of the natural world. The focal

phenomenon grounds the inquiry process in the natural world, while inviting students to pose their own questions in relation to it or a similar phenomenon. Choosing a phenomenon of scientific significance and of interest to students creates opportunities for them to learn core content and incorporate their own ideas and life experiences. Eliciting students' initial explanations supports a focus on explaining the mechanisms underlying the natural world, and makes their ideas a substantive part of the inquiry process from the beginning.

Designers Should Analyze and Identify the Components of the Target Explanation

A scientific argument supports an explanation: *designers should construct and analyze a target explanation for the explanandum that is appropriate to the knowledge and understanding expected of students at that grade level.* It therefore will incorporate some, but not all, of the potentially relevant science ideas, at an appropriate depth and level of sophistication. A given phenomenon could serve as the *explanandum* at multiple grade levels; what would vary is the sophistication and depth of the explanation that is set as a goal. We expect students to be able to explain that the Atacama Desert is as dry as it is for two primary reasons. First, **prevailing winds** blow air that contains a lot of **water vapor** that **evaporated** from the waters of the **warm currents** off the eastern coast of South America, most of which falls as **rain** as the **wind** carries it over the Amazon rainforest. The remainder falls on the **windward side** of the **mountains** before the air reaches Atacama (the **rain shadow effect**). Second, the waters of the **cold currents** on the western coast **evaporate** very little **water vapor** into the air above them. The **water vapor** that does **evaporate** is carried away by **prevailing winds**, or does not reach the Atacama due to a similar **rain shadow effect**. If we expected greater detail or causal depth, however, we might also ask students to explain the role of energy and molecular movement in the differing rates of evaporation or the rain shadow effect.

A scientific explanation is not monolithic; it includes a variety of protagonists, and a series of events or interactions that involve them. For example, an early component of the Atacama Desert explanation is liquid water evaporating at a relatively high rate from the water of a warm Atlantic current, to become water vapor suspended in the air. This component idea is only a fragment of the full explanation, but by itself represents a complex process. Students will have to come to understand the protagonists and their characteristics (e.g., currents, temperature, water vapor, evaporation) and what rules describe their interactions (e.g., at the higher temperatures of warm currents, more water becomes water vapor through evaporation). To design learning activities that will lead to students successfully constructing and supporting the

target explanation, designers should deconstruct the explanation into its component ideas in order to analyze them.

For each of the component ideas that make up the target explanation, designers should determine what protagonists and rules are involved, and what resources students will use to build an understanding of them. First, the designer should identify the protagonists, the actors involved in the target explanation. Referring back to our summary of the Atacama target explanation, the primary protagonists are highlighted in bold. Next, the designer should identify any rules that students will need to infer by reasoning from the data provided related to the focal phenomenon. For example, although they do not do so during the unit, students need to recognize that annual precipitation in South American cities decreases from east to west toward the Atacama, and infer that this means the amount of water vapor in the air is moving as the prevailing wind is decreasing. Finally, the designer should identify the rules that students will need to apply in constructing the explanation because they are relevant to the circumstances, such as the relationship between temperature and evaporation rate. These rules will be the foci of instructional activities (the intermediate learning goals) as students work toward a complete explanation.

Designers Should Identify Sources of Evidence for the Explanation and Relevant Rules

A scientific argument typically uses specific data to support the explanation offered as being the best available. *Designers should determine the data related to the explanandum that students will need in order to construct the target explanation, and provide them as students can identify them as necessary.* For example, for students to explain the primary factors affecting the climate of the Atacama Desert, they would need data representations for South America's precipitation, temperature, topography, prevailing winds, and local ocean surface current movement and temperature. Just as science ideas should not be introduced or incorporated until students have need of them as they construct the explanation, the different types of data should not be introduced until students are in a position to identify them as relevant. For example, until students are familiar with the idea that a given region has prevailing winds that reliably blow in a particular direction, they will have difficulty interpreting a map representing them, or understand its significance.

Another important possibility to consider is providing students with more data than is necessary or immediately relevant to explaining the focal phenomenon, either by including superfluous data points in the representations of relevant data (e.g., the annual precipitation of a

city far from the Atacama, and not aligned with the prevailing winds), or representations of data that might be seductive but is irrelevant to constructing the explanation (e.g., the population density of South America). Providing these kinds of data will likely increase the cognitive demand on students in constructing their arguments, but it also creates opportunities for them to develop and demonstrate important science practices in identifying relevant data to use as evidence [18]. Grounding any final explanation of the focal phenomenon in data emphasizes important aspects of science inquiry; it gives priority to evidence as students construct their explanations, and provides a culminating opportunity for them to analyze and interpret data relevant to the unit focus.

For each of the rules and the protagonists identified in analyzing the explanation, designers should identify the sources of evidence—both first-hand experiences and texts—that will provide a basis for students to infer the relevant rules, and understand the characteristics of the protagonists. Some rules can reasonably be generalized based on hands-on investigations in the classroom setting. Of these, some can be constructed using data gathered through direct investigation in the classroom setting; these activities afford students the opportunity to design and conduct first-hand investigations themselves, an important aspect of science inquiry. For example, to generalize a rule about the relationship between water temperature and evaporation rate, students could measure the surface level in containers of water kept at different temperatures, observing that the level decreased more in containers kept at higher temperatures. An important consideration for these activities will be the tools and techniques that students will require to gather data. If sophisticated methods are required, designers should build in opportunities for students to become familiar with them. Some methods, whether procedural or analytical, can be introduced through model texts, which describe scientists using the methods for authentic purposes [34].

Other rules will be generalizable based on physical models that function similarly to corresponding real-world phenomena. Students can infer rules from hands-on investigation of these models, but will need support in analyzing how the model is similar and different in comparison to what it is modeling. Any rules they infer should only be based on aspects that are similar. For example, when students learn about the factors that influence the movement of surface ocean currents, they model the currents in a small tank of water, creating “wind” by blowing through straws and observing the water movement in and around foil “continents.” Students can conclude that wind and continent shape influence surface currents, but also need

support in recognizing that the winds do not blow in arbitrary directions—there are prevailing patterns in winds that in turn create patterns in surface currents.

Not all questions are directly investigable in a classroom setting, and students can learn important content and practices by analyzing and critiquing secondary data [35]. Designers should identify rules that are best inferred through second-hand investigation using texts that provide data and describe the methods used to gather it [34]. This includes rules that are derived from contexts that are inaccessible or use methods that are not feasible. For example, when students learn about evaporation and ocean currents, they analyze maps that show evaporation rates and the movement of surface currents of different temperatures. They identify patterns across the maps, and infer a general rule about the relationship between current temperature and evaporation rate. The maps summarize authentic data that would never be feasible for students to collect themselves, and allow them to engage in an analysis of the data and derive an accurate general earth science principle in context.

A common misinterpretation of constructivist learning theory is that students must discover all science knowledge for themselves, essentially inferring all of the rules and protagonists that make up currently accepted science knowledge [36]. It is hardly pragmatic for students to do so, and such an approach would not prepare them to make sense of science texts presenting abstract ideas, which will be common in their future experiences as learners and citizens. Designers should determine which protagonists or rules need to be introduced to students through expository text or other representations, because they are not directly observable and will be difficult to infer. They can then select texts and design activities to support students in making sense of the text, integrating the protagonists into the rules and explanations, and applying the rules to specific scenarios. For example, we decided that molecular interactions in evaporation and condensation are too much for students to infer on their own, and introduce them through a set of texts and animations. Students are then prompted to incorporate these new protagonists into predictions and explanations that involve phase changes of water, drawing on the information sources as appropriate. Drawing from a variety of sources of data, generated through first-hand investigation and interpreted from text, reflects the view of inquiry as a diverse set of practices [5].

Designers Should Identify Reasoning and Design Scaffolds to Support It

Finally, having analyzed the explanation, the data supporting it, and the means by which students will construct the rules they need to understand to explain the focal phenomenon,

designers should identify the kinds of reasoning students will need to use in constructing rules and the target explanation, and create scaffolds to support their developing thinking. Reasoning in the construction of evidence-based explanations is a vital part of inquiry that can be particularly challenging for students [37]. Designers should identify the reasoning that students will need to use in generalizing the rules that they will ultimately use in their explanation. For example, students observe and record the behavior of balloons filled with water of different temperatures and salinities when placed in a tank of room temperature fresh water. From this data, they need to infer the general patterns that colder water sinks in warmer water, and saltier water sinks in fresher water. They are then introduced to the protagonist density and the relative densities of the different types of water, and must incorporate density with the patterns to construct a causal relationship. Designers should also identify the kinds of reasoning students will need to use in applying rules to construct the target explanation. For example, students need to apply the rain shadow effect to explain the lack of precipitation in the Atacama Desert, attending to the mountain range bordering the Desert, and the prevailing winds that blow perpendicularly to it.

Having identified the reasoning that will be required, designers should create scaffolds that will be provided and faded to support students in reasoning in the ways identified and in articulating their reasoning clearly. For example, once students have learned about the rain shadow effect, they examine several hypothetical situations, determining whether or not the effect is likely to be responsible for a particular dry region. In doing so, they are practicing identifying situations in which the rule is applicable. When writing arguments, they are provided with sentence stems that structure explicit articulation of reasoning: “We know that the rain shadow effect occurs when . . . We can see from the data that . . . Therefore . . .” In addition, when first using a reasoning in a particular way, the teacher explicitly names that kind of thinking, and encourages students to name it thereafter. “We are looking at each situation to decide whether or not the rain shadow effect can help us explain why the area is so dry. In science, we call using an idea to conclude something about a relevant situation *application* of that idea.”

Designers Should Provide Students with Opportunities to Learn about and Practice Evaluating Lines of Argument in Science Using Explicit Criteria

Because the quality of a line of argument ultimately rests on the quality of its grounds, *designers should provide students with opportunities and support for evaluating the quality of information that might be used as evidence.* These opportunities can take multiple forms as students develop understanding and facility. Students should first be provided with models of the

thinking involved in evaluating sources, including the teacher explicitly modeling the process with a source used by the class, and/or model texts that show scientists engaged in evaluating information—procedures, data, or informational text—for legitimacy and credibility. Students can then be provided with opportunities to evaluate and choose between sources of evidence to use to answer an explanatory question, where the sources differ in quality. Furthermore, students should have opportunities to critique provided arguments based on the credibility of information that is used as evidence, or the transparency regarding the source (or lack thereof) that allows for critique.

Designers should also provide students with opportunities during the unit to consider and critique multiple explanations for their relative merits in relation to each other, either of the focal phenomenon, or as part of sub-investigations. The teacher should have access to multiple explanations that could be introduced to and evaluated by students, but also be in a position to capitalize on different explanations generated by students. We mentioned previously that having students represent their initial explanations of the focal phenomenon can provide multiple explanations for comparison. Any provided explanations should vary in ways that allow one to be identified as superior, based on the criteria for justification. They could differ in causal depth, with one explanation extending further than the other. They could differ in refutability, where one explanation conflicts with some available evidence. They could differ in coherence, with one explanation accounting for more of the available evidence than the other. Also, they could differ in the credibility of the evidence, with one explanation drawing on evidence that is more credible in some way (this is similar to students' critique of arguments we described in the previous paragraph).

Comparing multiple explanations presents an opportunity to specifically confront alternative conceptions held by students that can be resolved through argumentation; these explanations could be developed based on alternative conceptions reported in the literature or from common ideas that have been generated by students in other classes [38]. It is important, however, that these explanations be refutable based on evidence that the class has or could obtain. If students don't already have access to the information necessary to refute it, deciding between multiple explanations might require a return to investigation to gather relevant data. For example, one explanation students might offer for the sinking of a saltwater balloon is because it is denser than a freshwater balloon. Another explanation could be because the saltwater balloon weighs more. If students have read an expository text about density and sinking and floating, they could critique the second explanation based on consistency with available information. If they have yet

to read such a text, they could return to investigation, comparing a smaller saltwater balloon that weighs less to a freshwater balloon that weighs more—which could then motivate the reading of the expository text to introduce density as a protagonist.

Designers Should Create Iterative Opportunities for Students to Engage in Argumentation to Develop and Refine Their Explanations of the Focal Phenomenon

Learning to critique sources of evidence and explanations prepares students to construct and critique lines of argument in more holistic and iterative ways. To emphasize the dialogic nature of argumentation, *designers should provide students with periodic opportunities to engage in more and less formally structured argumentation over the course of the unit in order to work toward increasingly better explanations.* These opportunities can include the following: casual discussions about how newly constructed rules or newly acquired data support or suggest revisions to current explanations; structured discussions for which students have time to prepare a particular explanation and marshal evidence for it before talking with their peers in small or whole-group settings; or, a scaffolded process in which students create and critique written arguments with their peers. Supporting these kinds of interaction require cultivating a classroom community that treats each argument as a collaborative effort to work toward the best explanation by testing multiple possibilities against evidence and criteria. This perspective on argumentation differs from many students' everyday perspectives on argumentation, which often view it as an emotionally loaded situation in which individuals feel hesitant to risk being attacked or being wrong [15].

To support students' re-conceptualization of argumentation, designers should include regular opportunities for students to revisit and revise their arguments about the focal phenomenon. Students may revise their arguments in multiple ways, and should have support for all that might be relevant at a particular point in the unit. They may revise their explanation to be consistent with any relevant rules that they have developed since their previous explanation. New rules may also prompt students to identify data that they require that is relevant to the explanation; designers should anticipate when students might do so, and ensure that the data is available in resources already available to them, or can be provided by the teacher. Moreover, students should justify explicitly how and why a new explanation is better than previous and/or alternative explanations. The process of revisiting and revising their arguments provides students (and teachers) with evidence of their developing understanding of the focal phenomenon, as well as experience using an explicit set of criteria to assess and improve that understanding.

Designers should determine a sequence of learning activities that will afford opportunities for students to improve and refine their explanations of the focal phenomenon through a connected series of investigations. While there are no doubt multiple ways to achieve this, we suggest that *learning activities should be sequenced in order to help students develop explanations with increasing causal depth*. This means beginning with the focal phenomenon and moving “backward,” using the answer to one question to generate the next, extending the causal story, or identifying new relationships between protagonists. For example, presenting the contrast between the Atacama and the Amazon prompts the question “Why is one area drier than the other?” A brief analysis of precipitation data might then prompt the question “Where does the rain come from?” which in turn leads to “Where does water vapor come from?” Mapping back through the causal story in this way corresponds to the way in which findings often generate new questions in science [7].

An approach that organizes instruction around opportunities for students to work toward better explanations of a focal phenomenon through guided inquiry and argumentation offers dual benefits. It not only creates opportunities for students to develop an understanding of core science ideas, but it does so by their engaging in and developing facility with the fundamental practices of inquiry science. Students ask and pursue answers to questions about the workings of the natural world. Students conduct investigations and analyze texts in order to generate new data and identify relevant credible information. They analyze the data and ideas to use as evidence in supporting or revising their explanations based on a critique using common criteria and, in doing so, develop new science knowledge which in turn leads to new questions. We recognize that there are other practices that can and should be incorporated into students’ learning, such as engineering and design, but we propose that explanation and argumentation should be a dominant focus, as multiple practices fundamental to inquiry (questioning, investigating, gathering and analyzing data, modeling, critiquing and interpreting texts) can all be incorporated as authentic tools in arguing toward better explanations [18].

Conclusion

If inquiry is important for the critical thinking skills it teaches, the training of citizens in a democracy for making evidence-based decisions, and for preparing some students to make science a vocation, then finding a way to coherently embed inquiry in school science is essential. Designing units around a scientific argument connects the practices of inquiry to the content and to each other in a meaningful way. By focusing on the construction of a scientific argument, students will not be learning just procedures or discrete facts, but will be practicing critical

thinking skills as they address a question, and seek and evaluate evidence to construct increasingly complex explanations. It is this type of critical thinking that is needed to make choices outside of the classroom as well. Throughout a unit of argumentation, the role of the student will be to question assumptions and to think not just about finding a right answer, but about finding the best answer that relies on the best available evidence. Learning to critique and to weigh alternatives are invaluable skills that are applicable well beyond the science class. Finally, by participating in the co-construction of these classroom explanations, students will have a better appreciation for the nature of scientific knowledge. Understanding the process of communal knowledge construction practiced by scientists will provide students with real preparation for pursuing a career in science, and will better equip them to evaluate the science they encounter as they make decisions in their lives.

While these design principles are grounded in a coherent conception of scientific argumentation and provide initial guidance in constructing learning activities, continued empirical testing with students is a critical next step. As students attempt to explain focal phenomena using the data they gather and ideas they have derived from interpretation of text, new opportunities and challenges will become evident. Analysis of how students work to take up the practices and values of science in their efforts to explain the natural world will reveal areas of unexpected promise and difficulty.

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CHALLENGING PRE-SERVICE STUDENTS' TEACHING PERSPECTIVES IN AN INQUIRY-FOCUSED PROGRAM

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Abstract

Inquiry teaching based on constructivist learning theory has been an emphasis in pre-service education for over a decade. In general, a developmental teaching perspective supports inquiry-based instruction where teachers view learners as constructors of knowledge and teaching as providing questions, problems, and challenges that form a bridge from the learners' prior knowledge to a new, more sophisticated form of reasoning. Since teaching perspectives influence student learning, teacher effectiveness, and teacher attrition, challenging pre-service teachers to overcome experience-based convictions of a transmission perspective is necessary in teacher education. In this study, we examined the teaching perspectives of secondary, pre-service methods students at the midpoint of an inquiry-focused program. Our findings suggest that, despite being introduced to a variety of teaching perspectives, overcoming preconceptions of "good teaching" and considering a perspective counter to one's disciplinary major presents a dilemma for pre-service teachers.

Introduction

The work of psychological theorists like Piaget, Bruner, and Vygotsky underpins the development of constructivist learning theory and the basis of educational reforms toward the end of the twentieth century, which promote a shift from discipline-based, teacher-directed instruction to constructivist-based, student-centered instruction [1]. In general, constructivist teaching involves the facilitation of students actively exploring ideas through inquiry [2]. The National Research Council (NRC) published standards that emphasize developing student abilities of inquiry, learning subject matter disciplines in context of inquiry, and implementing inquiry as instructional strategies, abilities, and ideas to be learned [3]. Most states follow suit by identifying inquiry as a standard to be taught in the curriculum. Thus, the majority of teacher education programs in the twentieth century adopt a constructivist-based inquiry approach to

teaching. Further, the integration of inquiry in secondary science instruction is one of the only topics that the majority of pre-service teaching programs focus on worldwide [4].

For most, the concept of a *teacher* develops from a variety of experiences and interactions to create a schema for characterizing effective and ineffective teaching, with pre-service teachers not being an exception [5]. Pre-service teachers spend their formative school years observing the practices of and interacting with teachers, thereby creating memories that can act as a filter for beliefs and acceptable practices that may or may not be supported by educational theories [5-11]. Since these preconceptions are based on many years of experience, they can be hard to overcome, even though various research suggests some pre-service teachers' beliefs are amenable to change through reflection and teaching [12-18]. Varma, Volkman, and Hanusci provide evidence indicating that pre-service elementary teachers experiencing inquiry-based pedagogy in a science methods and field experience course develop conceptions of constructivist science teaching [19]. Furthermore, the prospective teachers acquired a comfort with inquiry methodology and an intention to teach via this method. In a similar study, Bleicher and Lindgren found that reflection, discussion, and experience with inquiry-based methods improved pre-service teachers' self-efficacy, scientific conceptual understanding, and intention to use reform-based methods as a classroom teacher [20]. Both studies indicate a change in teacher self-efficacy with implementing inquiry-based pedagogy, but neither presented data to indicate the change in views beyond the methods course.

Despite over a decade of emphasis in pre-service education on inquiry teaching, teachers continue to indicate a comfort preference with didactic teaching methods [3, 21-25]. Parker and Brindley found that graduate pre-service teachers were more likely than undergraduate pre-service teachers to indicate the intention to use reform-based teaching methods, possibly a result of professional experiences; however, their naïve understanding of the high stakes within the current educational context allows an unrealistic idealism that undergraduates do not have because they experienced accountability as a student [26]. Even though teacher preparation programs typically focus on reform-based pedagogy, these ideals can be incompatible with the schema pre-service teachers have created before entering the program [27]. Research studies have indicated that pre-service teachers' beliefs become their actions and behaviors as teachers [28, 29].

Since teaching methods and perspectives influence student learning, teacher effectiveness, and teacher attrition, challenging pre-service teachers to overcome naïve, experience-based

convictions and base their teaching on best practices rather than episodic conceptions of good teaching is necessary in teacher education. Exploring pre-service teachers' teaching perspectives allows teacher educators to gauge students' internal teaching models based on beliefs, intentions, and actions. The purpose of this study was to examine the teaching perspectives of secondary, pre-service methods students in an inquiry-focused program. Since education students' teaching perspectives are influenced by their prior experiences in the classroom, many students often exhibit a transmission perspective [23]. The program's inquiry-focused conceptual framework aligns to a more developmental or constructivist approach to teaching, thus providing an obstacle for students to overcome. The intent of this article is to share the results of students' teaching perspectives and thoughts when confronted with different views of effective teaching. The rationale for researching pre-service teachers' thoughts on being challenged to consider different views of teaching is to provide insight into their conceptions of effective teaching. Further, understanding prospective teachers' challenges to consider different perspectives of teaching provides insight into the possibility of broadening pre-service teachers' methods of instruction.

Theoretical Framework

Teaching is a complex and multifaceted endeavor and, accordingly, systematic differences exist in the way teachers view their roles and responsibilities. According to Pratt, a teacher's point of view or perspective "is an expression of personal beliefs and values related to learning and teaching" which is influenced by experiences and reflection [30]. After reviewing thirteen studies conducted between 1983 and 1996 investigating conceptions of teaching, Kember identified five appreciably different views of teaching [31]. Rather than presenting perspectives of teaching on a continuum, Pratt legitimizes each of the five perspectives as a compilation of actions and beliefs [30]. Teaching perspectives are an interrelated set of beliefs and intentions that direct and justify teacher actions, and therefore, provide a lens through which to examine teaching and learning.

Actions, intentions, and beliefs are used as indicators of commitment to a particular perspective on teaching. Actions are the ways in which a teacher helps students to learn the subject content, and are best understood when viewed in terms of intentions or what a teacher is trying to accomplish, and beliefs or why a teacher thinks it is important. Intentions are what gives meaning to actions and, as such, are a direct statement of commitment. Perhaps the most crucial indicator is beliefs because they are central to teachers' core values. Beliefs about knowledge and learning are the most unyielding and least flexible indicator of commitment.

The five perspectives on teaching are transmission, apprenticeship, developmental, nurturing, and social reform. Pratt and Collins provide an overall profile for each perspective based on the many representative people interviewed during their research [32]. While each perspective varies in views of knowledge, learning, and teaching, some overlap of actions, intentions, and beliefs exists. Regardless of some similarities, individual perspectives are fundamentally different in terms of the elements and relationships that dominate in Pratt's general model of teaching (see Figure 1).

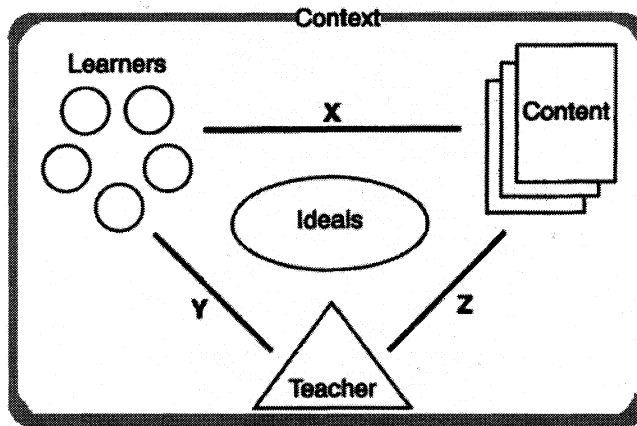


Figure 1. General model of teaching [30].

Transmission Perspective

Teachers with transmission as their dominant perspective think effective teaching involves having mastery over the content and exhibit a commitment to the subject matter. They view knowledge as existing outside the learner, either in texts or with the teacher. It is the teacher's role to provide a common body of knowledge to the learner efficiently and accurately. Effective teachers lead learners to authorized or legitimate forms of content mastery by systematically taking them through a set of tasks. These teachers provide clear objectives, adjust the pace of lecturing, use class time efficiently, answer questions, correct errors, summarize presentations, and provide reviews [33]. By conveying their enthusiasm about their content to their students, they are typically memorable presenters. Referring to the general model of teaching, the dominant elements for the transmission perspective are teacher and context, and the dominant relationship is line *z*, which represents the teacher's concern for and authority over learners [30].

Apprenticeship Perspective

Teachers with apprenticeship as their dominant perspective think effective teaching involves being skillful and having expertise in the subject matter. They view learning as a sequential process from simple to complex in an environment of authentic tasks in real settings. Teaching is a process of enculturation, whereby students come to understand social norms and ways of working by observing and then doing. Effective teachers engage students within their “zone of development,” and know when students can work on their own and when more guidance and direction is necessary. Over time, teachers provide less direction and give more responsibility to the student helping them to progress from dependent learners to independent workers. Referring to the general model of teaching, the dominant elements are teacher, content, and context, with the teacher and content inseparable within context [30].

Developmental Perspective

Teachers with developmental as their dominant perspective think the learner’s point of view takes precedence when planning and conducting lessons. They view learners as constructors of knowledge using what they know to interpret new information. It is the teacher’s role to provide questions, problems, and challenges that form a bridge from the learner’s previous way of thinking and reasoning to a new, more sophisticated form of reasoning and problem solving. Referring to the general model of teaching, the dominant element for the developing perspective is learners, and the dominant relationship is line x which represents learners expanding their ways of knowing the content [30].

Nurturing Perspective

Teachers with nurturing as their dominant perspective think effective teaching involves respecting the learner’s self-concept and self-efficacy. They view learners as more productive in a supportive environment free from failure. Central to this view is a commitment to the whole learner and not just their intellectual development. Effective teachers balance promoting a climate of caring, challenging students to do their best while setting clear expectations. Referring to the general model of teaching, the dominant elements for the nurturing perspective are teacher and learner, and the dominant relationship is line y , which represents the teacher-student relationship [30].

Social Reform Perspective

Teachers with social reform as their dominant perspective think effective teaching involves pursuing social change in substantive ways. They view teaching as exciting students to

the values and ideologies embedded within the subject matter. Effective teachers are clear and articulate about changes that must take place in society. They focus class discussions of readings on what is and is not said, what is included and excluded, and who is represented and omitted. Students are empowered to take a critical stance and improve their lives. Referring to the general model of teaching, ideas emerge as a prominent element and overshadow all other elements and relationships for the social reform perspective [30].

Research Approach—Program Description

The four-year teacher education program admits undergraduate mathematics and science majors interested in obtaining secondary certification. As part of the degree program, students take a series of field-based experience courses. During the first two credits of introductory education courses, students observe experienced teachers in both elementary and middle schools. They then work in pairs to teach inquiry-based lessons from an age-appropriate science kit. The third course in the program sequence is a three-credit, non-field based educational psychology course where students learn how constructivist learning theory supports an inquiry approach to instruction. After taking these prerequisites, students continue their coursework with two methods courses. During the first methods course, students observe a high school classroom and later design and teach a one-day, interactive lecture-based lesson and a three-day, inquiry-based lesson. Students taking the second methods course observe at a project-based learning school, and design and teach a mini-unit by coherently sequencing four lessons using a project-based approach.

Participants in this study were taking the first methods course, which is centered on a close examination of the interplay between teachers, K-12 students and content, and how these types of interactions enable students to develop deep conceptual understanding. The course builds on the educational psychology course, moving students from a focus on thinking and learning to a focus on teaching and learning. Participants are taught how content and pedagogy combine to make effective teaching. During the course, participants work in teams of two or three to design and teach one-day and three-day lessons. Also in this course, students take Pratt and Collins' Teaching Perspectives Inventory (TPI). The inventory is used to help students to understand different teaching perspectives before challenging them to consider the advantages of each perspective and how they support different educational standards.

During the first four weeks of the course, students explore the interplay between teachers and content by unpacking the standards and developing content learning progressions. The next

four weeks are dedicated to the relationship of K-12 students to content. Participants consider their understandings from educational psychology, and reflect on additional readings about how people learn. By the midpoint of the course, participants design and teach a one-day, Madelyn Hunter model lesson using best practices from a transmission perspective. The third four weeks investigates the interplay between teachers and K-12 students. During the last four weeks of class, students are challenged to design and teach an inquiry-based lesson incorporating best practices from a developing teaching perspective using a 5E (Engage, Explore, Explain, Elaborate, Evaluate) inquiry-model.

Research Approach—Participants

Twenty students who were enrolled in an inquiry-focused methods course consented to participate in this study. After providing the results of the 45-question TPI, four case study participants (“Jess,” “Quanda,” “Kristina,” and “Valerie”) who best represented the different mean values of the various students’ teaching perspectives agreed to provide additional qualitative data. Jess co-planned with “Andrea” and “Mandy,” but partnered only with Andrea to teach their chemistry lessons during the course. Quanda did not have a partner to design and implement her mathematics lessons. Jess and Quanda’s self-reported TPI was representative of the majority (45%) of the participants. “Kristina” paired with “Marcus” to design and teach biology lessons. Kristina’s self-reported TPI was representative of about 30% of the participants. Valerie partnered with “Emily” to design and implement their biology lessons. Valerie’s self-reported TPI was representative of 10% of the participants.

Research Approach—Data Collection

A sequential exploratory, mixed-methods strategy informed the design of this study [34]. Drawing on teaching perspectives as our framework, we first collected and analyzed the quantitative TPI data to determine participants’ teaching perspectives. This data informed the selection of the three representative case study participants from which to collect and analyze qualitative data. Qualitative data consisted of students’ lesson plans, blog postings, and individual interviews. Both authors first met to create start codes for analyzing lesson plans, and then independently examined the data for characteristics of best practices within the five teaching perspectives: transmission, apprenticeship, developmental, nurturing, and social reform. The coders then met again to compare their findings [35].

After teaching their sequenced, inquiry-based lesson, participants responded on a blog to the following questions:

- After finding out your dominant and recessive teaching perspectives in addition to learning about the six different perspectives, did it challenge your views on teaching?
- When designing your lesson plan, did you consider trying to integrate any characteristics of any teaching perspective? If yes, what perspective and why?
- Reflecting on your teaching experience, do you feel you taught using your dominant perspective?
- Do you feel you taught using your recessive perspective?
- What influenced your teaching perspective?

Responses to the questions helped to inform the degree to which participants may have been challenged to consider teaching perspectives when designing and teaching.

Analysis of blog post responses helped with designing personalized, semi-structured interview questions. The following starter questions were used to guide case study participant interviews:

- How do you interpret your preferred teaching perspective?
- What aspects of your lesson showcased this perspective?
- What are the differences in the way you taught the one-day and the three-day teach, if any?
- Why did you include or not include social reform perspective in the lesson you taught?
- What do you think influences your teaching perspective?

Participant responses to these questions provided further insight into the development and challenge of teaching perspectives.

Findings—Teaching Perspectives Inventory Data

The TPI is a 45-item, 5-point Likert survey containing fifteen statements each on beliefs, actions, and intentions. After taking the on-line survey, participants submitted a report presenting their global perspective scores for each of the five teaching perspectives. Perspectives with scores one or more standard deviations above the mean of the five are considered dominant, and perspectives with one or more standard deviations below the mean of the five are considered recessive [23]. According to student-reported TPI data, 55% of the participants did not have a dominant teaching perspective and about 30% of the participants showed a dominant teaching perspective of nurturing. Eighty-five percent of the participants, including all case study

participants, revealed a recessive teaching perspective of social reform. Tables 1 and 2 present participants' overall TPI results.

Table 1
Descriptive Statistics and Teaching Perspectives of Participants (n=20)

Perspective	Transmission	Apprenticeship	Developmental	Nurturing	Social Reform	None
Mean	35.28	37.22	36.33	38.22	29.78	
Std. Dev.	2.987	4.052	5.520	4.319	3.228	
Range	26 - 39	29 - 42	25 - 44	33 - 45	25 - 36	
Dominant	0	1	2	6	0	11
Recessive	0	0	2	0	17	1

In Table 1, descriptive statistics are presented for each participant's survey results with respect to each of the five teaching perspectives. Dominant and recessive provides the total number out of the twenty participants with a dominant or recessive teaching perspective for each category as identified by the TPI.

Table 2
Teaching Perspectives of Participants

Dominant Perspective	Recessive Perspective	Percent of participants	Case Study Participants and Partners
No significant dominant perspective	Social reform	45	Jess, Quanda, Emily
Nurturing	Social reform	30	Kristina, Andrea
Developmental	Social reform	10	Valerie
Apprenticeship	Social reform	5	Mandy
No significant dominant perspective	Developmental	10	Marcus

In Table 2, Jess, Quanda, and Emily are representative of 45% of study participants who held no dominant perspective and a social reform recessive perspective. Kristina and Andrea are representative of 30% of study participants with a nurturing dominant perspective and a social reform recessive perspective. With a developmental dominant perspective and a social reform recessive perspective, Valerie is representative of 10% of study participants. Mandy represents 5% of study participants with an apprenticeship dominant perspective and a social reform recessive perspective. Marcus is representative of 10% of study participants with no dominant

perspective and a developmental recessive perspective.

The scores of participants in this study are consistent with the findings of Jarvis-Selinger, Collins, and Pratt on students seeking secondary-school certification in mathematics or science [23]. The mean score for nurturing perspective of participants is highest while the mean score for social reform perspective is lowest. Theoretically, participants' scores on the five TPI scales are a 36-point range from nine to forty-five. Scores for participants in this study ranged from twenty-four to forty-four, which is also consistent with the findings of the study by Jarvis-Selinger, Collins, and Pratt [23]. According to the TPI analysis, the participants in this study have actions, beliefs, and intentions consistent with similar pre-service students seeking secondary certification in mathematics or science.

Qualitative Case Studies—Jess

Jess self-reported no dominant, but a recessive social reform teaching perspective. Her partner, Andrea, reported a dominant nurturing and a recessive social reform teaching perspective. While Mandy taught her lesson separately, she co-planned with Jess and Andrea. Mandy reported a dominant apprenticeship and a recessive social reform teaching perspective. An analysis of their 5E lesson plan on states of matter revealed best practices for both a transmission and developing orientation. They provided students with exploratory stations and opportunities to discover content while she related the activities to real-life meaningful examples. However, it appears that Jess and her co-planners maintained control of the classroom and activities via transmission strategies. For example, they provided clear objectives by having students “follow directions for activities,” and correcting errors by “clarifying student misconceptions/misunderstandings.” Elements of developmental best practices included bridging knowledge by “asking probing questions” throughout the activities and “relating back to example” of a real-world application.

After teaching the lesson, Jess blogged that learning about teaching perspectives did not change her views on teaching. At this point in her coursework, she isn't comfortable changing her perspective. While the different teaching perspectives made her “more aware of the different styles,” she stated, “I would not purposefully try to change my perspective just because a different one looks or sounds better.” Her blog also revealed a misunderstanding she has about her own teaching perspective being apprenticeship. While her self-reported highest teaching perspective was apprenticeship, she in fact had no dominant perspective because transmission, developing, and nurturing were statistically equally as high. According to Jess, the inquiry-

learning focus of the program fits best with apprenticeship teaching and that her coursework to date have influenced her perspective greatly. Jess failed to recognize that inquiry-based strategies align best with a developmental teaching perspective.

Jess's interview revealed apprenticeship perspective as being "caring nurturing towards the kids, but like you kind of scaffold them the entire way and it works well with like science and math." She views apprenticeship as "inquiry-based," and that this was showcased by "starting the lesson without really telling the students anything, doing mini-labs, giving worksheets and having them work together and discuss with each other about what they were learning ... we [Jess and Andrea] helped them along." When asked about not including social reform perspective in her lesson, Jess responded that "social reform isn't something I think about a lot and it's nothing I've ever had in my classroom experience that I know of, so it's not something that I think about like, 'oh let me add this to my lesson plan because it will help the students social,' like, it's never been a priority of mine." According to Jess, "our one-day teach was just 'this is how you do it, now go ahead and do it.' [For the three-day teach] we reversed it: 'do this and now what did you find?'"

Qualitative Case Studies—Quanda

Quanda, like Jess, self-reported no dominant, but a recessive social reform teaching perspective. Unlike the other participants in this study, Quanda planned and taught her lesson alone. An analysis of her 5E, inquiry-based lesson plan on exponential graphs and functions revealed a majority of her best practices aligning to a transmission approach. For example, she provided clear objectives when beginning the lesson by "explaining to the class that they will be exploring exponential graphs." She sequenced tasks to lead learners to content mastery beginning by initially demonstrating the lab experiment to the class, and modeling so students' work would "look similar to the teacher's example." Quanda included a developmental approach of bridging knowledge when commenting on how exponential graphs "happen in everyday life."

While the majority of the ideas Quanda presented in her lesson plan were transmission oriented, she blogged about not believing that she "taught this way [transmission oriented] because it does not really go well with the 5E method of teaching." She also explained that discovering her teaching perspectives, "didn't challenge [my] views on teaching as much as it did clarify [my] ideas," and made her conscious of the ideas of teaching she wants to use. Furthermore, she mentioned that her "previous teachers in high school" and "teaching role models" impacted how she wants to act as a teacher. In her interview she confirmed this, explaining that her "teaching perspective was more representative of the teachers I liked in high

school” and “it would be kind of what I want to be.” In explaining why she thinks her social reform score is so low, she remarks that she is “not trying to change the world,” and though she “would like to see change,” she does not think as a teacher she has the power to do so. Moreover, she explains that the coded lesson plan had more inquiry elements and an earlier lesson plan that was more transmission oriented was “so much easier” and she “got to stick to the lesson plan,” which made her enjoy that experience more.

Qualitative Case Studies—Kristina

Kristina self-reported a dominant nurturing and a recessive social reform teaching perspective. Her partner, Marcus, self-reported no dominant perspective, but being recessive in the developing teaching perspective. An analysis of their 5E, inquiry lesson plan on classification of organisms revealed best practices more aligned with a transmission-oriented teaching approach. Their lesson included delivering content accurately and effectively by asking students to “follow along, take notes, and answer various questions as the teacher discusses the different classifications of organisms.” Kristina and Marcus also included tasks that led to content mastery by “providing a set of questions that asks students to compare organisms” and having students “describe characteristics and to classify seven organisms into correct categories.” By “going over answers with students and reviewing the material” to close the lesson, they provided timely feedback. Additionally, they provided clear objectives during the lesson when “introducing the major objectives and concepts” and “going over the discussions for the activity.”

Also in the lesson were a few examples of best practices from a nurturing perspective. Kristina and Marcus provided encouragement and support when “going around the room to help students with questions” multiple times during the lesson, and making an explicit point to both greet and encourage students. Included in the lesson plan were two specific instances of best practices from a developing perspective. First, they provided an opportunity for learners to think and reason when asking students to respond with “why they chose the answer they chose” and second, an occasion for bridging knowledge by providing meaningful examples, such as including examples students “might encounter daily or have previous knowledge about.”

Kristina blogged, after teaching the lessons, that teaching perspectives challenged her views to an extent, believing that all “views are important to incorporate when teaching because they are all important at different times in the classroom.” She did not “consider trying to integrate any characteristics of any teaching perspective,” stating that if any view was integrated “it would be transmission because our main focus was just trying to ‘transmit’ the information to

students through *PowerPoint* presentations and other activities.” Kristina also provided a rationale for not using her dominant perspective, which was nurturing, commenting that she “did not know the students enough to be able to give them the ‘nurturing’ environment.” According to Kristina, a nurturing environment requires a teacher to personally know her students.

During Kristina’s interview, she commented that “inquiry-based is more student-centered and transmission is more teacher-centered.” Her inquiry-based lesson was on classification and she “felt like we really couldn’t make that student-centered too much without the teacher first giving them all the information first ... using *PowerPoint* and stuff like that.” She stated, “It would be more difficult with the time allotted to have [it be] more student-centered, I felt it would be easier to just kind of like give them information.” Thus, Kristina believes that teaching from a transmission perspective is easier and more efficient. Kristina defines her dominant perspective, nurturing, as creating a “caring environment letting the student know that they can always come to the teacher,” and, “the nurturing teacher makes it so the students can raise their hands at all times, come to the teacher after class, and a very caring environment.” Kristina commented that to create a more nurturing environment in her three-day teach she would “have tried to let the students know us [her and Marcus] more so they could feel free to talk to us one-on-one.” Kristina acknowledged that “the one-day teach was supposed to be more direct teach and the three-day teach more inquiry-based,” but, “we wound up teaching the three-day teach very similar to the one-day teach using *PowerPoint*; it was very similar.”

Qualitative Case Studies—Valerie

Valerie self-reported a dominant developmental and a recessive social reform teaching perspective. Her partner, Emily, self-reported no dominant, but a recessive social reform teaching perspective. An analysis of their 5E, inquiry lesson plan on evolution revealed best practices mostly matching a transmission-oriented teaching approach. Several examples of delivering content accurately and effectively included having students “listen, take notes, and discuss,” explaining “Darwin’s observations,” mentioning “artificial selection is when humans choose who mates with whom,” and providing answers to students’ questions. Also in the lesson were tasks that led to content mastery, such as looking at projected pictures and discussing questions in small groups, think-pair-share about textbook terms, a brainstorm of how animals have changed over time, class discussion of dominant traits, and a “short film on natural selection.”

Valerie and Emily also included several best practices from a developing perspective. They helped students to develop increasingly complex cognitive structures for comprehending the content by asking students to “draw conclusions from observations,” picturing similar bacteria with varying genetic makeup, and “assessing how well students have understood and can apply the material.” In addition, Valerie and Emily incorporated two examples of bridging knowledge through providing meaningful examples by relating material to the real-world environment and including “how traits that were not favored in society died off.” A few best practices included in the lesson from a nurturing perspective were not sacrificing self-esteem for achievement through encouragement and asking students unable to answer a question to give an example instead. Another involved assessing individual growth, as well as absolute achievement, by using a ticket-out-the-door asking students to “write one thing they did not understand, they would like us to elaborate on the next day, or a question they have that we can address the next day.”

Valerie blogged that teaching perspectives challenged her views by making her think more as she taught her three-day lesson. As an example, she stated, “when my partner and I taught antibiotic resistance, I tried to put myself in the students’ place and see how they understood it. It also led me to ask them a couple more questions about a topic they may have had misconceptions about.” Valerie insightfully mentioned that she tried to become her dominant perspective, but believed incorporating other perspectives was also important. According to Valerie, her past experiences, as well as experiences she never had, attributed to her teaching perspective. She states that she “tried to entertain the students...and teach the students by showing enthusiasm about the topic because the most influential teachers were the ones who loved what they were doing and teaching.” Clearly, Valerie believes that her high school teachers greatly influence her practice.

Summary

Participants of this study overwhelmingly held social reform as a recessive teaching perspective and the majority reported a dominant teaching perspective of either none or nurturing. In comparing the lesson plans of all four case study participants, social reform was not incorporated in any of their lesson plans. As a rationale, Jess didn’t consider social reform anything she thought about and not a priority. Quanda was not trying to change the world and did not think teachers had the power to do so. While most participants held no dominant teaching perspective, nurturing, on average, was participants’ highest self-reported teaching perspective.

Despite designing lessons using a 5E inquiry template intended to be more consistent

with a developmental perspective, participants' instructional plans mostly maintained elements of best practices from a transmission orientation. Some participants, like Kristina and Valerie, incorporated multiple teaching perspectives into their lessons contrary to their preferred teaching perspective. Some participants, like Kristina and Quanda, reverted to a preferred one when the lesson was not succeeding. Both Kristina and Quanda commented that teaching from a transmission perspective was easier and, Kristina added, more efficient. Valerie considered incorporating multiple perspectives to be valuable.

Case study participants suggested an awareness of different teaching perspectives and a resistance toward challenging their preferred transmission perspective. Valerie stated best what appears to influence participants most as being both past experience and lack of experience with different teaching perspectives. Participants considered former high school teachers as prominent in their development, emulating lessons after teachers they liked. Jess added that the inquiry-based focus of the program has had the greatest impact on her.

Summary—Discussions

Collins and Pratt found through a decade of studies using the teaching perspectives inventory that nurturing is the most common dominant teaching perspective and social reform is the most common recessive perspective when considering all instructional levels worldwide [36]. Participants in this study were representative of mathematics and science teachers, in that social reform was overwhelmingly their lowest teaching perspective score, yet many did not have a dominant teaching perspective score [23, 36]. This is similar to a finding of Deggs, Machtmes, and Johnson [37]. According to Pratt, the teacher's views of knowledge, learning, and teaching are what determine each fundamentally different perspective [38]. For this reason, 90% of over two thousand teachers who have to take the TPI report one or two perspectives as their dominant view of teaching. Pratt cautions teachers who suggest using multiple perspectives at different times. He contends that many methods of instruction are common within each perspective and what is important is the intent behind the method.

In this study, we attempted to challenge participants to deliver a 5E, instructional lesson sequence using best practices from a developmental perspective. However, participants mostly taught lessons from a transmission orientation. Participants' schema for the qualities of effective teaching were primarily based on previous experiences as learners, even though they acknowledged being taught alternative ways of presenting curriculum. Fajet, Bello, Leftwich, Mesler, and Shaver found similar results when surveying and interviewing students about the

features of effective and inadequate teachers [6]. Our pre-service mathematics and science teachers struggled with reconciling an inquiry-focused course with their view of teaching perspectives within the discipline. Despite being introduced to a variety of teaching perspectives, overcoming preconceptions of “good teaching” and considering a perspective counter to one’s disciplinary major presents a dilemma.

This study confirms the importance of prior learning experiences in determining views on teaching [6, 8-11]. Providing early field experiences and reflection opportunities with caring elementary teachers may have contributed to nurturing as the most dominant teaching perspective of study participants. However, university field experience supervisors comment on the difficulty in providing cooperating teachers that model inquiry-based practices during the first three field-based courses, which includes the course involving this study. The second 3-credit course in our inquiry-focused program introduces project-based learning (PBL) where participants’ field-based experiences occur in PBL schools with experienced inquiry-based, cooperating teachers. During this course, participants are challenged to prepare and teach a mini-unit that includes best practices from a developmental perspective and are encouraged to incorporate aspects of a social reform perspective. By definition, PBL is an inquiry-based teaching approach to provide questions, problems, or challenges that form a bridge from the learner’s previous way of thinking and reasoning to a new more sophisticated form of reasoning and problem solving; precisely how Pratt defines developmental perspective [30]. Further research is needed to determine if an entire sequence of pedagogical courses can expand perceptions of effective teaching.

Inquiry learning from a developmental perspective has been a consistent emphasis in science education programs. However, transmission teaching continues to be a prevailing viewpoint among mathematics and science teachers, especially in secondary and vocational teaching environments [23, 36]. The time to challenge perspectives on teaching is during pre-service teacher education programs before they continue to use the pedagogy they felt was effective as a student. To best serve potential teachers, teacher educators must be aware that broadening teaching perspectives is a difficult task. While the reflection within our study did make students consider their perspectives on a deeper level, a more intensive reflection process, perhaps on a weekly basis, could better challenge pre-service teachers’ teaching perspectives [39, 40]. Melville, Fazio, Bartley, and Jones provided data to suggest that experience with and reflection of inquiry-based pedagogy help pre-service teachers identify and cope with potential implementation challenges, rather than eliminate inquiry pedagogy due to commonly conceived misconceptions [41]. Further, they posit that without actual experiences with inquiry teaching,

reflection is undermined and without reflection, identifying areas of weakness and solution to problems is difficult, which leads to a much greater challenge with nontraditional teaching perspectives. In helping pre-service and in-service teachers move from traditional pedagogy to an inquiry-based practice, current perspectives, which can be a limiting factor, must be considered. Considering alternative perspectives of teaching can be a difficult shift because reform-based pedagogy can conflict with current perspectives and therefore require rigorous and continuous professional development, or teachers may revert to traditional instructional methods when reform-based methods are difficult to implement [42, 43].

Biographies

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HOW DOES LEADERSHIP MATTER? DEVELOPING AND TEACHING A DEFINITION OF HANDS-ON SCIENCE, A PREREQUISITE FOR EFFECTIVE INQUIRY TEACHING

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Abstract

This descriptive case study describes leadership skills and planning for setting clear directions by program leaders for a statewide professional development initiative to extend improvement in science teaching and learning. For science teachers and leaders in Virginia, a critical part of setting clear goals that everyone can understand is defining key science terms. One of the four key terms, “hands-on science,” is defined here. Materials to develop teachers’ understanding of the term for effective implementation of classroom inquiry activities are shared, along with a rubric for evaluation by and for teachers. Understanding of the term “hands-on science” is necessary before inquiry-based science teaching can be fully implemented. Authentic science materials, when safe, are necessary for doing authentic, inquiry-based science teaching in a way similar to how a scientist investigates science.

Leadership

Science education reform in the United States is dynamic and messy, as educators grapple with emerging challenges and demands. Leadership matters at all levels whether local, state, or national. Leaders in science education reform provide clear directions, are data driven, and influence policy and effective practice in science education. Their contributions are crucial to initiatives aimed at improving student learning and future workforce development [1].

Effective education leadership makes a difference in improving teacher and student learning. What is less clear is how leadership matters, what the essential ingredients of successful leadership are, and how to promote the learning of all students. Greater attention and investment in effective leadership is a pathway sought by many for large-scale education improvement. How do high-quality leaders achieve this impact? According to research, they use the following methods:

- Set directions – chart a clear course that everyone understands;
- Establish high expectations – use data to track progress and performance; and,
- Develop people – provide teachers and others with the necessary support and training to succeed [2].

Leaders are able to influence teaching and learning through the contributions they make to positive feelings of efficacy. According to Bandura, one's belief in one's self and others determines the likelihood of setting a direction and achieving a goal. Self-efficacy is belief in one's own ability, whereas collective efficacy is belief in one's colleagues to perform a task or achieve a goal. Strong efficacy beliefs are key to leaders' ability to get things done [3]. They affect the choices leaders make and they affect coping efforts [4, 5]. The stronger the feeling of collective and self-efficacy is, the greater the persistence for a goal. The sense of collective efficacy for leaders at all levels, whether teachers, principals, science coordinators, or superintendents, is central to undertaking and persisting in school improvement for teaching and learning [6].

The report, *The Three Essentials: Improving Schools Requires District Vision, District and State Support, and Principal Leadership*, identified three critical aspects of leadership for school improvement based on a study by the Southern Regional Education Board of seven very different school districts [7]. They found that states and school districts must develop and communicate a clear coherent vision and a collaborative framework of support in order for school improvement to become a reality. In addition, they found that the most significant change was the mindset of district staff which includes holding themselves responsible for results.

If teachers and leaders are going to hold themselves responsible for results, they need to develop an understanding of what the results will look like, thus the necessity of defining relevant terms. According to the National Assessment for Educational Progress report released in June 2012, students doing hands-on projects in class score higher more frequently on student assessment tests, with students doing hands-on science almost every day scoring the highest [8]. Thus, if we want our students to score well on achievement tests, there is a need to understand the term "hands-on."

Two publications from the National Science Teachers Association (NSTA), *Position Statement: Leadership in Science Education* and *Position Statement: National Science Education Standards*, support the importance of leadership with a clear coherent vision of effective science teaching and learning and a collaborative plan for reform [9, 10]. The *NSTA Position Statements* also focus on the following: the importance of sustained professional development for teachers and leaders; the alignment of curriculum, instruction, and assessment; and, data-driven decision making. Effective professional development expands knowledge of

content and pedagogical content, challenges the beliefs of teachers and leaders, and is transformative over time [11]. For sustained professional development impact, Horizon Research found in their study, *Lessons from a Decade of Mathematics and Science Reform: A Capstone Report for the Local Systemic Change through Teacher Enhancement Initiative*, that long-term sustained effort and support by district and local leaders is essential when implementing new instructional strategies and materials [12].

VISTA Program Description

The Virginia Initiative for Science Teaching and Achievement (VISTA) is a partnership among sixty-five school districts, six universities, and the Virginia Department of Education to build an infrastructure to provide sustained, intensive science teacher professional development to increase student achievement. The goal of VISTA is to improve science teaching and student learning, especially in high-need (high-poverty, high-minority) schools, as well as for limited English proficient students, rural students, and students with disabilities.

Through a validation study of previous targeted efforts, the programs are being extended across multiple school divisions. The initiative is funded by the United States Department of Education through the Investing in Innovation (i3) program, part of the American Recovery and Reinvestment Act. In conjunction with validating prior program research efforts, the grant-funded project has been designed to build leadership and shape policy, and practice through four intensive professional development programs: 1) upper elementary teachers (grades 4-6) receive professional development for one year in problem-based learning (PBL) science instruction, working in teams as they plan and teach PBL lessons; 2) first- or second-year secondary science teachers (grades 6-12) are provided just-in-time coaching and “big picture,” research-based science teaching coursework for two years; 3) school district science coordinators focus on strategic planning for effective science teaching, data-driven decision making, and leadership; and, 4) university science education faculty members investigate new science teaching, and learning research and reform practices.

Research Questions

All four professional development programs require a common vocabulary. This study investigated the following questions: 1) What key words need to be defined? 2) What are the definitions of these words? 3) What learning materials help participants grapple with the meaning of these words? 4) What rubrics are helpful for assessment of implementation? This article focuses on “hands-on science,” the first of the four terms introduced.

Methods

This descriptive case study describes how defining a critical term, “hands-on science,” aided in developing a clear, common understanding by all constituencies across the Commonwealth of Virginia. The overall purpose of defining key science teaching pedagogy is to support the statewide infrastructure necessary to bring improvement to classroom instruction and student achievement.

Methods—Participants

This study chronicles the experiences of multiple participants at three stages of designing and testing definitions. Participants included the principal investigator (Caucasian, female), nine VISTA staff members from three universities (8 Caucasian, 1 African-American; 8 female, 1 male), thirteen school division science coordinators (8 Caucasian, 2 African-American, 1 Asian, 2 unknown; 10 female, 3 male), and eight science education university faculty (6 Caucasian, 2 African-American; 4 female, 4 male) from seven other universities for a total of ten universities. This article is based on the perspectives of the program implementers regarding challenges they encountered for the overall program as it was being created and implemented at the three program delivery sites for validation purposes.

Methods—Research Design

From the pilot studies, the researchers knew that common science pedagogical terms such as “hands-on” were used in different ways. Therefore, they were aware that definitions needed to be established for the program to successfully expand throughout Virginia. The researchers collected qualitative data concurrently from key program implementers throughout the Commonwealth as the program was initially being created and implemented.

Data collection consisted of participants’ responses to surveys, observations, interviews, focus/working groups, and reflections. The surveys contained open-ended items and were administered pre-/post-professional development. The surveys were designed to elicit participants’ perceptions of the effectiveness of the professional development and key objectives of the professional development regarding four pedagogical terms: hands-on science, inquiry, problem-based learning (PBL), and nature of science (NOS) instruction. Validity for the definitions and training materials developed was supported by review by a panel of experts with backgrounds in science education and research evaluation. The panel’s revisions were

incorporated into the final version of the instrument, a process which resulted in consensus on the face and content validity of the instruments.

Methods—Data Analysis

Qualitative data were analyzed using the constant comparative process of grounded theory [13, 14]. Grounded theory drove the determination of themes/categories. A comparison of themes occurred, which allowed preliminary answers to the study questions [15]. Analyses were reviewed by the research team in order to reach consensus.

Results—Four Science Teaching Definitions

An emergent theme was the discovery that teachers had multiple meanings for the same pedagogical phrase. In order to clarify the goals of VISTA and establish a common language and unity across the Commonwealth, four key phrases were identified and defined: hands-on science, inquiry-based teaching, problem-based learning (PBL), and nature of science (NOS). Only “hands-on science” will be defined in this article, including the process used to develop the definitions, the materials used with the teachers to establish common understanding, and the assessment materials to gauge progress.

Results—The Definition and Acceptance

The definition for hands-on science is, “Students purposefully manipulating real science materials when safe and appropriate in a way similar to a scientist.” The definition has the following five parts:

- 1) students
- 2) purposefully manipulating
- 3) real science materials
- 4) when safe and appropriate
- 5) in a way similar to a scientist.

The definition was developed over time in a three-step refinement process:

- 1) The initial definition of hands-on science was developed and refined by the author and used over approximately five years in her science methods courses for pre-service teachers and science leadership courses for in-service teachers.
- 2) Before adopting this and the other definitions, the definitions were reviewed and discussed with nine VISTA leaders at the six universities participating in VISTA. The

hands-on science definition was not changed by the VISTA leadership, whereas the other definitions were expanded.

- 3) Lastly, the definitions were reviewed by eight additional university science education faculty and thirteen school division science coordinators from across Virginia who were participating in the VISTA leadership academies. At this point, the word “purposefully” was added to the definition.

Results—Clarifying Examples and Non-Examples

Before clarifying examples were discussed during professional development, the teachers or leaders were asked: What percentage of time should be spent by students doing hands-on science? After thinking individually, the participants discussed this in small groups of four, and then shared with the whole group. Subsequently, the initial NSTA recommendation that students should be engaged in hands-on learning at least 50% of the time was shared. Now, NSTA is moving toward describing more what the laboratory investigations should look like on a weekly basis than a particular percentage of time. However, NSTA explicitly states that middle school teachers should “engage students in laboratory investigations a minimum of 80% of the science instruction time” [16].

To refine the teachers’ understanding of hands-on science, we found it is necessary for them to classify a series of examples and non-examples of hands-on science. To describe the progression of examples, we use a *PowerPoint* presentation with pictures (see Table 1). For each example, the teachers are asked to evaluate and defend their answer to the question: Is this hands-on science? They do this analysis (see Figures 1 and 2) individually, and then discuss in a small group before sharing with the whole class. Lastly, when teachers have trouble giving up their favorite activities when they don’t meet the definition of hands-on science, we come back to the NSTA recommendation which is that less than 100% needs to be hands-on science. This allows them to do their favorite activity, but not count it as hands-on science.

Table 1
Is This Hands-on Science?

Example	Analysis	Hands-on Science
Using silk flowers to study plants	<u>Not</u> real science materials. <u>Not</u> in a way similar to a scientist.	No
Using paper models to represent the parts of a cell, the layers of the earth, DNA,	<u>Not</u> real science materials. <u>Not</u> in a way similar to a scientist.	No

etc.		
Using a computer simulated pendulum lab	<p><u>Not</u> real science materials. A string and a mass is easy to obtain and use. Students remember what makes a difference with real materials, not on computer. <u>Not</u> in a way similar to a scientist.</p>	No
Using a computer to analyze images of celestial objects	<p><u>Real computer images</u> of planets are real science materials. <u>Scientists</u> study planets using real pictures, since they can't go there.</p>	Yes

Is This Hands-on Science?

- Evaluate and defend
 - Using a computer to analyze images of celestial objects

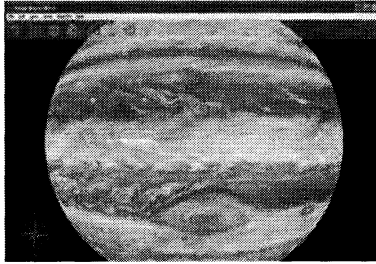


Figure 1. Presentation slide showing an example of hands-on science.

Planets

- **Students purposely manipulating real science materials when safe and appropriate in a way similar to a scientist.**
 - **Real computer images of planets are real science materials.**
 - **Scientists study planets using real pictures, since they cannot go there.**
- **Therefore hands-on science.**




Figure 2. Presentation slide showing explanation for computer planet example.

Hands-on Science Demonstration

The apple lab strongly makes the point that using real science materials when they are available helps the students learn more. In this lab, participants observe three images/models of an apple, and then compare what they can observe from each image. First, the participants are given a picture of a real red apple and asked to write down everything they can observe about it (see Figure 3). Second, the participants are given a realistic model of a red apple and asked to write down everything they can observe about the apple. Third, the participants are given a real red apple and a plastic knife, and asked to write down everything they can observe about the apple. Each time, the list of observations gets longer (see Table 2). The lab is concluded by having a discussion about which form of the apple provided the most information. The participants should easily recognize that their lists were longer as they progressed from the picture, to the model, to the real apple and therefore, their lists were more detailed for the real apple. Thus, the teachers conclude that students should use real science materials as much as possible because the amount of learning is significantly greater.

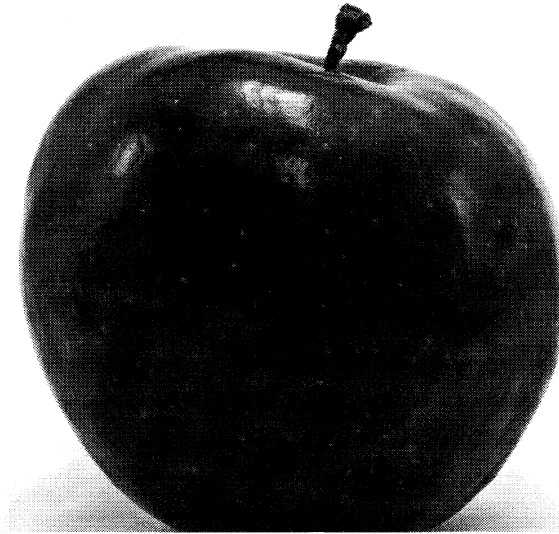


Figure 3. Picture of a real red apple.

Table 2
Observations of Three Different Depictions of an Apple

Apple	Observations
Picture of a real red apple	Red Round One brown long thing sticking out
Model of a real red apple	All above plus: Sphere Red all over One brown toothpick-like long thing sticking out about 2 cm Balances on one side (bottom)
A real red apple	All above plus: Red all over with slight red variations Light colored yellowish dots all over the outside skin Brown stem Smells sweet White inside Tastes sweet Juicy Small dark seeds in the middle Clear hard flexible pieces surrounding seeds

As needed during the apple observation activity, the difference between an observation and an inference is discussed. It is typical for students to make inferences for which they have no direct observations. For example, you can't observe the apple is white inside until you have the real apple and cut into it. In the picture or model, it is an inference that it is white inside, not an observation.

Assessing Instruction

A rubric was developed to assess a teacher's implementation of hands-on science in teaching (see Table 3). The rubric was designed to assess the five parts of the definition. Initially, the rubric was used by a teacher to assess another teacher's lesson for hands-on science teaching. This approach helped the teacher become more familiar and proficient about the nuances of each aspect of the rubric. Then, the rubric was used by other program participants on each other. This way, the teachers each grew in their proficiency of interpreting each aspect of the definition of hands-on science. A unique aspect of using the rubric was for the teacher to use the rubric on others before it was used on them. This enabled them to use their growing understanding of hands-on science before they designed a hands-on lesson that was critiqued by others using the rubric.

Table 3
Hands-on Science Rubric

Hands-on <u>Students purposefully manipulating real science materials when safe and appropriate in a way similar to a scientist.</u>						
Students are...	Not Observed	Rarely Observed	Occasionally Observed	Often Observed	Consistently Observed	Evidence
...conducting the activity.	0	1	2	3	4	
... <u>purposefully manipulating materials.</u>	0	1	2	3	4	
...using <u>real science materials.</u>	0	1	2	3	4	

...using materials in a <u>safe & appropriate</u> manner.	0	1	2	3	4	
...working in a way <u>similar to a scientist</u> .	0	1	2	3	4	

Discussion

Leaders are most effective when working collaboratively toward clear, common goals. It takes leadership skills and planning to build a common language for all participants in a teaching reform program. Identifying and defining key terms is a crucial, but messy process as consensus is built across the developing learning communities and program. This article outlines a key term, “hands-on science,” needed in one statewide program in Virginia for the improvement of science teaching and student learning. This article shares the definition, the definition development process, the teaching materials created to develop understanding, and the assessment of actual classroom practice. Expectations and accountability measures emerged as key leadership foci.

The school division science coordinators and university science education faculty who participated in the above hands-on science activities as learners not only felt that they developed a deeper and consensus understanding of the term themselves, but that they were also able to use the activities with their pre-service or in-service teachers to develop these teachers’ understanding. In addition, the science coordinators and faculty indicated that they had used the definition and activities for creating a new vision of effective science teaching and for strategic planning. Setting clear expectations and common understanding leads to clearly focused goals for the program and appear to be linked to higher student achievement.

Our findings are consistent with the research on the importance of leadership for setting directions and expectations, and developing teachers’ skills as cited earlier [2, 9, 10]. In general, leaders found that instructionally helpful leadership practices: focused on clear school teaching goals; provided professional development for teachers and leaders aimed at understanding the goals; and, created structures and opportunities for teachers and leaders to collaborate to meet the

goals. Clearly defining five parts of the definition for hands-on science clarified important nuances, such as real science materials and using them in a way similar to a scientist. Following this with examples and non-examples focused the teachers and leaders on essential aspects of the definition and provided a platform to discuss and defend explanations, thus building greater understanding. Since implementing effective science teaching in the classroom was a program goal, clearly defining materials to use for learning focused teachers on critical aspects of actually implementing inquiry-based teaching and problem-based learning.

Implications for Policy and Practice

Two implications for policy and practice emerged for leaders from the development of definitions in our study:

- 1) Program and district leaders need to establish clear expectations across multiple dimensions of improvement activities as the bases for increasing coherence, coordination, and synergy in the effectiveness of statewide and district improvement efforts over time; and,
- 2) Program and district leaders should combine a common core of communications and support for efforts to implement district expectations with differentiated support aligned to the needs of individuals and programs.

By developing differentiated support for using an explicit definition for hands-on science, program and district leaders, as well as teachers, established a common language for expressing what hands-on science is and is not across the program which increased program coherence and synergy for students to meaningfully investigate science.

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INFUSING PROBLEM-BASED LEARNING (PBL) INTO SCIENCE METHODS COURSES ACROSS VIRGINIA

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Abstract

This article outlines the results of a collaborative study of the effects of infusing problem-based learning (PBL) into K-12 science methods courses across four universities in Virginia. Changes in pre-service teachers' attitudes surrounding science teaching were measured before and after completing a science methods course in which they experienced PBL first-hand as participants, and then practiced designing their own PBL units for use in their future classrooms. The results indicate that exposure to PBL enhances pre-service teachers' knowledge of inquiry methods and self-efficacy in teaching science.

Introduction: Why Incorporate Problem-Based Learning into Science Methods Courses?

A growing number of students in the United States find it difficult to connect science content and skills to real-world scenarios, indicating a true lack of understanding. The most recent Program for International Student Assessment revealed that fifteen-year-olds in the United States could not apply scientific knowledge and skills to real-world issues as well as their peers in sixteen of twenty-nine countries [1]. Data on science achievement in higher education are similarly concerning. The United States now ranks 27th among industrialized countries for the number of students who receive bachelor's degrees in science or engineering [2].

Regardless of the reasons, it is clear that science is not engaging many students. *Rising Above the Gathering Storm Revisited* focused on mathematics, science, and engineering not only because they are essential to job creation, but also because the committee concluded that "these

are the disciplines in which American education is failing most convincingly” [2]. These data, combined with other performance indicators, led the committee to assert “for the first time in history, America’s younger generation is less well-educated than its parents” [2].

Based on indicators of students’ poor performance in science, it comes as little surprise that research reveals students view school science as neither popular nor pertinent [3]. Science education must do a better job of engaging students. Science is no longer just for “future scientists.” Today, every student needs a strong foundation in scientific content and process skills. While not all students will go into science fields, all are members of a global society. Individuals can no longer be unaware of how their actions or inactions impact others near and far. The goal of science education must be that of producing scientifically literate citizens. Such citizens would be able to actively participate in decisions on issues that impact their lives, such as: waste disposal, experimental medical treatments, water quality, and other issues of personal health and safety (socio-scientific issues). To do this, they need to have the skills to examine problems, ask important questions, develop plans for collecting evidence, analyze data, communicate and work with others as they propose solutions, and think critically to reflect on choices made.

Jobs in Science, Technology, Engineering, and Mathematics (STEM) are projected to be the most abundant careers of the foreseeable future [4]. Science educators in Virginia especially need to focus on equipping students with STEM skills because in 2005, 40% of STEM jobs were located in Virginia and five other states [5]. In addition to anticipated job growth in these fields, workers will also be needed to replace those retiring from STEM careers. These jobs would require workers to apply content and skills to real-world problems, the very knowledge and skills on which U.S. fifteen-year-olds students scored so poorly in 2009.

Scientific process skills, much like the skills of a professional athlete, are acquired through sustained and targeted practice, not by sitting behind a desk. Instead of telling students how they will use the information one day, science educators must provide experiences that allow students to apply it now in a meaningful way. For many, this requires a paradigm shift in the way science is taught. This is why inquiry and problem-based learning (PBL) are essential.

Literature Review—What Is PBL?

Problem-based learning (PBL) can be traced back to Dewey’s emphasis on learning by doing and thinking [6]. He argued that learning “should give students something to do...and the

doing is of such a nature as to demand thinking or intentional connections” [6]. As early as 1965, Gagné noted PBL’s effectiveness in developing science concepts [7]. McMaster University’s medical school implemented PBL because of concern over the limited application skills of many of their recent graduates [8].

Implementation of PBL in the K-12 setting has recently gained international attention as a way to provide creative inquiry that fosters critical thinking and is aligned with students’ interests and abilities [9]. It is a learning approach that allows for individual flexibility in learning and the social construction of knowledge. Aligned with Vygotsky’s theory of constructivism, PBL pushes students to connect prior knowledge with a current problem and solve it in their own way. The American Association for the Advancement of Science (AAAS), the National Research Council (NRC), and the Virginia Mathematics and Science Coalition’s (VMSC) visions of inquiry-based and student-centered science is supported by PBL [10-12].

Virginia Initiative for Science Teaching and Achievement (VISTA) researchers define problem-based learning (PBL) as “students solving a complex problem with multiple solutions over time like a scientist in a real-world-context” [13]. They further state the problem must be meaningful to students and is typically embedded in a course of study from one to five weeks in duration [13]. Through PBL, students ask scientific questions relevant to their lives, collect evidence, and develop explanations based on the evidence obtained. This type of inquiry provides students with the highest level of investigative control, unlike traditional teacher-led explorations [14]. Students use “The Problem-Solving Cycle,” which was created by Sterling in 2005 as a roadmap throughout their PBL investigations [13]. Contrary to the lockstep myth of “The Scientific Method,” The Problem-Solving Cycle allows students the flexibility to move forward or retrace their steps in the investigation as needed. This enables student researchers to backtrack in response to new information gained and better represents the way scientists work to find solutions in their profession.

Literature Review—Research Findings on PBL

Much of the early research on PBL implementation pertains to medical school students. More recent research examines the impact of PBL in the K-12 and post-secondary settings, yet research in this area is still in the early stages [15]. The current study seeks to identify the potential benefits of PBL on pre-service teachers and their future practice so the following literature review focuses on research relevant to this study.

Benefits to Students: Affective — Culturally responsive pedagogy, such as PBL, allows students the flexibility to customize their own learning. Sterling reported students (grades 4-6) involved in a PBL camp showed an increase in positive attitudes toward science on pre- and post-attitudinal surveys [16]. Students indicated that the opportunity to shape the inquiry to meet their abilities and interests made them feel more empowered [16]. Increased confidence may change the way students think of science and a possible career in science as evidenced by findings from Sterling, Matkins, Frazier, and Logerwell who reported greater interest and more positive views of science among PBL participants [17]. Similarly, PBL was found to positively impact post-secondary students' attitudes toward the learning environment relative to peers in a traditional program [18].

Osborne and Collins found that students want more experience in authentic work, longer inquiries, and more time to discuss these experiences, all components of PBL [3]. Their research with nine- to fourteen-year-olds concluded that school science lacks “relevance and greater autonomy” [3]. Relevance and autonomy have been linked to motivation [19]. Research with students of varying ages trained in PBL found that students had increased motivation [16, 20-21].

Benefits to Students: Elementary/Middle Cognitive — More recently, Frazier and Sterling conducted a mixed-methods study on their PBL summer camps for students aged nine to twelve [22]. The camps were offered across a three-year period and included 116 participants designated as at-risk by their schools. The researchers examined student artifacts, teaching curriculum, and students' performance on pre- and post-science content assessments. They found students “experienced significant growth in their science content knowledge and skills” [22]. Further research with elementary students support Frazier and Sterling's findings [15, 23-24]. Drake and Long also determined that PBL students were better able to create problem-solving strategies than students in a comparison group [15].

Benefits to Students: Middle and Secondary Cognitive— Studies provide conflicting reports of the degree of student academic performance related to PBL implementation. Results of PBL implementation in a grade 11 chemistry class revealed PBL positively impacted students' achievement and helped address misconceptions in a significant way [20]. Additionally, PBL was found to promote test success in science among twelve- and thirteen-year-olds according to Wong and Day [21]. Research documents evidence of academic success of students in other content areas taught through PBL [25]. Gallagher and Stepien found students in American studies performed at least as well on multiple choice tests as students taught traditionally [25].

Benefits to Students: Post-Secondary/Professional Cognitive — An analysis of the performance of biochemistry students taught through PBL revealed a greater depth of understanding of the material than those in a traditional program [26]. Pre-service teachers taught in a PBL methods course showed increases in pedagogical content knowledge about modeling activities [27]. Etherington's work with pre-service teachers demonstrated that PBL fosters academic risk taking and resulted in intellectual gains in science [28].

Benefits to Students: Social — Interviews were conducted with chemistry PBL students to determine their beliefs according to PBL activity. The findings, according to the interviews, revealed that students in the PBL class were more motivated, self-confident, willing to problem solve and share knowledge, and were more active in cooperative group activities than students of traditional instruction [20].

Benefits to Teachers: Time on Task — Students in the PBL experimental classroom spent 4.27 more minutes on task of each 45-minute class period relative to the comparison group. The cumulative effect of this daily increase in time on task equates to 21.35 minutes of science engagement per week, and 12.80 hours of science over the course of the school year [15].

Benefits to Teachers: Professional Confidence — Teachers who lack confidence and comfort with a student-centered approach tend to fall back on traditional modes of teaching, leading to marginal learning [29]. Teachers who were trained in PBL and provided with ongoing coaching showed improved confidence in their ability to use problem-based instruction [28].

Benefits to Teachers: Student Behavior — Self-determination theory states that students have three academic needs: competence, relatedness to others, and autonomy. In PBL, teachers serve as facilitators who enhance student autonomy and engagement [30]. Perceived autonomy is a major predictor of engagement in learning and school achievement [31]. Engaged students are intrinsically motivated and less likely to become classroom management problems.

Literature Review—Obstacles to PBL Implementation

Learning and utilizing PBL requires time and commitment from teachers and students. Wong and Day reported expected resistance at the beginning of PBL development in science education and other areas [21]. Changing the pedagogy of science is problematic because many teachers lack the skills and confidence needed to lead discussions and manage student-directed classrooms [28, 32]. Etherington reported some pre-service teachers became antagonistic when

forced to work on critical thinking and open-ended PBL [28]. Goodnough found teachers often needed coaching in PBL problem design [32]. Other obstacles related to the adoption of PBL center around time and standardized testing concerns. Research documenting the academic performance of PBL students has begun to address standardized testing concerns [20-22, 25].

Literature Review—Summary

Problem-based learning offers students the opportunity to take control of their learning. Studies indicate students across grade levels respond favorably to this type of investigative autonomy [3, 16, 21]. Research on academic gains related to PBL report positive findings, but the degree of improvement varies [15, 20-24, 27, 28]. More research is needed on the impact of PBL in varying grade levels and subject content areas.

While questions remain about the degree of the academic impact of PBL, all studies reviewed reported positive impact in the affective domain [16-18, 21]. Students of PBL reported feeling empowered and more interested in the learning environment. Furthermore, social impact was often cited as a positive aspect of PBL implementation. Data revealed students were more willing to share knowledge and participated more actively in cooperative learning than peers in a traditional setting [20].

Institutional and personal impediments to PBL implementation exist. Driven by high-stakes testing, school divisions often lack flexibility in schedules and instructional strategies utilized by teachers. The issue of training and continued professional support adds an additional burden to the already overscheduled school day. On an individual level, resistance to PBL instruction was noted among teachers. Teachers expressed concerns over their ability to manage behavior and lead essential discussions in a student-centered classroom.

Today's students do not see classroom science as popular or related to the real world. Traditional lecture methods have not engaged students in a meaningful way. Problem-based learning shows promise as an instructional method capable of connecting students with science. For teachers to be equipped to teach PBL science, they must be exposed to science methods courses that model this strategy.

Methodology—Introduction

Though the use of PBL has been widely studied through the lens of improving student outcomes and achievement at the K-12 level, little work has been done in studying the use of PBL

as a means of preparing pre-service teachers to teach science in their future classrooms [16, 22, 33]. To address this gap in the literature, four university-based science educators from three institutions of higher education across Virginia engaged in a collaborative study to investigate the value-added effects of infusing PBL methodology into their respective elementary, middle, and secondary science methods courses taken by pre-service teachers as part of professional education preparation programs.

Methodology—Participants

The study was facilitated at all three institutions during the 15-week instructional period of the Fall 2011 semester. During the pre-test, a total of twenty-nine pre-service teachers from across the institutions participated in the study, including twenty-one pre-service elementary school teachers and eight pre-service middle/secondary science teachers. During the post-test, a total of twenty-five pre-service teachers from the pre-test participated in the study, including seventeen pre-service elementary school teachers and eight pre-service middle/secondary science teachers. Table 1 provides a breakdown of demographic data of the participants.

Table 1
Demographic Data for Pre-Test ($N=29$) and Post-Test ($N=25$)

Demographic	Pre-Test <i>N</i>	Post-Test <i>N</i>
Male	1	1
Female	28	24
<i>Total</i>	29	25
African-American	9	5
Caucasian	20	20
<i>Total</i>	29	25
Elementary	21	17
Secondary	8	8
<i>Total</i>	29	25

Methodology—Research Questions

In order to gather the information necessary, the following research questions helped guide the research:

- 1) What are pre-service teachers' perceptions of delivering problem-based learning?
- 2) How do pre-service teachers differ on personal science teaching efficacy beliefs and science teaching expectancy outcomes with respect to elementary and secondary pre-service teaching?

Methodology—Instrumentation

In all methods courses, study participants completed a survey developed by Enochs and Riggs (1990) known as the Science Teaching Efficacy Belief Instrument (STEBI-B) [34]. The STEBI-B was developed as a survey to evaluate pre-service teachers' self-efficacy toward teaching science. The instrument was based around Bandura's social learning theory, and consists of two constructs: Personal Science Teaching Efficacy (PSTE), and Science Teaching Outcome Expectancy (STOE) [35]. The STEBI-B has a reliability rating of .90 (PSTE) and .76 (STOE), making it a reliable instrument. The instrument utilizes a 5-point Likert scale ("Strongly Agree" – "Strongly Disagree"). Enochs and Riggs suggest that the following numbers, 5 = Strongly Agree, 4 = Agree, 3 = Undecided, 2 = Disagree, and 1 = Strongly Disagree, correspond with responses [34].

Methodology—Procedure

During the first week of the courses, pre-service teachers were given the STEBI-B as a benchmark indicating their self-efficacy with respect to their ability to teach science. During the course of the semester, the pre-service teachers participated in PBL activities facilitated by their course instructors, and then were tasked with developing their own PBL units for use in their future science classrooms. The STEBI-B survey was administered again during the final week of the course to detect any changes in the pre-service teachers' self-efficacy which could potentially occur as a result of their exposure to PBL methodologies infused into the methods courses.

Methodology—Analysis of Results

This study was completed during the Fall 2011 semester at three institutions. In the study, descriptive statistics and an analysis of variance (ANOVA) were conducted to address the research questions.

Research Question 1: What are pre-service teachers’ perceptions of delivering problem-based learning? To address this question, the researchers conducted descriptive statistics to display pre-service teachers’ perceptions prior to the delivery of coursework toward teaching problem-based learning and after the coursework was completed. Prior to coursework, pre-service teachers scored toward undecided ($M = 3.53, SD = .539$) on personal science teaching efficacy (PSTE) and moderately low as well on science teaching outcome expectancy (STOE) ($M = 3.50, SD = .437$). For pre-service teachers, results from the post-tests suggest that pre-service students perceived themselves to be moderately high in personal science teaching efficacy (PSTE) ($M = 4.13, SD = .413$) as a result of the coursework. Furthermore, while their science teaching outcome expectancy (STOE) was not as high ($M = 3.87, SD = .564$), there was a small gain from the pre-tests. Moreover, the effect size, using Cohen’s d , were computed to identify practical significance of the differences between the pre-tests and post-tests [36]. The pre-tests and post-tests revealed strong effects on PSTE ($d = 1.019$) and STOE ($d = 1.109$). Means, standard deviations, and effect size are displayed in Table 2.

Table 2
Descriptive Statistics on Pre-Test ($N = 29$) and Post-Test ($N = 25$)

Subscale	Pre-Test		Post-Test		Effect Size
	M	SD	M	SD	d
PSTE	3.53	.539	4.13	.413	1.019*
STOE	3.50	.437	3.87	.564	1.109*

Note: Effect size strength was determined using Cohen’s breakdown for small ($d = .20-.49$), moderate ($d = .50-.79$), or strong ($d = .80$ or higher) [36].

*Strong effect.

Research Question 2: How do pre-service teachers differ on personal science teaching efficacy beliefs and science teaching expectancy outcomes with respect to elementary and secondary

pre-service teaching during the post-test? A one-way analysis of variance (ANOVA) was run, in which elementary pre-service teachers and secondary pre-service teachers did not differ significantly on PSTE because the p value was greater than .05 and .001 levels at $F(1,24) = 3.137$, $p < \text{no significance}$. Post-test results revealed significance on the subscale STOE between elementary pre-service teachers and secondary pre-service teachers at $F(1, 24) = 4.655$, $p < .05$ level, with a higher mean for elementary pre-service teachers. Table 3 summarizes the results of the analysis of variance on PSTE and STOE of the STEBI-B post-test.

Table 3
Analysis of Variance on Elementary Pre-Service and Secondary Teachers

Source	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>p</i>
<u>Between Groups</u>					
PSTE	.491	1	.491	3.137	.090
STOE	1.285	1	1.285	4.655	.042*
<u>Within Groups</u>					
PSTE	3.598	23	.156	3.137	.090
STOE	6.349	23	.276	4.655	.042*

Note: * $p < .05$

Methodology—Summary

Data revealed that students initially did not perceive themselves as capable of delivering problem-based learning prior to their training. The participants were undecided in whether they could perform problem-based learning at an acceptable level. However, the data did reveal that the coursework improved their understanding of PBL and enhanced their self-efficacy toward delivering this method of instruction in a science class. Furthermore, pre-service teachers felt they were capable of getting their future students to obtain student outcomes toward problem-based learning.

Discussion

Perceived Science Teaching Efficacy — Pre-data revealed participants were undecided about their abilities to effectively teach and engage students in science. Post-data showed that pre-service teachers gained confidence in their science teaching abilities throughout their experience with PBL. This finding is significant because teacher confidence is directly related to the type of instruction found in the classroom. Teachers who lack confidence are more likely to focus on teacher-directed instruction that can marginalize students and minimize learning [29]. With the current emphasis on student-led inquiry, science teachers must be confident enough to relinquish some of the decision-making duties and provide students with a more active role in their science education [10-12]. Data from this study indicate PBL training was effective in strengthening participants' confidence in teaching science. This finding suggests PBL-infused science methods courses are of value in informing pre-service teachers' PSTE and potentially impacting how science will be taught in their future classrooms.

Effectively implementing a particular instructional model takes time and practice. It is essential for pre-service teachers to observe a master teacher modeling PBL so they know what true PBL looks like. Additionally, pre-service teachers must be provided the opportunity to be students of PBL in order to judge first-hand the impact of learning science in that manner. With the awareness that PBL implementation presents challenges for many beginning and experienced teachers, science methods educators should model the role of facilitator by asking probing and guiding questions and fostering student-led inquiries. This type of science methods instruction will help students learn content and learn how to learn. Teachers must have a strong Pedagogical Content Knowledge (PCK) to model for students. Similarly, teachers in training need science education professors to model a strong PCK for them. Findings from this study align with work by Van Driel and DeJong who determined pre-service teachers' PCK improved when taught in a PBL format [27]. Etherington reported intellectual gains for pre-service teachers who engaged in PBL learning [28]. This supports findings for the current study because students who gain intellectual understanding of content would be expected to show improvements in beliefs about their abilities. While the initial improved confidence found in the current study is of interest, it is important to remember the importance of ongoing professional coaching to maintain confidence and effective implementation of PBL.

Science Teaching Outcome Expectancy — Prior to PBL methods courses, participants reported they were somewhat undecided about how their teaching might impact student learning. Post-data indicated improvement in participants' STOE values that is of practical significance. These

findings add additional strength to the call for PBL-infused science methods courses. Pre-service teachers' views of their abilities to impact student learning grew after PBL coursework. For these reasons, science education faculty should incorporate PBL into their courses in order to help future teachers develop skills and confidence in PBL implementation.

Furthermore, data from this study found pre-service elementary and secondary teachers did not differ significantly in their PSTE post-test scores. The fact that pre-service elementary teachers felt as confident as pre-service secondary teachers in science instruction is important because most elementary science teachers are not science majors. It stands to reason that teachers with a science background will feel more confident teaching science than teachers without a science background. The fact that PBL played a part in pre-service elementary majors becoming more confident in their ability to teach science is an interesting finding that warrants further investigation.

Pre-service elementary and secondary teachers were found to have significant post-study differences on the STOE, with elementary pre-service teachers yielding a higher mean. This finding is important because elementary teachers as a whole tend to report a lack of confidence and/or interest in science instruction. If pre-service teachers taught via PBL grow in the belief that they can positively impact student learning, they are more likely to show an interest and enthusiasm for science that will come across to their students. Teachers who feel capable and empowered are more likely to produce capable and empowered students.

Diversity continues to increase among today's students. The diversity of the classroom teacher is not keeping up with that of the larger population. The majority of educators continue to be white females. Diverse instructional strategies present a method of addressing the social and cultural differences that exist between teachers and students. When students are able to lead their own science inquiries, the experiences will be much more relevant, meaningful, and motivating. Problem-based learning offers a means for highly effective science instruction that is culturally responsive.

Implications for Education

This initial study provided a foundation for infusing PBL strategies into pre-service science methods courses spanning the K-12 level offered by multiple institutions of higher education across Virginia. Though the study was relatively small in terms of the number of participants, the impact of the findings can be extended to a wider educational context.

Preliminary results indicate that the benefits of employing problem-based learning strategies at all levels of science education are numerous for all parties involved, and the science education community as a whole should continue to embrace and support this emerging methodology of science instruction.

Suggestions for Best Practices in Pre-Service Learning

Based on the preliminary results of this study, the following suggestions for best practices in pre-service science learning have been identified:

- **Pre-service science teachers should be given the opportunity to participate in authentic problem-based learning scenarios as part of their own science education—**Since PBL methods likely differ from the traditional methods many pre-service teachers experienced during their own K-12 science education, it is crucial to allow prospective teachers to experience PBL in order to convince them of its added benefit of exploring the world in a scientific way. In addition, first-hand experience will increase their comfort level with PBL methods.
- **In introducing PBL strategies into science methods courses, instructors should make thoughtful linkages between PBL methodology and other successful constructivist methodologies in science education—**For example, the four phases of developing effective PBL scenarios are very compatible with the stages of the learning cycle, which may be more familiar to pre-service teachers [37]. Though the benefits of employing PBL methods within science classrooms across Virginia are becoming apparent, it is important to keep in mind that PBL did not emerge without a solid grounding in constructivist learning theory [38].
- **Pre-service science teachers should be given the opportunity to practice designing PBL units for use in the classroom, ideally with the opportunity to implement their units in the classroom in cooperation with veteran K-12 teachers—**Pairing pre-service and in-service teachers to implement PBL units in science classrooms benefits both the pre-service teachers and in-service teachers in multiple ways. In working with veteran teachers, pre-service teachers are afforded the intuition and guidance of experienced teachers as they design their units. Even if a veteran teacher has not used PBL strategies in the past, s/he possesses the pedagogical content knowledge to discern whether an activity is appropriate for the students, as well as whether it will be an

effective way for them to learn the content at hand. In working with pre-service teachers who have received instruction in PBL methods, veteran teachers gain exposure to new pedagogy that may be unfamiliar or seem chaotic at first glance. Having experienced PBL methods as a way of approaching an authentic problem first-hand, the pre-service teachers can offer support to veteran teachers in implementing PBL instruction, and offer suggestions for providing support to students throughout the course of the unit without resorting to direct instruction.

Promoting Awareness of PBL: Removing Obstacles

One of the primary challenges to the widespread use of PBL methodology in K-12 schools is the prevalent perception that there is not enough time to do so. If we solidly believe in the value-added benefits of PBL as a means for empowering science students to establish cross-thematic connections between science concepts, then we must work together as a science education community to convince educators, administrators, colleagues, and parents that the additional time, if any, required to implement PBL units in science classes is more educationally valuable to students than methods of direct instruction. It is also important to wholly support K-12 educators in doing so. There are several initial ways to approach this formidable task:

- **We must link PBL units to the Virginia *Standards of Learning (SOL)* explicitly**—In designing PBL units for use in K-12 science classrooms, we must be sensitive to the time constraints experienced by classroom teachers at all levels, and duly acknowledge these concerns by making sure that PBL scenarios embody a multitude of science *SOL* that would otherwise need to be covered as a means of justifying the use of class time to complete the PBL unit.
- **Design cross-disciplinary PBL units which encourage cooperation between teachers of different disciplines**—Sharing the development and implementation of PBL units across multiple classrooms at all levels can ease the burden of class time required to complete the unit. Additionally, having students approach the same problem from different disciplinary lenses encourages the type of global thinking which PBL aims to engender.
- **Make PBL a focal point of pre-service science teacher education**—By providing support in learning how to effectively implement PBL to the next generation of science teachers, the science education community can help make pre-service teachers become

more comfortable in employing a methodology which they did not experience as students themselves. Thus, the science education community is making strides in combatting the old adage that “we teach the way that we were taught,” and promoting real reform in science education. These pre-service teachers will be equipped to become the PBL experts in their future schools, providing a support network to veteran teachers in implementing PBL strategies in their classrooms.

Future Directions of PBL

Though preliminary results of this study and others are favorable in terms of the widespread use of PBL in science education, continued study of PBL is needed, particularly in the area of the effects of the infusion of PBL methodology in pre-service science teacher education. Future directions include further study of PBL in pre-service, K-12 science teachers across Virginia via a lesson study model in order to investigate how pre-service science teachers implement PBL units in their first classrooms, and how their use of PBL evolves over time.

One of the limitations of the current study was the use of the STEBI-B as the primary tool for identifying changes in teacher self-efficacy as a result of instruction in PBL methodology. Though this instrument is known to be flawed, locating and designing more accurate instruments to capture such subtle and personal teacher characteristics is difficult. In future studies, a more qualitative model could provide a more detailed description of the impact of PBL on pre-service teachers’ transitions to the science classroom.

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INQUIRY TEACHING: IT IS EASIER THAN YOU THINK!

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Abstract

This article is a survey of the literature on inquiry teaching. Many teachers do not participate in inquiry teaching for various reasons. The following are the main reasons: it takes too much time; students do not learn what they need for the state test; and, the teachers do not know how to grade projects and presentations. These reasons sound like rhetoric from long ago, but it is very current. In this article, research is used to show that students who participate in inquiry learning or any type of problem-based education do much better than students who do not have that opportunity. The student participants not only have better grades, but they think on a higher level, become more civic minded, and are better problem solvers.

Included in the article are four models which can be used to teach inquiry science, and two lesson plans with rubrics to help grade the inquiry STS lesson. The major point being made throughout is that there is an advantage to teaching students using inquiry. The only disadvantage is not giving the students the opportunity to use inquiry and to grow.

Introduction

What is inquiry? When one is asked this question, it can be properly explained that, “It is the process of questioning, asking, and interrogating.” Thus, inquiry in science thus would be the process of asking a question or seeking the solutions to science questions. Some teachers will say it is that method which takes too much time. However, there are more definitive and descriptive definitions of inquiry: “Inquiry is the process by which scientists pose questions about the natural world and seek answers and deeper understanding, rather than knowing by authority or other processes” [1]. This should encourage teachers to “yearn” for inquiry and not fear it.

Inquiry is found as a major component of scientific literacy. As a means of the methods of science, it focuses on the basic skills of observing, inferring, predicting, measuring, and experimenting [2]. To many teachers, it is the act of asking students questions, and then directing them on how to answer the questions. There are others who will let students suggest their own questions and design experiments to answer them. In short, there are many interpretations of the

meaning of inquiry, but there really is a definition with special characteristics that make an activity or practice an inquiry one.

Definitions of Inquiry

Science as inquiry is one of the *content standards* of the National Science Education Standards [3]. It is a basic in curriculum organization and in students' science education experience. This standard highlights the ability to do inquiry and the fundamental concepts about scientific inquiry that should develop. The emphasis on inquiry moves, "beyond the processes of science and emphasizes the students' cognitive development based on critical thinking and scientific reasoning required in the use of evidence and information to construct scientific explanations [4].

As one of the science *teaching standards*, it is recommended that effective science teachers plan an inquiry-based science program for their students. This means that the teachers would develop a framework of yearlong short-term goals for students, select science content, and adapt and design curricula to meet the interests and experiences of students. They would also select teaching and assessment strategies that support the development of students' understanding and would nurture a community of science learners. Inquiry-supporting teachers work together as colleagues within and across disciplines and grade levels for the benefit of the students [4].

The National Science Education Standards (NSES) also have *professional development standards* concerning inquiry. It calls for teachers to learn the essential science content through the perspectives and methods of inquiry. It emphasizes that teachers are taught as they will teach their students by stating that science teaching experiences or professional development for teachers must include being a participant in inquiry. This means taking the following actions: actively investigating phenomena that can be studied scientifically, interpreting results, and making sense of findings consistent with currently accepted scientific understanding; addressing issues, events, problems, or topics significant in science and of interest to participants; and, incorporating ongoing reflection on the process and outcomes of understanding science through inquiry [4].

Inquiry teaching goes back to Dewey when he noted that developing thinking and reasoning, formulating habits of mind, learning science subjects, and understanding the process of science were the objectives of teaching science through inquiry [5]. Through the idea of hands-

on science, inquiry was promoted in the 1960s with the goal of engaging students in the kind of science practiced by scientists using hands-on activities, ultimately helping students develop scientific concepts and process skills [6-8].

Inquiry has its beginning in constructivism which included hands-on activities as a way to motivate and engage students while trying to solidify science concepts. Constructivist approaches emphasize that knowledge is constructed by an individual through active thinking, defined as selective attention, and organization of information and integration with or replacement of existing knowledge. In addition, social interaction is necessary to create shared meaning; therefore, an individual needs to be actively engaged both behaviorally and mentally in the learning process for learning to take place. As constructivist approaches permeated much of the educational practices in the 1970s, it became particularly prominent in science education through the focus on inquiry [9].

The NSES extends the definition and differentiates the terms “scientific inquiry,” “inquiry learning,” and “inquiry teaching.” DeBoer stressed that science was both process and product whether it is practiced by scientists or studied in classrooms [10]. Trowbridge, et al. state, “It is important to note, however, inquiry teaching does not require students to behave exactly as scientists do. Science inquiry is simply a metaphor for what goes on in an inquiry-based classroom” [4]. Inquiry can be demonstrated on a continuum. The National Research Council (NRC) defined it as full, partial, open, and guided: full inquiry is when students engage in all features of inquiry; partial is when students engage in fewer essential features of inquiry; open is when fully directed by the students; and, guided is when the teacher directs the activities [6].

Some educators equate inquiry with discovery learning. Discovery learning only involves students using their minds to gain insight into a concept or principle. While in inquiry, an individual may use all of the discovery mental processes in addition to formulating problems, hypothesizing, designing experiments, synthesizing knowledge, and demonstrating such attitudes as objectivity, curiosity, open-mindedness, and respect for theoretical models, values, and attitudes. Inquiry methods seem to engender the following: increase higher level thinking; cause a shift from extrinsic to intrinsic rewards; help students learn how to investigate; increase knowledge retention; make instruction student-centered, thereby contributing to a person’s self-

concept; increase expectancy level; develop multiple, not just academic, talents; and, allow more time for students to assimilate and accommodate information [4].

Many researchers, scientists, and educators have studied classrooms and evaluated investigations, experiments, and practices to see the commonalities of those labeled as “inquiry practices.” All hands-on activities are not inquiry activities. If students are solving a problem using data analysis which began with a research question, then it is most likely an inquiry-based practice or activity. Another criteria for labeling a science practice or activity as inquiry is if the students use the collected data to answer the research question [2].

Research on Inquiry Practices

Dalton, et al. directly compared two hands-on curricula that made a difference in students learning some physics concepts [11]. It was found that the hands-on activities alone were not sufficient for conceptual change. Students also needed an opportunity to process the activities and concepts. Discussing meaning and interactions through class discussions of the reasons behind the observations in their independent design activity were needed for conceptual change.

Crawford found that mentor teachers’ beliefs and preferred instructional approaches influence pre-service teachers’ willingness to take risks in creating inquiry-based lessons [6, 12]. Demer and Abell found that teachers not only had a wide variety of conceptions of inquiry, but also considered inquiry as any student-driven activities, student generated questions, and student independent research with either little or no teacher intervention [6]. To promote inquiry in all levels of education, practitioners need to recognize broader views of inquiry that include the essential features of inquiry as supported by the NRC.

It was found in a study by Minner, Levy, and Century that the majority (51%) of their fifty-eight studies showed positive impacts of some level of inquiry on science instruction on student content learning and retention [9]. Forty-five (33%) showed mixed impact of inquiry instruction, nineteen (14%) showed no impact, and three (2%) showed negative impact. There were nine studies that looked at some contrasting aspects of student responsibility for learning. Six of those studies found a statistically significant increase in student conceptual learning when there was more student responsibility in the instruction with higher inquiry saturation. In studies where there were more teacher-directed learning goals and activities or lower inquiry saturation, the student conceptual learning was very low. Five of the six studies also showed a statistically

significant improvement in student conceptual learning from instruction that had hands-on activities with more inquiry saturation when compared with treatment with less emphasis on inquiry-based practices.

The Education Development Center, Inc. (EDC) did a four-year study to address the research question, “What is the impact of inquiry science instruction on K-12 student outcomes?” [13] One hundred thirty-eight studies were analyzed; they indicated a clear positive trend favoring inquiry-based instructional practices, particularly instruction that emphasized student active thinking and drawing conclusions from data. Teaching strategies that actively engaged the students in the learning process through scientific investigations were more likely to increase conceptual understanding than the strategies that used more passive techniques [9].

The value of the inquiry approach has yielded positive evidence as related to students’ attitudes and self-concept, and involving critical thinking rather than traditional instruction. Carnegie-Mellon University found that an inquiry-oriented social studies curriculum significantly increased students’ abilities to inquire about human affairs, compared to those who were studying non-inquiry materials [14].

The term “inquiry” has invaded science education with three distinct categories of activities: 1) what scientists do; 2) how students learn; and, 3) a pedagogical approach that teachers use [3, 15]. Whether it is the students, the scientists or the teachers, there are six essential features or components from the learners’ perspectives as essential features of classroom inquiry:

- 1) Learners are engaged by scientifically oriented questions.
- 2) Learners give priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions.
- 3) Learners formulate explanations from evidence to address scientifically oriented questions.
- 4) Learners evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding.
- 5) Learners communicate and justify their proposed explanations [6, 9, 16].

- 6) The amount of direction and decision making done by the teacher versus the student has produced distinctions, such as open and guided inquiry [16].

Additional Benefits of Inquiry

Project 2061 defined the goal of inquiry as helping people in every walk of life deal knowledgeable with problems that often involve evidence, quantitative considerations, logical arguments, and uncertainty. Much of the research explained how engaging students in scientific inquiry can serve many purposes, including student motivation, the preparation of future scientists, and the development of citizens who will be autonomous, independent thinkers [6]. Inquiry methods seem to give rise to the following: increase intellectual potency; cause a shift from extrinsic to intrinsic rewards; help students learn how to investigate; increase memory retention; make instruction student-centered, thereby contributing to a person's self-concept; increase expectancy level; develop multiple, not just academic talents; avoid learning only on the verbal level; and, allow more time for students to assimilate and accommodate information [17]. There are many benefits for students using the inquiry method when it is taught correctly.

Inquiry Teaching

There are definitely two aspects of inquiry: one is the students' learning, their attitudes, and their abilities; the other is teaching approaches and learning strategies. Therefore, inquiry instruction can be defined as an active process in which students answer a research question through data analysis. Teachers should be able to scaffold inquiry instruction for the students to help them develop inquiry abilities. By varying the amount of information given to students, teachers can scaffold inquiry activities and model the process of scientific inquiry [2, 18].

An old adage states, "Tell me and I forget; show me and I remember; involve me and I understand." One dictionary defines "inquiry" as "a close examination of a matter in search for information or truth" [19]. That same dictionary defines "involvement" as the process of occupying or engaging the interest of someone. The learning process embraced by inquiry-based learners allows them to utilize what they already know about a topic as the basis for continued learning. The inquiry-based learning approach encourages students to investigate and discover more knowledge about a topic or natural phenomenon as they attempt to determine and understand why something is the way it is or how it works. So, how does this apply to the classroom?

Inquiry-based teaching is a teaching method which combines the curiosity of the students and the scientific method, while developing critical thinking skills of science. Students usually engage in five activities when participating in inquiry practices. The students usually question, investigate, connect evidence to knowledge, share findings, and use evidence to describe, explain, and predict [20].

Inquiry-based lessons encourage students to formulate explanations that address scientific questions. This approach to learning guides students into developing the skills needed to convert information and data into useful knowledge that they can convey to others successfully. According to Chiappetta and Koballa, “Scientific inquiry centers on natural phenomena and is an attempt to understand nature, to explain that understanding, to make accurate predictions from knowledge, and to apply the knowledge to societal needs” [21].

Successful implementation of inquiry-based learning requires that lessons, when developed, encourage students to collaborate with one another, gain a new or deeper understanding of why something is the way it is, and to use this understanding effectively to communicate with others about their findings [3]. This approach differs from the traditional classroom where individual learning is prized, even demanded and tested. Although both classrooms would embrace the scientific method during the learning process, the traditional approach differs in that it offers students a lab with sequenced steps, basic questions, and pre-determined conclusions. The traditional approach makes no allowances for student prior learning or for the individual thought process encouraged by the opportunity to inquire freely. In contrast, students are encouraged to protect their findings from their peers, to share ideas of ways to improve the investigation only if asked, and to communicate with other students during the learning experience only when allowed by the teacher—if they are allowed to talk at all. To be successful with inquiry-based learning, teachers must have an in-depth knowledge and understanding of the topic being presented. They should have the pedagogical tools to support the students in their thought processes while stimulating their interests in learning more than they already do [21]. Just as scientists do, students should have the opportunity to share as they learn, and the teachers should be able to facilitate a forum that encourages discussions and arguments among the students. Having a strong background in the topic is essential. Without in-depth, critical knowledge about a topic, teachers are not going to be effective in leading collaborative discussions which encourages students to evaluate or synthesize what is being presented by classmates. For example, students may need to clarify what they have stated or incorporate visual

models for a better understanding of their position. Teachers should be able to identify that need and facilitate these interactions.

During lesson planning, teachers should anticipate opportunities that may arise where they will need to encourage students to dig deeper into the topic content. Teachers need to consider students' thought processes in their lesson [21]. As teachers compose their lesson plans, the focus should be on ensuring that students will gain the conceptual understanding for the skill or concept. The lesson objectives and assessment measures must reflect this focus. As an example, goals in an introductory, inquiry-based learning lesson would be for students to understand what inquiry is, conduct an investigation utilizing inquiry-based learning, conceptually understand the topic, and demonstrate growth in knowledge by how they develop their conclusions about their investigation.

Because the inquiry-based approach to learning deviates from the traditional classroom approach, teachers must motivate students to learn by inquiry, rather than directing them. In order to motivate students in this learning approach, teachers need to create a rapport with the students. Teachers need to reassure students that there is a support system behind the approach that will not leave them fumbling around, but will offer guidance and structure when required. It is the responsibility of the teachers to ensure that students have a warm, welcoming learning environment that encourages student learning instead of "student floundering." This is a critical factor to ensure individual success in learning.

The demonstration that learning has taken place results when students finish their investigation and are able to apply it to real life, explaining how their findings contribute to society. Full lesson effectiveness is demonstrated when students are able to apply the outcomes of their investigation—their artifacts—across the curricula. This means that students are able to show correlations or applications within subject areas, such as mathematics and language arts. This would be demonstrated by improved expression when writing, and improved analysis when working with mathematics problems.

For students that need enrichment or remediation, inquiry-based learning supports all of the multiple intelligences. Inquiry-based learning encourages students to use their preferred learning style, allowing them to learn in ways that are comfortable for them. This increases successful learning by these students because it reduces stress during the learning process. The

sky is the limit! Using inquiry-based learning allows students who think outside of the box to do so, as well as stay outside the box as long as they wish. It also allows those students that like the “middle of the road” to be in their comfort zone. For remedial students, this approach encourages them to collaborate with others, to develop their own ideas, and to capture explorations on paper in a way that is less threatening, because help from mentoring students or even from the teacher is part of the course of learning rather than the exception. It allows these students to explore and learn by doing, thus giving them control over how they learn. It is the role of the teacher to facilitate the learning process, keep students on task, and ensure a learning environment that encourages each student to strive for their full potential.

Inquiry-based learning is supported by both long-term and short-term goals, just as any learning should be. The experiences of inquiry-based learning support all learners regardless of their educational background or capabilities. Teachers are challenged by inquiry-based learning to create environments and experiences that ensure all students will gain additional knowledge, apply that knowledge, and evaluate that knowledge culminating in the ability of the students to apply their new knowledge to real-life experiences. Inquiry-based learning is a proven approach that teachers can use successfully to develop students interested in answering their own questions and owning their own knowledge.

Teaching Models

To ensure that students have successful experiences using inquiry, teachers must feel secure that they can teach and coach the students in the inquiry process. The authors introduce the teachers to four inquiry teaching models: 1) the traditional Suchman model, 2) the 5-E model, 3) the Science Technology Society (STS) model, and 4) the Problem-Based model. Each teaching model relinquishes more responsibility to the students to the extent that the STS and Problem-Based Learning models can be full inquiry.

Traditional Suchman Inquiry Model — The traditional Suchman inquiry model consists of five steps: 1) posing a question; 2) constructing a hypothesis; 3) designing a plan to answer or research the hypothesis; 4) reevaluate the hypothesis after the collection of data; 5) forming a general statement about the results from the data collection process, and then sharing and teaching it to the class [3, 22-25]. In pre-service classes and professional development sessions, I use the Traditional Inquiry Model organizer with the teachers. Phase I of this process introduces the teachers to the variability of inquiry (see Appendix A) and shows how to focus on the student

and not just the task. The phases or steps in this model are defined and explained in Appendix B. Teachers are then asked to complete the organizer (see Appendix C), anticipating what the students will do when answering research questions. It is visible and written for the teacher to see that the student is to do these activities and practices without the intervention of the teacher. It takes some time, but after several practices, written and orally, the teachers begin to understand that inquiry is about the students' learning, hypothesizing, examining, and forming conclusions.

5-E Inquiry Model — The five steps learning cycle, or the 5-E model, includes five phases: 1) engagement, 2) exploration, 3) explanation, 4) elaboration, and 5) evaluation. The engagement phase is used to pique the students' interest and provide focus for the activities. The exploration phase proceeds like guided discovery where the teacher serves as a facilitator. The explanation phase includes more involvement of the teacher with the introduction of new concepts while answering questions and guiding students to connect the new knowledge with their prior knowledge. The elaboration phase follows the explanation phase and includes students or students' groups applying newly learned concepts to new situations. Students show the ability to transfer their learning in this phase. The final phase is the evaluation phase where the learning and understanding are assessed. This assessment can be formal, informal, or even a self-assessment, but students are given feedback at this time [26]. The stages are dominated by the students' actions, except the explanation phase (see Appendix D) where the teacher can lead discussions and help students make connections with the new knowledge.

Science Technology Society (STS) Inquiry Model — The third model, Science Technology Society (STS), is similar to the traditional Suchman inquiry model except students study an issue and then exhibit or propose a behavior change. They (students in pairs or groups) proceed through the five steps; in addition, they propose a solution to the issue, and design and execute a plan to address or solve the issue. The STS movement/curricula intent was to integrate technological and societal issues into the science classroom. It put the motivation for science instruction in the natural curiosity to understand the world. Once the understanding is obtained, the knowledge is then applied [27].

The STS lesson is an integrated science lesson which shows the impact of science on technology and the impact of technology on society. It demonstrates the following: how progress affects people; how people interact with progress or new technology; and, the impact of new technology on the world. The STS lesson not only teaches content and technology, but it

requires some actions from the students. The students must perform some task, such as make a presentation to a governing body, construct posters to inform the community, or survey the community to see if they are aware of a specific issue. It can be used with either the Traditional Inquiry Method (see Appendix B) or the 5-E Model (see Appendix D).

Problem-Based Learning (PBL) — Another approach to science education and the teaching of science is the design-based or project based immersion units referred to as full inquiry units or Project-Based Science (PBS). Those units usually last for some weeks and provide students with one overarching problem. Most of the projects have learning goals in areas that include communication about scientific explanations or arguments, and students developing scientific reasoning. Design-based curriculum like PBS evolved out of an engineering model of teaching and learning, and has a strong focus on applying science concepts to solve real-world problems [28]. This epistemological view, like the integrative view, is nonlinear. Knowledge taught to students in an integrative curriculum is taught around broad themes and issues that are important to students and part of their lives: “Curriculum is integrative when it helps make sense of their life experiences” [29, 30]. It helps students find answers to their questions and solve problems in the learning process. Many studies which have used this method have had successful and promising results [31].

The distinction between problem-based learning and other forms of active learning often are confusing because they share certain common features and approaches. However, an essential component of problem-based learning is that content is introduced in the context of complex, real-world problems. In other words, *the problem comes first* [32, 33]. This contrasts with prevalent teaching strategies where the concepts, presented in a lecture format, precede “end-of-the-chapter” problems. In problem-based learning, students working in small groups must identify what they know and, more importantly, what they don't know and must learn (learning issues) in order to solve a problem. These are prerequisites for understanding the problem and making decisions required by it. The nature of the problem precludes simple answers. Students must go beyond their textbooks to pursue knowledge in other resources in between their group meetings. The primary role of the instructor is to facilitate group process and learning, not to provide easy answers. Different forms of assessment come with the change in format, such as group examinations and application of the new knowledge.

The model for problem-based learning comes from a few medical schools, notably McMaster, where more than twenty-five years ago, they questioned how well traditional, pre-clinical science courses trained physicians to be problem solvers and lifelong learners [34]. Information-dense lectures presented by a series of content experts to large student audiences seemed disconnected from the practice of medicine that required integration of knowledge, decision making, working with others, and communicating with patients. The curricula of several medical schools now include problem-based, pre-clinical science courses. The effectiveness of the problem-based learning approach in the medical school environment has been debated, evaluated, and given qualified endorsement based on a number of studies [35-37].

In problem-based learning (PBL), students use “triggers” from the problem case or scenario to define their own learning objectives. Subsequently, they do independent, self-directed study before returning to the group to discuss and refine their acquired knowledge. Thus, PBL is not about problem solving per se, but rather it uses appropriate problems to increase knowledge and understanding. The process is clearly defined, and the several variations that exist all follow a similar series of steps (see Appendix E).

There have been significant scholarly achievements seen with PBL. With the successful achievement results, it is believed that PBL should be promoted in middle school classrooms [31, 38]. Traditionally underrepresented groups in science have higher achievement with problem-based learning, and this would provide an opportunity for increased science achievement by all students. Problem-based learning is compatible to many of their learning styles, field dependency. Problem-based learning would give all students an opportunity for higher-level thinking and transformational opportunities in their daily lives. The problems are usually relevant, but always involve the students’ contributions and understanding.

Inquiry Lessons

There are seven important elements of any inquiry lesson:

- 1) The Problem—Meets the condition of focus, and the problem should be real, meaningful, and capable of study [39];
- 2) The Background Information—Some means of putting the class on a common level;
- 3) The Materials—Same as Suchman’s responsive environment;
- 4) The Guiding Question—Consists of an anticipated list of questions to be asked by the teacher to direct students’ thought processes;

- 5) The Hypothesis—Should be formulated as a result of discussions and guiding questions;
- 6) The Data Gathering and Analysis—The hands-on components and experimental parts of the inquiry lesson (this is a low pressure area to allow for mistakes and repeats);
- 7) The Conclusion—The lesson’s closure should culminate in some final result based on experimentation and discussion (group conclusions are accepted) [4].

There is a great deal of information and various models to enable use of inquiry in the classroom. Because of its effectiveness with all students, it can be applied as guided and full inquiry using some of the traditional lessons. It depends on the amount of student interaction compared to the teacher interaction and input. For the classroom teacher, Appendix F shows a traditional lesson converted to a guided inquiry lesson. This is to illustrate that “It is easier than you think!”

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Appendix A

The Inquiry Process

Phase 1: Description of Inquiry Activities

I. Inquiry can be viewed as a systematic way to investigate a question or problem.

Scientists use the process of inquiry to generate and validate knowledge.

Examples: The investigation of disease and other health-related matters are all essentially inquiry problems.

- The tentative conclusions suggesting that smoking, high cholesterol foods, excessive weight, and lack of exercise are detrimental to health are the result of inquiry.
- They originate in studies that ask questions, such as "Why does one sample of people have a higher incidence of heart disease than does another?"
- The decision to install black boxes in aircraft attempts to answer the question, "Why did the accident happen?"
- "Why did the students in one set of classrooms achieve more than those in another set of classrooms?"

Inquiry is a process for answering questions and solving problems based on facts and observations.

II. At the classroom level, inquiry is a teaching strategy designed to teach students how to attack questions and problems encountered in various content areas. As a teaching strategy, the Inquiry Model is operationally defined as a five-step method that proceeds as follows:

1. Question or problem identification
2. Hypothesis generation
3. Data gathering
4. Assessment of hypotheses through data analysis
5. Generalizing

III. Inquiry is a model designed specifically for the development of thinking skills.

Students develop their skills first at the general problem-solving level, and they also practice the specific micro-thinking skills contained within the model, such as generating hypotheses and analyzing data.

Appendix B

The Inquiry Teaching Model

Phase II. 5 General Steps

This Inquiry Teaching Model is designed to aid the student to facilitate inquiry science processes while teaching traditional science concepts. This model reflects and resembles the Scientific Methods which is an inquiry method as well. It allows the students to imitate the scientists and investigate questions of their own. The 5 general steps are:

1. **Question or problem identification**—student or groups brainstorm and identify a problem or question they wish to solve.
2. **Hypothesis generation**—student or groups brainstorm and identify a hypothesis they wish to test.
3. **Data gathering**—student or groups brainstorm and identify a procedure they wish to follow. They write out the procedure they wish to use, gather materials needed, and test for their variable. They collect data in this step and use it to accept their hypothesis and form their result statement or generalizing statement.
4. **Hypothesis Assessment**—student or groups brainstorm and decide to accept their hypothesis or reject it. They discuss the results they got and compare it with the question and hypothesis. Based upon their decision, they form a generalizing statement based upon what they did in their investigation.
5. **Generalizing**—student or groups brainstorm and identify a generalizing statement from their experimentation. All groups will share their results with the class for the class to form a generalizing statement/s if possible.

Appendix C Inquiry Teaching Model

Phase III. Students' Actions

In the procedure section of your lesson plan or the presenter's lesson, one should see the five steps of the Inquiry Model of Teaching. Please check it off as it is indicated in the column under "The Student will." The Inquiry model is a student-centered model, so the students should perform the actions. Please write what the students will do for each step under the column, "Actions by students/The Student will:"

Steps	Actions by students/The Student will:
1. Question or problem identification	
2. Hypothesis generation	
3. Data gathering and plan of testing	
4. Hypothesis Assessment	
5. Generalizing	

Appendix D
5-E (Inquiry) Teacher and Student Actions

Stages Of the Instructional Model	What the Teacher Does	What the Student Does
Engage	<p>Creates interest. Generates curiosity. Identifies what the student knows about the topic.</p>	<p>Asks questions, such as: Why did this happen? What do I already know about this? What can I find out about his? Show interest in the topic.</p>
Explore	<p>Encourages students to work together without direct instruction from the teacher.</p> <p>Observes and listens to students as they interact. Asks probing questions to redirect students' investigations when necessary.</p> <p>Provides time for students to puzzle through problems. Acts as a consultant for students.</p>	<p>Thinks freely, but within the limits of the activity. Tests predictions and hypotheses. Forms new predictions and hypotheses.</p> <p>Tries alternatives and discusses them with others.</p> <p>Records observations and ideas. Suspends judgment.</p>
Explain	<p>Encourages students to explain concepts and definitions in their own minds.</p> <p>Asks for justification (evidence) and clarification from students. Formally provides definitions, explanations, and new labels.</p> <p>Uses students' previous experience as the basis for explaining concepts.</p>	<p>Explains possible solutions or answers to others. Listens to and tries to comprehend explanations offered by the teacher.</p> <p>Refers to previous activities. Uses recorded observations in scientific explanations.</p>
Elaborate	<p>Expects students to use formal definitions and explanations. Encourages students to apply the concepts and skills in new situations.</p> <p>Reminds students to data and evidence and asks: What do you already know? Why do you think..?</p>	<p>Applies new labels, definitions, explanations and skills in new, but similar, situations. Uses previous information to ask questions, propose answers, make decisions, design experiments. Draws reasonable conclusions from evidence. Records observations and explanations. Checks for understanding among</p>

		peers.
Evaluate	<p>Observes students as they apply new concepts and skills. Assesses students' knowledge and/or skills.</p> <p>Looks for evidence that students have changed their thinking and behaviors.</p> <p>Allows students to assess their own learning and group-process skills. Asks open-ended questions, such as: why do you think..? What evidence do you have? What do you know about? How would you explain..?</p>	<p>Answers open-ended questions by using observations, evidence, and previously accepted explanations.</p> <p>Demonstrates an understanding or knowledge of the concept or skill.</p> <p>Evaluates his or her own progress and knowledge. Asks related questions that would encourage future investigations.</p>

Appendix E

STS Sample Lesson 2 for Pre-Service and In-Service Teachers

Major Standards and Prompt

1. Content. Teachers of science understand and can articulate the knowledge and practices of contemporary science. They can interrelate and interpret important concepts, ideas, and applications in their fields of licensure, and can conduct scientific investigations. To show that they are prepared in content, teachers of science must demonstrate that they:

- (a) understand and can successfully convey to students the unifying concepts of science delineated by the National Science Education Standards;
- (b) understand and can successfully convey to students important personal and technological applications of science in their fields of licensure.

2. Nature of Science. Teachers of science engage students effectively in studies of the history, philosophy, and practice of science. They enable students to distinguish science from nonscience, understand the evolution and practice of science as a human endeavor, and critically analyze assertions made in the name of science. To show they are prepared to teach the nature of science, teachers of science must demonstrate that they:

- (a) understand the historical and cultural development of science and the evolution of knowledge in their discipline;

- (b) understand the philosophical tenets, assumptions, goals, and values that distinguish science from technology and from other ways of knowing the world.

3. Inquiry. Teachers of science engage students both in studies of various methods of scientific inquiry and in active learning through scientific inquiry. They encourage students, individually and collaboratively, to observe, ask questions, design inquiries, and collect and interpret data in order to develop concepts and relationships from empirical experiences. To show that they are prepared to teach through inquiry, teachers of science must demonstrate that they:

- (a) understand the processes, tenets, and assumptions of multiple methods of inquiry leading to scientific knowledge.

4. Issues. Teachers of science recognize that informed citizens must be prepared to make decisions and take action on contemporary science- and technology-related issues of interest to the general society. They require students to conduct inquiries into the factual basis of such issues and to assess possible actions and outcomes based upon their goals and values. To show that they are prepared to engage students in studies of issues related to science, teachers of science must demonstrate that they:

- (a) understand socially important issues related to science and technology in their field of licensure, as well as processes used to analyze and make decisions on such issues.

5. General Skills of Teaching. Teachers of science create a community of diverse learners who construct meaning from their science experiences and possess a disposition for further exploration and learning. They use, and can justify, a variety of classroom arrangements, groupings, actions, strategies, and methodologies. To show that they are prepared to create a community of diverse learners, teachers of science must demonstrate that they:

- (a) Vary their teaching actions, strategies, and methods to promote the development of multiple student skills and levels of understanding;
- (b) Successfully promote the learning of science by students with different abilities, needs, interests, and backgrounds;
- (c) Successfully organize and engage students in collaborative learning using different student group learning strategies;

- (d) Successfully use technological tools, including but not limited to computer technology, to access resources, collect and process data, and facilitate the learning of science;
- (e) Understand and build effectively upon the prior beliefs, knowledge, experiences, and interests of students;
- (f) Create and maintain a psychologically and socially safe and supportive learning environment

6. Science in the Community. Teachers of science relate their discipline to their local and regional communities, involving stakeholders and using the individual, institutional, and natural resources of the community in their teaching. They actively engage students in science-related studies or activities related to locally important issues. To show that they are prepared to relate science to the community, teachers of science must demonstrate that they:

- (a) identify ways to relate science to the community, involve stakeholders, and use community resources to promote the learning of science.

An Example of a STS Lesson

Prompt: You will be given or allowed to choose a relevant and current issue in the scientific perspective, include opinions of all stakeholders, and propose a solution based upon the data collected (NSTA 3.0).

Example: In a city in a southern state, there is a prominent chemical company named Velux. *If you investigated this problem, you would find out what chemical Velux manufactures and give the chemistry background of the chemical.* Velux has been accused of dumping the chemicals and by-products into Calm Creek which runs through several northern communities (NSTA 4.0, 7.0). These communities have been found through research and documentation to have high deaths due to cancer. *You will need to get the facts from past records and interview a sample of persons from each affected neighborhood to get the perspectives of these stakeholders. The opinions of the Velux employees and owners are important, too* (NSTA 2.0).

The public asserts that Velux's chemical has penetrated the soil of the surrounding communities and has caused illness in children, also. *You can do soil testing or find records of soil testing done in the areas. If you are a biology teacher, you may want to look for flora and fauna at, in, and along the creek* (NSTA 1.0). *You may want to survey the schoolchildren or*

children living near Calm Creek to see if they noticed anything or has any idea about this issue. Soil around one apartment complex was excavated and replaced. An earth science teacher may wish to pursue this. Find out what the apartment manager/owner knows and what is told to prospective renters about the soil.

I think you are getting the picture and can see that science is an important and integral part of local and regional communities. It is also relevant to your students. You will notice that scientific and community issues involve stakeholders, and whether individual or institutional, they value the natural resources of the community, but in different ways. As you design your inquiry STS project, you will identify a discipline and a concept to follow as you identify ways to relate science to the community, involve stakeholders, and use community resources to promote the learning of science (NSTA 7.0).

Finally, you will write a lesson plan and scoring rubrics to show how you would involve students successfully in activities that relate your science issue to resources and stakeholders in the community and to the resolution of issues important to the community. You will state the follow-up action/behavior expected of your students based upon this data (see Appendix G).

Appendix F

Sample Lessons for Classroom Students

I. Hydrogen Peroxide and Potatoes: Actions of an Enzyme

Grade Level: 7-12

National Science Standards: Life Science Content Standards

- Using concepts and processes
- Science as inquiry
- Physical science: chemical reactions

Lesson Objectives:

- The student will experience inquiry through this investigation.
- The student will explore and discover what happens when hydrogen peroxide and potatoes come in contact.
- The student will evaluate what a catalase is and how it is used.
- The student will describe the relationship between organic matter and a catalase.

Materials:

Tomatoes, raw chicken livers, potatoes, hydrogen peroxide, eye droppers, knife.

Safety:

Applicable safety rules will be written on a poster and discussed before beginning the activity.

Lesson Activities:

1. Students will pair in groups of four to do the experiment. They will gather prior knowledge about hydrogen peroxide and how it reacts with organic material. Students will create a KWL chart to determine what questions they need to answer based on the guidelines of the experiment.
2. Students will research hydrogen peroxide and catalase. They will make predictions of the possible outcomes prior to beginning the experiment. Students will write a problem and then a hypothesis based on their research (see Appendix E).
3. Students will perform the experiment based on the guidelines that are given by the teacher or on the ones they are allowed to develop themselves. Students may choose to modify the experiment based on research and permission from the teacher. The students will test the catalase on the tomatoes, chicken livers, and potatoes to discover and explore what happens.
4. The students will record their data in each group and collaborate together to determine if their results validated their hypothesis or if another experiment needs to take place.
5. Once the students have determined what a catalase is, what the reaction is and why it takes place, the students will create a presentation to present their findings.

6. The presentation will report their findings. The teacher should look for relationships, correlations, and discoveries during the presentation to gauge the students' conceptual understanding. This will tell the teacher how to proceed with the students. The objectives should be stated in their own words by explaining how they conceptually understood them (Johnson and Raven, 2001).

Assessment:

Participation Rubric, Presentation Rubric, Graded Teacher-Created Worksheet

Enrichment:

Where else can we see catalase or any enzyme being used? What are advantages and disadvantages of catalase or other enzymes?

Students will be asked to design another experiment that will further their understanding of organic/inorganic matter and catalase.

Appendix G Lesson Design for Learning

Daily Lesson Planning Form (For all types of science lessons)

Name _____ Subject/Grade _____ Date _____	
Curriculum Connections ___ Six Weeks Length of Lesson _____ days	
Curriculum Guide Objective/National Science Standards: 1.0 Content 2.0 Nature of Science 3.0 Inquiry 4.0 Issues 5.0 General Skills of Teaching 7.0 Science in the Community For SPI, see the Major standards on the prompt page.	
<u>Guiding Question</u> How does pollution from plants and factories affect the environment? Concepts: chemistry, biology, botany, pH, soil types	
<u>Motivation</u> How many of you pass the bakery on the way to school or home? How can you tell when you are near it? Why? <u>Student Participation:</u> Whole class, individually, and in pairs. <u>Relate to Previous Learning:</u> Remember when we talked about ozone, car emissions, and how it affected the atmosphere? How do you feel about carbon emission today? Why? <u>Relate to Student Experience:</u> Do you remember how this community got sidewalk recycling bins? (<i>Some students may remember my class taking a survey to see who would use the bin at their home if the City gave them free recycling bins. They then mailed officials at City Hall and told them what data they had collected concerning recycling bins in their neighborhood.</i>) Today we will look at another issue confronting this community.	
<u>Strategies/Activities/Distributed Practice/Intervention</u> <ul style="list-style-type: none"> • Students will get in groups of four and 	<u>Assessment/s</u> <ul style="list-style-type: none"> • Notes on concepts being researched.

<p>brainstorm their problems using the traditional inquiry model worksheet (student version).</p> <ul style="list-style-type: none"> • All groups will debrief to the whole class. • Students will get in pairs and decide if they want to change their hypothesis and research a different part of the problem. • They will write another plan and begin to do their research. They will do most of the research out of class and in class, the content and concepts will be discussed. 	<ul style="list-style-type: none"> • Written report containing academic language for the project. • Having a plan deciding how to address the issue. • Result of the action to address the issue. • Result of the research showing information on increased knowledge related to the chosen concept. <p><i>(The rubric will usually help detect this, but teachers should look for this growth in the reports.)</i></p>
<p><u>Closure</u></p> <p>Each pair of students will report and afterward the whole class will respond to the community and other stakeholders to offer assistance and gratitude.</p>	
<p><u>Extend and Refine Knowledge</u></p> <p>Students may make an informative brochure for the stakeholders with the company or the positive stakeholders.</p> <p>They may investigate other companies within communities.</p>	<p>Assessment/Student Products and Performances/Technology</p> <p>Students can make a video of the community showing the positive and negative effects of the company.</p> <p>They can sponsor a health night with the medical community and find out if the community has a health problem related to the company.</p>

Appendix G (cont'd.)
The STS Lesson Rubric Criteria

Explanations

Explanation of the points 0, 1, 2 are shown below on the abbreviated rubric. These are from the *National Science Education Standards* and they explain what the pre-service teacher (candidate) should be able to do in a college classroom and in a public school classroom. (0 means that the knowledge is limited and the academic language is not there; 1 means that the knowledge level is acceptable and the academic language is there; and 2 means that the candidate has successfully exhibited the knowledge requested and has used the academic language excellently.

Standards Correlation and Scoring Rubric

NSTA Standards	0 Unacceptable	1 Acceptable	2 Optimal
NSTA 1B	Candidate does not understand and cannot successfully convey to students the unifying concepts of science.	Candidate understands and can minimally convey to students the unifying concepts of science.	Candidate understands and can successfully convey to students the unifying concepts of science delineated by the <i>National Science Education Standards</i> .
NSTA 1C	Candidate does not understand and cannot convey to students important personal and technological applications of science.	Candidate can convey to students some important personal and technological applications of science.	Candidate understands and can successfully convey to students important personal and technological applications of science in their fields of licensure.
NSTA 2A	Candidate does not understand the historical and cultural development of science and the evolution of knowledge in	Candidate understands the historical and cultural development of science and the evolution of knowledge in their	Candidate successfully understands the historical and cultural

	their discipline.	discipline.	development of science and the evolution of knowledge in their discipline.
NSTA 2B	Candidate does not demonstrate the philosophical tenets, assumptions, goals, and values that distinguish science from technology and from other ways of knowing the world.	Candidate does demonstrate the philosophical tenets, assumptions, goals, and values that distinguish science from technology and from other ways of knowing the world.	Candidate does demonstrate and understand the philosophical tenets, assumptions, goals, and values that distinguish science from technology and from other ways of knowing the world.
NSTA 3A NSTA 3B	Candidate does not demonstrate the processes, tenets, and assumptions of multiple methods of inquiry leading to scientific knowledge.	Candidate demonstrates the processes, tenets, and assumptions of inquiry leading to scientific knowledge.	Candidate demonstrates and understands the processes, tenets, and assumptions of multiple methods of inquiry leading to scientific knowledge.
NSTA 4A	Candidate does not demonstrate the socially important issues related to science and technology and the processes used to analyze and make decisions on such issues.	Candidate demonstrates important issues related to science and technology and some processes used to analyze and make decisions on such issues.	Candidate demonstrates and understands socially important issues related to science and technology, as well as processes used to analyze and make decisions on such issues.
NSTA 7A	Candidate does not identify ways to relate science to the community, involve stakeholders, or	Candidate does identify ways to relate science to the community, involve stakeholders, and use	Candidate understands and identifies ways to relate science to the

	use community resources to promote the learning of science.	community resources to promote the learning of science.	community, involve stakeholders, and use community resources to promote the learning of science.
NSTA 1B NSTA 5A	Candidate does not give the title of the lesson and the designated grade (s) within specified time.	Candidate gives the title of the lesson and the designated grade (s).	Candidate successfully displays the title of the lesson, designated grade (s) and specified time.
NSTA 1B9 NSTA 5A	Candidate does not specify the NSTA or district science standards.	Candidate identifies the NSTA or district standards.	Candidate specifies the NSTA and the district science standards.
NSTA 1B9 NSTA 5.0	Candidate does not identify a major question or issue to guide the lesson.	Candidate gives a question or issue which weakly connects to or guides the lesson.	Candidate successfully identifies a major question or issue to guide the lesson.
NSTA 5.0 NSTA 1C	Candidate does not identify or name the major concepts which will be taught.	Candidate identifies a concept which will be taught.	Candidate successfully identifies major concepts and connections which will be taught.
NSTA 1B9	Candidate does not identify stakeholders and views.	Candidate identifies some stakeholders and some views.	Candidate identifies all stakeholders and examines all views.
NSTA 1B	Candidate does not identify a focus or attention set to start the lesson.	Candidate attempts a focus or attention getter to start the lesson.	Candidate successfully begins lesson with a relevant focus or attention getter to start the lesson.
NSTA 1B3	Candidate does not use community resources to	Candidate uses some community resources to	Candidate successfully uses

NSTA 7A	teach the lesson (people, natural, institutional).	teach the lesson (people, natural, or institutional).	community resources to teach the lesson (people, natural, institutional).
NSTA 1A	Candidate does not specify strategy or integration to teach the science behind the issues.	Candidate does specify strategy or integration used to teach the science behind the issues.	Candidate successfully identifies specific strategy or integration to teach the science behind the issues.
NSTA 2B NSTA 4B	Candidate does not use technology or specify interaction with and impact on society.	Candidate uses technology and minimally integrates the impact on society.	Candidate uses technology and successfully integrates the interaction with and impact of technology on society.
NSTA 1B9 NSTA 4B	Candidate does not relate science to the resources and to the resolution of the issues.	Candidate does relate science to the resources and to the resolution of the issues.	Candidate successfully relates science to the resources and to the resolution of the issues.

Appendix G (cont'd.)
The STS Lesson Plan Grading Rubric

This rubric is used to grade/evaluate your lesson plan. The above rubric categories have been shortened to state which standard is being used, such as NSTA 1b, and the earned points for each standard will be circled and totaled.

Components	Descriptions	Points
NSTA Standards		
1.NSTA 1B	Unifying concepts of science are delineated.	0 1 2
2.NSTA 1C	Personal and technological applications of science are delineated.	0 1 2
3.NSTA 2A	Understand the historical and cultural development of science and the evolution of knowledge in their discipline.	0 1 2
4.NSTA 2B	The philosophical tenets, assumptions, goals, and values that distinguish science from technology and from other ways are discussed.	0 1 2
5.NSTA 3A	The processes, tenets, and assumptions of multiple methods of inquiry are demonstrated.	0 1 2
6.NSTA 4A	Socially important issues are related to science and technology, and decisions made on such issues.	0 1 2
7.NSTA 7A	Related science to the community and stakeholders.	0 1 2
Lesson Plan Components		
8.NSTA 9.0 Safety	Appropriate safety rules and safety plans are reviewed with students.	0 1 2
9.NSTA 5.0 Grade Level, Title, Length of Time	Title of the lesson and the designated grade (s) within time specified.	0 1 2
10.NSTA 5.0	The NSTA, and Memphis City School standards are specified.	0 1 2

Standards		
11.NSTA 5.0 Guiding Question	A major question or issue is asked to guide the lesson.	0 1 2
12.NSTA 5.0 Concepts	Major concepts which will be taught are named.	0 1 2
13.NSTA 7A Stakeholders	All stakeholders and views are named and examined.	0 1 2
14.NSTA 5.0 Motivation	A type of focus or attention getter is used to start the lesson.	0 1 2
15.NSTA 3A Strategies/Activities	The inquiry method is used with various teaching strategies, including considerations of risks, costs, and benefits of alternative solutions; relating these to the knowledge, goals, and values of the students, and what behavior change is expected of the students.	0 1 2
16.NSTA 1B3 NSTA 7A Community Resources	Some community resources were used to teach the lesson (people, natural, institutional).	0 1 2
17.NSTA 5.0 Learning of Science	Specific strategy or integration is specified to teach the science behind the issues.	0 1 2
18.NSTA 2B NSTA 4B Technology	Technology and its interaction with and impact on society is specified.	0 1 2

19.NSTA 5.0 NSTA 1B NSTA 4B Closure	Students relate science to the resources and to the resolution of the issues.	0 1 2
Total Points		
Average Points Earned		

Points	Score
28-38 =	2 = Excellent; Optimal
17-27	1 = Acceptable; Good
0-16	0 = Unsatisfactory;
	Contact the professor

It is important that rubrics are used so that the students will know what is expected of them, and that they may be able to address everything and discuss with others what they do not know. It is also a helpful guide for the teacher; many students will be doing different things, but addressing some of the criteria from the rubrics will show the importance of the project and the value the teacher puts on it.

UNDERSTANDING MATHEMATICS AND SCIENCE ADVICE NETWORKS OF MIDDLE SCHOOL TEACHERS

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Abstract

We report findings from a research project designed to examine the mathematics and science advice networks of teachers who participated in professional development under the auspices of the NSF-funded Rocky Mountain-Middle School Math and Science Partnership. We provide descriptive statistics of results. Additionally, we reflect on the research process and discuss some of the practical challenges involved.

Introduction

A significant literature base discusses aspects of teacher professional networks, as there is an emerging consensus that they are an important part of school improvement [1]. Professional community among teachers is connected both to efforts to improve instruction and actual instructional improvement [2-6]. Often, this involves leadership or distributed leadership roles as a way of transmitting information among groups of teachers [7-8].

Professional development courses for teachers affect these networks. The Rocky Mountain-Middle School Math and Science Partnership (RM-MSMSP), developed at the University of Colorado Denver (UCD) and funded by a National Science Foundation Mathematics and Science Partnership (MSP) grant, offers professional development courses designed to increase teacher content knowledge. At the time of this study, over six hundred teachers had participated in courses offered through the RM-MSMSP. In addition to professional development, the RM-MSMSP focuses on contributing to the research base in middle school mathematics and science education. As part of the RM-MSMSP, we are using social networking to analyze the advice networks of participating mathematics and science teachers. That is, we investigate aspects of to whom these teachers turn for advice or information about teaching mathematics or science.

Numerous recent studies have used social network analysis to study professional community, district policy and its connection to teachers' social networks, distributed leadership, and to evaluate MSP grants [8, 9]. Similarly, our work sought to describe the social networks of a large MSP [10, 11].

Theoretical Framework

Professional development programs seek to improve and modify aspects of teachers' practices. They do this in a variety of ways, from building content knowledge in a discipline, to challenging assumptions about and enhancing aspects of pedagogical practices. There is significant literature to support the importance of school-based professional development [12-15].

However, as teachers spend more time in their schools, they become increasingly familiar with the expectations and beliefs of others who work there, and teaching can take on a more routine quality [16]. Teacher isolation can be a common issue [17, 18]. Thus, professional development opportunities that offer participants a chance to interact with and learn from teachers outside their schools can play a central role in affecting teacher practice and school change [19-21]. In particular, these external professional development opportunities have been cited as improving teachers' classroom practice and promoting teacher leadership [22]. Thus, it stands to reason that both in-school and out-of-school professional development communities play an important role for teachers.

Successful teacher learning communities are generally characterized by a trusting atmosphere in which members have confidence in their colleagues, and in which a flow of information is created [23, 24]. These networks provide support to teachers, as well as serving as channels for information and expertise to be shared. In addition, they create an opportunity for teachers to learn from one another as well as share ideas and resources [3, 5, 25-27]. In addition to benefiting teachers, several studies have shown that the professional networks of teachers have an impact on overall school performance and student learning [28-31]. Additionally, professional networks have been found to play an integral part in successful school reform and policy implementation [3, 5, 25, 28, 32-35].

Beliefs about teaching have been shown to be highly influenced by professional networks, and teachers' attitudes have been shown to impact students [26, 31, 36-38]. Moreover, beliefs about mathematics seem to affect teachers' behavior in the classroom, including their types of questions, depth of questions, and choice of methodologies and amount of direction to

provide students [39-40]. Specifically, teachers struggle to overcome their previous conceptions about how to teach mathematics [41-43]. Professional networks can aid in this.

Moreover, one study also found that the networks of literature teachers are larger than those of mathematics teachers, and that those literature teachers make more frequent contact than mathematics teachers. In the schools studied, this led to stronger literature support networks [44].

However, in general there seems to be a shortage of investigations in the literature on advice networks of mathematics and science teachers. Thus, we seek to further contribute to the research base regarding social networks and professional communities, primarily with regard to middle-level mathematics and science teachers. This study specifically addressed the following research issues:

- 1) Describe the social network information associated with participants in the RM-MSMSP. How does this vary across the participants in the network?
- 2) Do teachers who participated in a higher number of RM-MSMSP courses have stronger social networks with regard to mathematics and science education?
- 3) Do teachers at a given level (elementary, middle, high) have a greater propensity than others to discuss mathematics and science outside their own level?

Methods

Our study sought to capture data on the professional advice interactions of mathematics and science teachers who had participated in the RM-MSMSP, measured from the perspective of the teacher receiving advice. We proceed by providing details about the participants, and then discuss data collection and data analysis.

Participants

There are several unique challenges to social network surveys: the need for a clear network boundary, protecting confidentiality of respondents, and the need for a very high response rate [45-47]. To clearly define our network boundary, we chose to survey all of the teachers in partner districts who had participated in RM-MSMSP courses from its inception in Fall 2004 through Summer 2008. This grant was designed to meet the needs for middle school teachers in the Denver Front Range region to meet the needs of the federal No Child Left Behind legislation for teachers to be highly qualified in their discipline. Additionally, the program was designed under the assumption that teachers with higher content knowledge in their discipline

would have increased student achievement [48]. Over the first two years of the project, approximately eight mathematics courses and eight science courses were developed and implemented. In subsequent years, five additional courses (two mathematics, two science, and one integrated) were developed and implemented. These were offered for 4 graduate credits and ran for either two weeks full-time (8-5 daily) or three weeks part-time (8-12 daily). These courses were generally 80% content and 20% pedagogy-focused. In addition, each course that was initially developed had a pedagogy-focused “structured follow-up” during the next academic year. Additionally, semester-long academic year versions of the courses were offered, wherein the structured follow-up pedagogy content was integrated into the mathematics and science content of the course. Teachers received stipends and reduced tuition for participation in the courses. These teachers ranged from elementary to high school teachers, with most teaching at the middle school level.

We advertised the survey via an e-mail invitation to these teachers and sent weekly e-mail reminders to participants during the approximately four weeks in which the survey was active. Of the 569 teachers invited to participate, 368 had taken mathematics courses, 300 had taken science courses, and 99 had taken both. Participants were offered a small gift card for responding to the survey and, in total, 232 teachers responded.

A summary of the teachers responding to the survey is shown in Table 1. Note that the majority of participants taught in middle schools, and the number of elementary and high school teachers was approximately the same. Also, the number of participants who were mathematics teachers was approximately the same as the number who were science teachers, and there were some participants who did not teach either subject. These tended to be special education teachers, coaches, and administrators.

Table 1
Summary of Participant Data

	<i>Number</i>	
Elementary school teachers	40	
Middle school teachers	105	
High school teachers	47	
Mathematics teachers	70	
Science teachers	67	
Teachers of both mathematics and science	37	
Participants teaching neither mathematics nor science	24	
	<i>Mean</i>	<i>Standard Deviation</i>
Years teaching	8.50	6.53
Number of mathematics classes taken*	2.43	1.68
Number of science classes taken*	2.51	1.60

**This calculation only includes teachers who had taken at least one math/science class*

Notice that teachers averaged significant teaching experience, with an average of eight and a half years.

Data Collection

Our primary means of data collection was a slight modification of the School Staff Social Network Questionnaire (SSSNQ) survey. We adapted this from the one used in Distributed Leadership Study (DLS) for Middle School Mathematics Education at Northwestern University [10]. In this survey, participants' advice networks are measured using the technique of name generators, which ask survey respondents to recall, by listing specific names, various people from whom they have sought advice or information. The survey centered on the primary question of, "During this academic year, to whom have you gone for advice and/or information about teaching mathematics and/or science?"

For each name that a respondent listed, follow-up questions asked the respondent whether they received advice or information about mathematics, science, or both, to describe the role or job description of the person named, and to characterize their interactions with the person in terms of frequency and content matter. In order to improve accuracy, respondents were also

asked to provide possible alternate names (maiden names, nicknames) that their advisors might use. Finally, the survey also contained several demographic questions. Specifically, respondents were asked about the subject(s) they teach, at what levels of school(s) they have taught, and the number of years they have been teaching. The survey took between three and ten minutes to complete, depending on the number of advisors a respondent provided.

In order to minimize chances that respondents would misinterpret the questions, we followed the SSSNQ wording as closely as possible. The SSSNQ was evaluated using cognitive interviews to assess its clarity and effectiveness [49]. We also conducted a small pilot survey with teachers and made minor changes based on this feedback. Beyond that, reliability and validity were established through the DLS.

Data Analysis

Before detailed analysis on the data could be completed, significant data cleanup was necessary. Specifically, in order to obtain accurate data from the social network surveys, it is necessary that the spelling and formatting of names are consistent. Thus before beginning data analysis, it was necessary to clean up and format the data so that it could be entered into the analysis software. The majority of the data cleanup was necessary due to discrepancies in the spellings of names and the use of nicknames or maiden names. For example, one respondent may list an advisor as Bill Smith while another would list him as William Smith. Additionally, several teachers responded to the survey multiple times. In these cases, the responses were combined.

There are many measures available for analyzing social networks. We focused on out-degree due to its high level of robustness to incomplete network data and high correlation to other network measures [45, 47]. Out-degree is essentially a measure of the support network of an individual. In this case, it measures how many people a teacher turns to for advice or information about teaching mathematics and/or science based on self-report data.

To compute a more detailed measure of out-degree, we differentiated between ties seeking mathematics advice and ties seeking science advice. In addition, we computed a weighted out-degree by taking frequency of advice into consideration. That is, a tie to someone from whom a participant reported seeking more frequent advice was considered stronger than a tie to someone from whom the participant reported rarely seeking advice.

During the first round of analysis, we began by looking for correlations to assess whether

there were relationships between the number of RM-MSMSP classes taken and out-degree. Additionally, we looked for correlations between out-degree and number of years teaching, as well as differences between mathematics and science advice ties.

Recall that the primary survey question asked RM-MSMSP participants to list people to whom they have turned for advice over the last school year about teaching mathematics or science. During the first stage of the analysis, we used network visualization tools to provide initial insight into the advice network. Specifically, using NetDraw, we created visual depiction of the advice network using a graphical layout known as a sociogram.

For the next part of our analysis, we investigated from whom, on average, teachers were seeking advice. We calculated the average proportion of connections from respondents of one level to advisors of another level, as well as the average proportion of connections to other RM-MSMSP participants, aggregating the data by level and subject.

Results

In all, there were 198 usable, unique responses that provided a total of 465 unique names of advisers and respondents. Due to their low numbers, the six responses that were from participants who were not teachers were not included in the statistical analysis.

Figure 1 is a sociogram depicting the advice network of our respondents. The respondents are represented as circles. Black circles represent teachers who responded to the survey, while white circles represent teachers who were named as advisors but were not surveyed or did not respond. Two teachers are connected by an arrow if one teacher sought advice from the other. The arrow points from the teacher seeking advice to the individual who gave advice. The collection of black dots at the upper left of Figure 1 denotes those respondents who reported seeking no advice or information from others regarding mathematics and/or science, and who also were not named by any other participants in the study as a source of such advice. Looking at this sociogram, we see that most teachers have only a few advice connections. It further appears that there is a lack of widespread connectedness in the network. However, this last conclusion could be limited by lack of data.

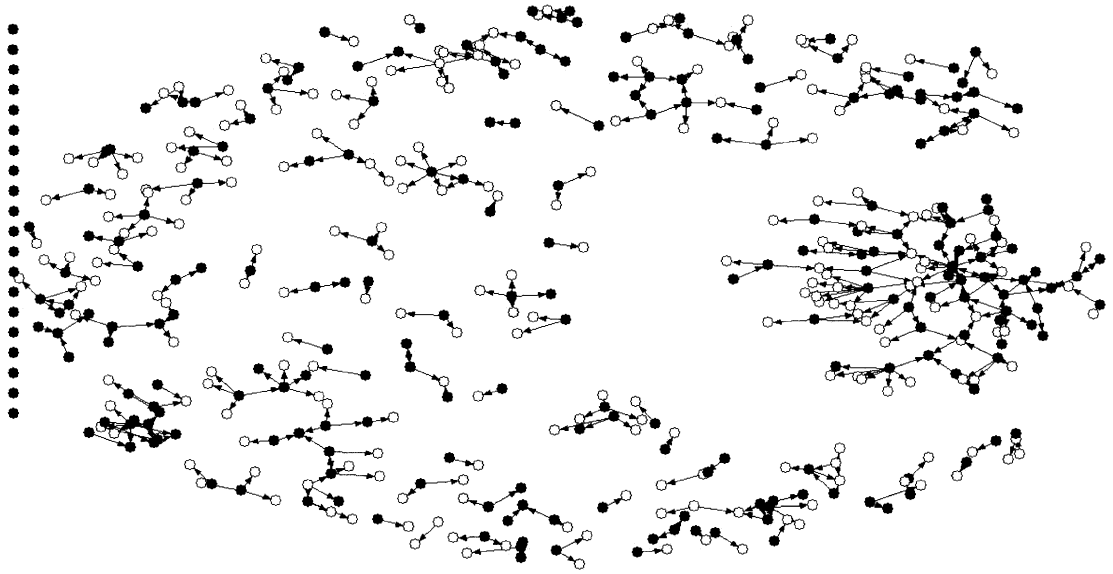


Figure 1.

Advice network of respondents.

A noticeable exception is the large group of connected teachers seen in the middle right of the sociogram. This group formed around several well-connected teachers. A sociogram isolating this group is shown in Figure 2. This group, containing ninety-nine individuals, centers on a teacher on special assignment from the Department for Learning and Achievement within a district. With an out-degree of ten, this teacher had the highest level of connectedness of all teachers surveyed. In addition, this group contains seventeen teachers with higher-than-average connectedness. This group was largely clustered by school, with these highly-connected teachers serving as links among the schools.

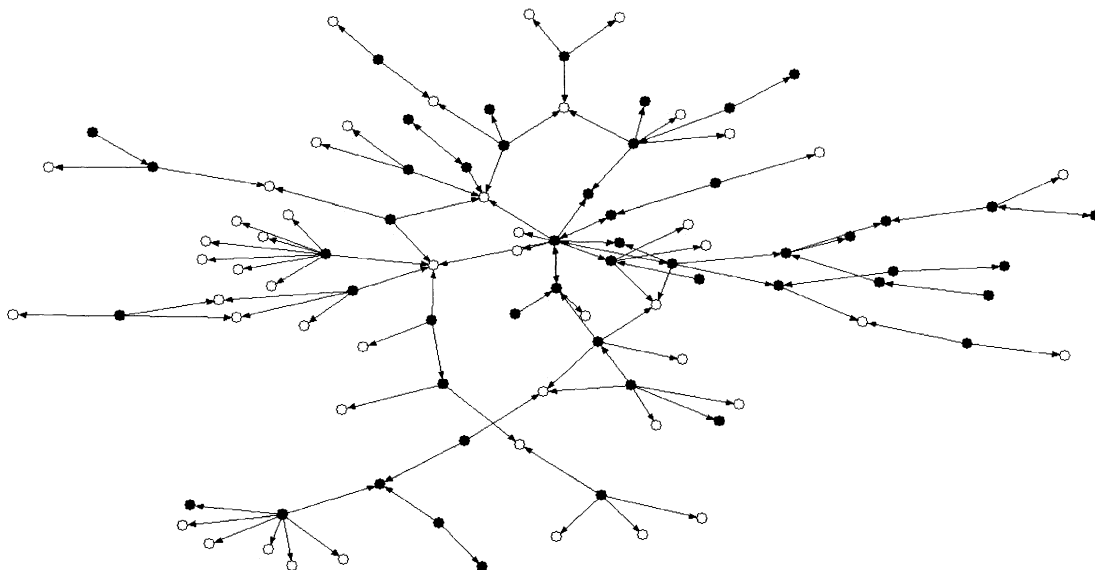


Figure 2.

Isolation of Figure 1 group formed around several well-connected teachers.

We next investigated how a teacher's level, subject, years teaching, and number of classes taken through RM-MSMSP affected the number of connections of teachers. We investigated total connections, mathematics connections, and science connections separately. There were no significant correlations found in the data. Also, there was no significant difference between data weighted by frequency of contact and non-weighted data.

Overall, the average number of advisors per respondent was 1.84. Of these connections, 0.96 were to mathematics teachers and 0.81 were to science teachers. Disaggregating the data by content area showed that teachers who taught only mathematics or only science had on average 2.0 advisors each. In contrast, teachers who taught both subjects sought less frequent advice, with the average number of advisors at 1.57, but this difference was not statistically significant. The average number of respondents did not vary significantly based on the level at which the teacher taught. For teachers who taught both subjects, the average number of advisors in each discipline was nearly the same. Overall respondents had, on average, 0.20 advisors who taught at the elementary level, 0.70 advisors who taught at the middle school level, and 0.42 who taught at the high school level. A summary of these connections is given in Table 2.

Table 2
Summary of Advisors

	<i>Average</i>	<i>Standard Deviation</i>
Total advisors	1.84	1.42
Mathematics advisors	0.96	1.18
Science advisors	0.81	1.15
Advisors in school	0.80	0.94
Advisors who teach elementary	0.20	0.47
Advisors who teach middle school	0.70	0.97
Advisors who teach high school	0.42	0.84

We next investigated the types of connections that teachers had. For this part of the analysis, it was necessary to remove the twenty-three respondents who reported not seeking any advice. For the remaining respondents, who reported at least one advisor, we analyzed the average proportion of connections each respondent had, aggregating the data across various characteristics.

First, we calculated the percent of advisors that teachers had at various grade levels (see Table 3). We note that each level of teacher had over half of their connections to teachers at the same level, with high school teachers having almost 70% of their advisors also at the high school level. This is consistent with what was found in Coburn, Choi, and Mata where in Year 1 of their study, 51% of their teachers' ties were actually to teachers at precisely the same grade level [1].

Table 3
Advisors by Level Taught

	<i>Average Percent of Advisors</i>			
	Advisors at elementary level	Advisors at middle school level	Advisors at high school level	Other advisors
Elementary teachers	55%	10%	2%	33%
Middle school teachers	4%	56%	7%	33%
High school teachers	2%	9%	69%	20%

Next, we calculated the percent of advisors that teachers had to others within their own school and to other participants in RM-MSMSP classes (see Table 4).

Table 4
Advisors

	<i>Average Percent of Advisors</i>			
	Advisors within teacher's school	Advisors not within teacher's school	Advisors who were RM-MSMSP participants	Advisors who were not RM-MSMSP participants
Elementary teachers	41%	59%	27%	73%
Middle school teachers	36%	64%	38%	62%
High school teachers	58%	42%	22%	78%

Discussion

This study investigated the professional advice networks of mathematics and science teachers who participated in a large mathematics and science partnership. It was grounded in the fields of social network analysis and teacher professional development.

We found evidence that there were not significant differences in the self-reported advice networks based on subject taught (mathematics or science) or level taught (elementary, middle, or high school). We found that, in the setting of this professional development program, most teachers reported a relatively small advice network. However, given the design of the professional development program, this does not seem too surprising. It does, however, suggest that this professional development (PD) model may not be ideal for the development of teacher professional networks. A small, more cohort-based model of PD may be more appropriate if strengthening teacher advice networks is the primary goal. However, this PD was designed to increase teachers' content knowledge of mathematics and science, and indicators support that it fulfilled this objective.

Our study also allows for several interesting comparisons to the Math in the Middle (M^2) Institute program. First, the average number of connections for these teachers was lower than the numbers found in the University of Nebraska at Lincoln (UNL) study of the Math in the Middle Institute Partnership. The UNL study reported the average number of advisors as 3.8, 3.5, 2.9, and 2.8, respectively, for their four cohorts of participants. This is considerably higher than the average of approximately 1.8 that we reported.

Second, for their first three cohorts, the M^2 mean number of advisors who were other M^2 participants was 1.7. In contrast, for middle school mathematics teachers who participated in our study, the mean number of connections to RM-MSMSP participants was 0.57, much lower than

the M^2 participants. We posit that a reason for this difference could be the cohort model that M^2 implemented, where groups of 25-35 teachers went through the program together, taking almost all of the same coursework for twenty-six months. Since our program lacked this cohort model, teachers often would not take further coursework with each other. Also, many teachers in our program only took a few courses, whereas the M^2 teachers took approximately ten courses together. It is logical to conclude that their cohesiveness would be much stronger as a result.

Limitations

There are several limitations with this study. First, we lacked baseline information on the participants' mathematics and science advice networks. This precluded us from making any comparisons over time or drawing any causal inferences.

Second, we lacked a high response rate. Social network survey analysis requires either a high response rate or sophisticated sampling techniques. We were aiming for a high response rate. However, we did not achieve this, and we hypothesize two main reasons. First, we were attempting to survey teachers who had taken courses over a six-year time span. Many of the e-mail addresses were likely out of date, as teachers had moved schools and/or districts, or left the field. Also, many responding teachers participated in a relatively low number of courses from the RM-MSMSP. Thus, they likely did not feel the same connection to the program that teachers who took more courses felt, and were thus less likely to respond. This is in stark contrast to the Nebraska Math in the Middle Institute Partnership where teachers went through an intensive, 26-month program in cohorts of approximately thirty-five teachers and the survey was administered in person to each cohort [10]. The low response rate of approximately 35% limits our ability to use many traditional social network analysis tools. Thus, we were restricted primarily to descriptive network measures. However, given the sparseness of information in the literature on mathematics and science advice networks of teachers, we still consider this information to be of value to the field.

Suggestions for Further Study

This article raises several questions worthy of further investigation. It would be helpful to have a more complete picture of how these advice networks change over time, both within the time frame of the professional development grant and for several years afterward.

There have been a few studies of network change over time in schools, but data on network change of participants in an intensive, sustained professional development experience

that is not situated in a given school or district seems limited. Another study of interest could more deeply examine the change of mathematics and/or science advice networks in schools over time.

Several other areas of study include how teacher professional development might be designed on a large scale to increase both content and pedagogical knowledge, while still developing teacher advice networks. Additionally, how can such advice networks be sustained and even further developed once the professional development opportunity ends?

Conclusion

There are many reasons to use social network analysis to study teachers' professional networks. This study examined a large advice network of mathematics and science teachers. We found that there were many commonalities between both the mathematics and science teachers, and across the different levels at which the teachers taught. While our study had significant data limitations, we feel that the research questions that it sought to address are significant and worthy of future study. We hope that our lessons learned will aid other researchers in studying the impact of large professional development programs on teacher professional networks.

Acknowledgment

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GRAPPLING WITH ISSUES OF LEARNING SCIENCE FROM EVERYDAY EXPERIENCE: AN ILLUSTRATIVE CASE STUDY

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Abstract

There are different perceptions among researchers with regard to the infusion of everyday experience in the teaching of science: 1) it hinders the learning of science concepts; or, 2) it increases the participation and motivation of students in science learning. This article attempts to contemplate those different perspectives of everyday knowledge in science classrooms by using everyday contexts to teach grade 3 science in Singapore. In this study, two groups of grade 3 students were presented with a scenario that required them to apply the concept of properties of materials to design a shoe. Subsequently, the transcripts of classroom discussions and interactions were analyzed using the framework of sociocultural learning and an interpretative analytic lens. Our analysis suggests that providing an authentic everyday context is insufficient to move young learners of science from their everyday knowledge to scientific knowledge. Further, group interactions among young learners of science to solve an everyday issue need to be scaffolded to ensure meaningful, focused, and sustained learning. Implications for research in science learning among younger students are discussed.

Introduction

Everyone, regardless of schooling opportunities, has everyday experiences that they can share with others. These everyday encounters are experiences that are real and familiar to each individual. The accessibility and familiarity of these experiences make informal everyday experience an ideal starting point for discussions and learning in the classroom. Classrooms provide the space and platform for the diverse everyday experiences of students to be presented,

discussed, negotiated, and appreciated. Despite the availability and potential usefulness of everyday experience in enriching classroom discussions and learning, critics of science learning see everyday experience as informal and a potential hindrance to students' learning as it increases the probability that students will develop misconceptions and naïve conceptions [1]. When compared with scientific knowledge, everyday experience and knowledge are viewed as less precise, more informal and, hence, less acceptable. In the face of this concern, there are also researchers and practitioners who position everyday experience as a valuable resource that will facilitate students' learning of scientific knowledge. Warren, Ogonowski, and Pothier argued for "scientific knowledge as growing out of experience, as a refinement, not a replacement, of experience" [1]. As such, science teachers create opportunities for students to recast familiar everyday experiences, through a process of creative synthesis, as scientific representation. Learning science can thus be described as a new interpretation of everyday experience. This study takes the stance that everyday experience enriches the science learning of young learners by increasing their participation in classroom discussion since everyday experiences are the most readily available resource.

Everyday Experience and Science Learning

Projects focusing on science education reform repeatedly highlight the need for students to learn both the content of science as well as the process of science. Indeed, one common recommendation is a call to move away from dull, uninteresting, memorized scientific facts presented in textbooks toward applications of science that are relevant to students' lives in the curriculum [2, 3]. The widespread isolation of school science knowledge from students' everyday experience often contributed to students' low motivation and interest in learning science [4]. In an era where scientific literacy is often emphasized as an asset and a desirable outcome of science education, the urgency for science education to make science more relevant to the lives of students is heightened. Scientific literacy can be defined as "an understanding of science and its applications to social experience," and teaching scientific literacy involves a process of socializing and enculturating young learners of science for active membership in a science- or technology-based democracy [3-5]. However, the urgent question that remains largely unanswered is how the socialization and enculturation of young learners can be carried out in schools that are often characterized by unique and independent cultures different from the real world. The school culture is often defined by a crowded curriculum, standardized testing, textbooks, and syllabi that are dogmatic about scientific facts that students are expected to learn.

Efforts have been made in many classrooms by science teachers and science education researchers to examine how students can be socialized and acculturated to become scientifically literate consumers of science and technology. For example, the promotion of science inquiry in science classrooms, the use of problem-based learning in solving authentic school science problems, and other innovations are strategies and programs planned to bring students' experience into science learning. The infusion of everyday context for the development of twenty-first century skills among students has been discussed at great length. Bybee aptly asks the question whether the focus of science curriculum in the twenty-first century ought to be on science subject matter itself or whether the emphasis should be on life situations whereby science plays a key role [5]. He argued that basic science concepts should be taught, but the knowledge must be applied in contexts that the learners encounter in life. The ability to apply scientific understanding to real-life situations should be an important outcome of science education. In this research, we take the position of applying science concepts to everyday life and use this as a starting point in a science learning activity. We structure the activity in such a way that scientific understanding is developed as the students share their everyday experiences and knowledge with each other in order to complete the task.

Research into these strategies and programs support the notion that productive learning of science is and can be built upon a foundation of students' shared everyday experience and their interaction with materials inside and outside the science classroom [6, 7]. However, King, Bellocchi, and Ritchie highlighted that methodological obstacles have prevented researchers from comparing context-based and content-based curricula [8]. Hence, we have knowledge of what students gain from an experience of learning with everyday context, but we have little knowledge of their process of learning. Additionally, the bulk of earlier research in the use of context and applications of science—or science-technology-society approach—to develop scientific understanding was carried out with learners of science between the ages of eleven to sixteen years of age [9]. Further, in their review, Bennett, Lubben, and Hogarth suggested that more research ought to be carried out on particular activities that are not traditionally associated with science teaching, and how they can be used to support development of scientific understanding by appealing to students' everyday experience [9]. Therefore, this study was designed to examine the kinds of knowledge and the resultant tensions during interaction in developing scientific knowledge of young learners of science (aged nine) by using their everyday experiences as starting points.

Everyday Knowledge and Scientific Knowledge

This study stems from a sociocultural perspective of learning [10, 11]. Adopting a social view of learning means that higher order functions like logic and argumentation of scientific knowledge are a result of social interaction. Physical tools and language are used to facilitate the learning process by mediating the relationship between the learners and the world. Based on this perspective, we examine students' learning of elementary science content and processes by examining three key components: 1) individual ideas; 2) knowledge (everyday and scientific) that is revealed by the situation; and, 3) how students use language/tools to articulate or represent their knowledge. Individual ideas refer to students' prior knowledge about the contents of science, their personal beliefs about science, and their experience with the phenomena. Learning in this context views students using and applying their prior knowledge, beliefs, and experiences to make sense of the circumstances. Finally, we also note how students communicate and present their ideas.

In this research, we acknowledge the presence of different kinds of knowledge. According to Thomas Jefferson, knowledge can be scholarly or practical—or it can be stable or situational [12]. Furthermore, knowledge can be classified according to where and how it is applied. For example, we can have knowledge that is practiced by a particular group of people (such as scientists), knowledge that is presented in books, and knowledge as content that resides in the minds of individuals. Knowledge, we argue, is not bound to a situation, but rather located within a particular situation [12]. As such, an individual's idea, the context in which this idea is accessed, used, and discussed does not have a static nature, but rather it changes in nature and complexity when applied to different situations. The way that knowledge is talked about in the classroom can also be different. Students can be engaged in contextualized discourse which is characterized by talk that focuses only on the situations and objects in the immediate context. Students can also be occupied in decontextualised talk which is discourse involving past or future events that are not part of the present environment [13]. Engagement in different kinds of discourse suggests the application and formation of different kinds of knowledge.

Scientific knowledge in school is often perceived as “abstract and self-contained” entities, and one of the possible reasons for this is that science is often presented as standalone statements of truth that are context free, having little relevance and application to real-life situations [3, 14]. Students who are exposed to compartmentalized, ready-made, and textbook-based knowledge of science might develop misconceptions about the nature of science and possibly lose interest in it. There is little opportunity for application of these abstract concepts in

authentic situations, and the absence of appropriate application of scientific concepts often results in the learning of unusable scientific knowledge. The learning and acquisition of unusable scientific knowledge will ultimately impact the motivation of students and how they learn science. We postulate that increasing students' abilities to make relevant connections between school science and their everyday experience would develop more motivation in studying science and, in the process, develop more accurate conceptions of the nature of science. As such, we devised this research to examine the kinds of knowledge grade 3 students use when they interact with each other as they learn science through solving a problem based within an everyday context. We hypothesize that using familiar everyday contexts and knowledge as starting points for students to gain school science knowledge would present a more concrete means for young learners of science to build their scientific knowledge. To facilitate our understanding, we examine the forms of interaction in the light of the kinds of knowledge, talk, and skills that the students practice in solving the problems and learning the science.

In many classrooms, science teachers and students are faced with the challenges of curriculum demands, standardized testing, and inadequate resources, as well as a lack of curriculum time. Such limitations often result in frustration among teachers who resort to planning lessons for students to "do the lesson" rather than "do science" [15]. Students' everyday experience is often ignored in the urgency to cram as much content within the limited curriculum time. Based on a sociocultural perspective, we hypothesize that students' everyday experience and knowledge can serve as valuable resources in science learning, and can be used as a primer to develop authentic and in-depth scientific understanding in schools. Research has argued for the use of everyday context in the learning of science as it helps improve students' enjoyment of learning [16, 17]. We concur with the notion that the role of everyday context in the learning of science will make science more manageable and approachable for young learners of science since "concepts in the scientific domain are explicitly defined, based on rules and universally coherent logic. Concepts in the everyday domain are implicit, based on experimental schema, and organized through locally coherent association" [16].

Purpose

The primary purpose of this study was to examine the classroom interactions and the learning outcomes of two groups of grade 3 students' learning about properties of materials. This is done through a detailed analysis of events that take place when a video of a scenario related to their everyday experience was presented to the students. This research is guided by the following

research question: “What forms of interaction occur among grade 3 students when they work in groups to solve a science problem that is based on everyday experience?”

Integrating Everyday Context Using the Scenario-Based Inquiry Approach

In this section, we present the principles and rationale of “scenario-based inquiry”—a strategy that utilizes video playback technology to present an everyday issue that would require the students to use at least one scientific principle to either explain an issue or solve a problem that is embedded in the story presented in the video. Scenario-based inquiry is used as a means of incorporating everyday context in elementary science classrooms. The context presented in the video contains a situation that is familiar to the students, and each situation presented contains both information that is useful for the students to solve the problem and also information that is not required by the students. This condition creates the opportunity for the students to discuss and make decisions about which piece of information (evidence) is necessary and useful to help them solve the problem. The different information is incorporated into the scenario to allow for multiple perspectives to be formulated during group discussions. Chinn and Malhotra argued that opportunities for multiple perspectives are necessary to make science inquiry tasks authentic [18]. We termed the information that is not required by the students “noise.” This “noise” can come in two forms: 1) that which is intrinsic within the scenario that is presented; and, 2) the diverse prior knowledge (often naïve conceptions) that the students bring into the discussion. This is fundamentally the basis for the need for students to talk and discuss the issue as a group so that all of their ideas are presented in a public forum, and thus scrutinized by their peers before it becomes legitimate knowledge. In authentic situations, scientists also bring with them a multitude of ideas and knowledge, some orthodox while others less so. It is also a negotiating process to legitimize knowledge.

Video playback technology is chosen as the medium of presentation of the scenarios as it allows motion, sounds, and colors to be integrated, unlike traditional stories that are predominantly textual. Video playback technology also allows the incorporation of “noise” within the scenario in the form of graphics, colors, sounds, and actions; these could possibly serve as distractions to the actual evidence on which the students should be focused. All of these components increase the authenticity of the learning experience. Distinct from problem-based learning, the scenario presented to the students focuses on the targeted application of scientific concepts in the context of the scenario presented, rather than on solving a problem that may have multiple solutions which may be unscientific and too complex for young learners of science.

The scenarios in the videos are crafted with the intention of harnessing students' everyday experience in developing scientific understandings. Components of these scenario-based videos are aimed at engaging the students with scientifically oriented questions in a serious, informed, and sustained manner (see Table 1). In addition, these videos provide situations in which the students take the scenarios as a personal or collective challenge which require creative responses to understand.

Table 1
Characteristics of Scenario-Based Videos

Categories	Characteristics
Story line	<ul style="list-style-type: none"> • Based on everyday experience or exposure to popular culture of students • Must have at least one scientific principle/concept embedded • Must have an issue or a scientific question for the students to discuss or solve scientifically • Embedded in the scenarios are “noise” which serves as distractions to the learning process or embedded information, and helps students solve problems or questions by allowing for multiple perspectives to be presented
Duration	Five to eight minutes
Language	English
Software	Windows Movie Maker® or iMovie®

Method—Participants

The school where the study was conducted is situated in a prestigious neighborhood with students generally coming from privileged family backgrounds. The participants in this study are two classes, each with forty students in grade 3 (both girls and boys) and their teachers. The two teachers are “Ling” and “Feng,” both of whom have an average of five years of teaching experience.

Method—Context

The elementary science curriculum is designed around five themes: Diversity, Cycles, Systems, Interactions, and Energy [19]. The scenario-based video was incorporated as part of the unit of work on materials that is under the theme of Diversity. In this unit, the students are to

learn about the diversity of non-living things, with the goal of achieving the following learning outcomes:

- to list the various types of materials and relate their properties to their uses (for example plastics, wood, ruler, metals);
- to compare materials based on their physical properties of hardness, strength, flexibility, and ability to float/sink in water; and,
- to show objectivity by using data and information to validate observations and explanations about the properties and uses of materials.

Method—Video Content

The scenario video is eight minutes long and is intended for grade 3 students. The scientific content of this video illustrates the properties of different materials, which include hardness, strength, flexibility, and the ability of materials to float or sink in water. The video is based on the popular children's fairy tale of Cinderella and her glass slipper. The key character in the story is a prince who broke the glass slipper he intended to present to the princess. As a result, he commissioned the shoemakers in his kingdom to design a new pair of shoes for his princess. The following materials were given to the shoemakers: 1) rubber bands; 2) plastic bags; 3) Styrofoam™; 4) metal rulers; 5) a piece of wood; 6) name cards; 7) ceramics; 8) cloth; 9) sponge; and 10) leather. The students were also given a worksheet with two parts: the first part required them to record their observations about the materials; and in the second part, they made decisions about the materials best suited to make the shoe. The two parts of the worksheet allowed students to engage in a decision-making process based on their observations, as well as on their everyday experience and prior knowledge.

Based on the context and content of the video, the task required students to evaluate the properties of the materials required to make a good pair of shoes for the princess. The scientific content they needed for this task consisted of the properties of the materials provided, as well as the design and construction of shoes. The everyday experience that they brought into the discussion included the following: 1) their exposure to different kinds of shoes; 2) observations about the durability of different parts of the shoes; and, 3) the different materials that they are exposed to in their everyday life. The task also required the students to communicate, negotiate, convince, and collaborate with their group members. Consequently, this task demanded that students put together knowledge gained from the video, their everyday experience, their prior scientific knowledge, and their science process skills.

Method—Data Collection and Analysis

This study used an interpretive qualitative case study method to illustrate the students' response to the use of scenario-based videos in learning science. The illustration is based on the two data sources of video recordings of classroom observation and students' worksheets. Video recordings of the lessons were transcribed, the transcriptions of the lesson were read, and then events during the lessons were coded (see Appendix A). Data analysis was carried out by examining the classroom interaction between the following groups: 1) between students; 2) between students and materials; 3) between students and the teacher; and, 4) between students and scientific knowledge. Here, we examine the four forms of interaction in light of the kinds of knowledge and skills that the students practiced in solving the problems and learning the science. The students' worksheets were examined to index the scientific knowledge that they acquired through the lessons.

Results and Discussion

Analysis of the interactions and events in the classroom revealed the prominence of two forms of interactions and knowledge within the grade 3 science classroom: teacher-directed learning, and students' learning and interaction to solve the problem. In *teacher-directed learning*, we discuss how teacher-directed instruction fulfilled instructional goals so that the knowledge presented in textbooks can be transmitted, then we discuss how students engaged in group work accomplished the goal of task completion, and that the knowledge practiced is the knowledge of doing school science and making explicit the knowledge that resides in the minds of different individuals.

Further, it became evident that younger learners of science exhibited two difficulties: 1) they needed more scaffolding so that they could present their points of view within a group context to convince their peers; and, 2) they had an unclear idea of the boundary between scientific and everyday language when using everyday contexts as the starting point to learn scientific knowledge. The everyday contexts presented bring forth different types of knowledge usage among the students, and consequently shape the interactions in the classroom. Furthermore, our analysis of these interactions among the students suggest the following results: 1) they are concerned with task completion goals more than knowledge building given the limited curriculum time; 2) they need to be taught explicitly how to construct scientific knowledge from everyday knowledge when solving problems; and 3) they need to learn how to work collaboratively in a group setting to solve problems. These three points will be explained in the section "Students' Learning and Interaction to Solve Problems."

Teacher-Directed Learning

At the beginning of class time, Ling asked her class of thirty-seven students to push back their desks and sit on the cleared floor, facing the projector screen (see Figure 1). After orienting them about the day's agenda, she showed a video that presented a Cinderella-like story. In the story, the prince faced the problem of replacing the maiden's broken glass shoe and posed the question, "What materials should I use?" Excerpt 1 begins where the teacher paused the video to discuss what the students understood from what they had seen up to that point. Sequential line numbers have been assigned to the dialogue in the Excerpts, and are used to illustrate our observations.

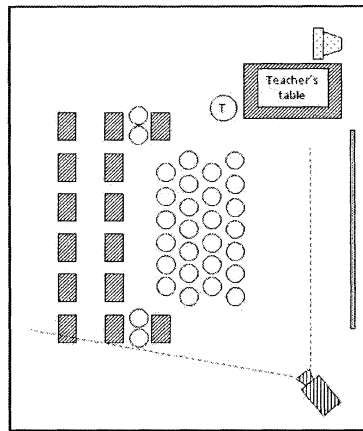


Figure 1. Arrangement of students with respect to the teacher and the projector screen; the video recorder was placed at the corner of the classroom.

After watching the video, Ling addressed the whole class, asking "What actually happened? What's the story all about?" These questions provided a springboard for discussing the science concept of properties of materials that was embedded in the story shown in the video. In conversations with the researchers prior to this class observation, Ling expressed that her aim was to take an inquiry teaching approach for the lesson and to use the story scenario as a platform for instruction. While constantly referring to the events in the Cinderella-like story, she systematically led the discussion with her questioning to elicit students' knowledge of the properties of materials (i.e., glass). She referred to the glass slipper and asked why it broke (15); and after showing another segment of the video, she directly presented the prince's question on the properties of glass (50) and connected the student's responses to a past discussion on this topic (58). While deploying these concept questions, she also helped the students recall particular

story elements (3, 7, 9) and, before showing the next video segment, asked them to predict what would happen next (24).

The foregoing moments of instructional discourse in the teacher's instruction were interspersed with, or embedded within, regulative discourse [20]. She asked her students to wait to be called upon (15, 17), required non-verbal cues for attention (24), instructed the students to guess what would happen next (24), asked them to quiet down (45, 64) and watch the "movie" (47, 62), and directed them to recall a previous discussion to connect with the current topic (57). It is therefore quite evident that the interaction was to a large extent shaped by the combination of the teacher's purposes and the chosen instructional material. In some sense, the interaction was predetermined and the teacher exercised control over the task to be accomplished for that day. The institutional roles of being a *teacher* and a *student* were expressed in the strict turn-taking format of the interaction.

In Excerpt 1, pauses often appeared as thinking time in the classroom interaction. Every time the teacher addressed a question to the whole class, she paused for varying lengths of time (1, 15, 30, 48), although in most instances she took only a fraction of a second. According to Owocki and Goodman, the length of the pause has been said to be critical in engaging more students to participate in discussion [21]. However, in this excerpt the students were already quite engaged by the story in the video. Many were eager to answer the teacher's questions. At one point, Ling had to tell an eager student to wait (15) and she complained that too many of them were responding to her question at the same time (17). Moreover, pauses were used not only to give students time to think, but also to command the students' attention, to make sure they were listening and keeping up (9, 45, 63). Sometimes, they were used to put emphasis on a conjunction ("but") (9) or on an adverb ("anyway") (15), or to solicit tacit agreement with forthcoming words (22, line 2).

Excerpt 1 The Lovely Maiden's Glass Shoe Is Fragile

Turn	Speaker
1	Ling OK, now, what actually happens? (.) If the sou:nd is not really that clear, but from (T): what you have observed just now, what actually happens? What's the story all about? (0.2) Yes, Arlie?
2	Arlie: The shoe is (brittle)
3	T: The shoe is made from?
4	Ss: Glass

- 5 T: Gla:::ss. OK [(0.6) so↑]
 6 John: [Cinderella]
 7 T: Ok who is the lady in the picture, [(.) in the] video?
 8 John: [Cinderella]
 9 T: Ok maybe Cinderella, but (.) alright what name did the prince call the lovely maiden?
 10 Ss: ((talking among themselves))
 11 T: S:::o yes Bong?
 12 Bong: This (is East) Park ((pointing to the projector screen))
 13 T: Ok never mind↓ Yes. Oh, ok! Did you get to see them recording?
 14 Bong: No ((shaking his head))
 15 T: Ok. Wait ah ((addressing a student who has been calling out teacher's name while raising his hand)) Anyway (0.2) why do you think the slipper (0.4) broke?
 16 Ss: ((speaking all at the same time))
 17 T: Too many of you are answering me. Ok, Grace.
 18 Grace: Glass is fragile.
 19 T: Glass is fragile. Very good!
 20 ((One student answers inaudibly))
 21 T: Sorry? ((looking at the student; student gives no response))
 22 T: Alright so because glass is fragile (.) and unfortunately alright the lovely maiden's shoe is made from glass, ok? (.) And the prince's itchy fingers (0.4) <alright held the> slippers and he was not careful↑ he let it go and it broke.
 23 Ss: ((students talking loudly among themselves))
 24 T: So ((raising her hand)) what do you think happened next? Guess what happens (0.4) Dion?
 25 Dion: I think (.) he go[es to] buy another pair.
 26 T: He will buy another pair of shoes for the lovely maiden. Ok↑
 27 ((some students talking and some raising their hands))
 28 T: Wahidah?
 29 Wahida He will make
 h:
 30 T: He will make, [alright↑ (0.4)] He will make another pair of slippers. (.) Yusuf?
 31 Bong: [I know I know] ((raising his hand, vying to be called))
 32 Yusuf: He will just fix it.
 33 T: He will just fix it with what?
 34 P: Glue=
 35 P: =super [glue!]
 36 T: [Ok super glue↑]
 37 ((students talking animatedly among themselves))

- 38 Bong: Teacher, I know! I know! The prince go take the other shoe and drop and buy another pair.
- 39 T: Ok↓ now
- 40 Ss: ((everyone laughs))
- 41 T: Let's (.) Let's see
- 42 P: Shhhhh!
- 43 T: Right, who gets it right, ok? Right now you know that.
- 44 P: Shhhhh!
- 45 T: ↑Three Flex::ibility↓ (.) ((class name)) You want to listen very carefully right?
- 46 P: Yes.
- 47 T: Ok so let's go watch the movie. ((Teacher resumes the video and students all quietly face the projector screen. After a 28 s video segment, the teacher continues with the discussion.))
- 48 T: Ok (1.0) so (.) eventually what happened? (.) The prince decided to↑=
- 49 P: =Create!
- 50 T: Create another pair of shoes, a:::nd (2.0) the prince is asking you, what's the properties of glass↓ What did you say just [now?]
- 51 Gie: [Fragile.]
- 52 T: Fragile↑
- 53 Gie: Breaka[ble]
- 54 Brian: [°hard°] ((uttered while hand raised))
- 55 T: Ok fragile and breakable↑
- 56 Brian: Hard (1.0) °hard° ((student put down his hand))
- 57 T: °Hard°. Alth::ough, remember what I said yesterday, alth::ough (0.4) somebody says glass is hard, alright it is when you ok when it fell it will definitely↑=
- 58 P: Break
- 59 T: =be broken. Yes ((moves to the computer behind her desk to control video)) Are you ready?
- 60 P: °Yes°
- 61 T: Shall I continue the story?
- 62 Ss: Yes, yes.
- 63 T: So what am I supposed to expect you people (1.0) ok. (5.0) ok? Now. ((video plays again))

While students individually brought into the classroom various everyday knowledge, the teacher arbitrated which knowledge was relevant to the task at hand. When Ling posed the question, "What's the story all about?" at the onset of the whole class discussion, Arlie answered,

“The shoe is brittle” (2). It was difficult to ascertain if Ling heard the last word of Arlie’s utterance because it was made in quite a soft tone, or if she thought it was not the appropriate description for the shoe. However, we could still ask if the adjective *brittle* is an acceptable replacement for the word *glass* that Ling validated as the correct response (5) to her complete-the-sentence question, “The shoe is made from—?” (3) In other words, can a glass material be described as being *brittle*? Evidently, Ling did not take up this issue in the turns following Arlie’s utterance.

John readily associated the story in the video to the well-known Disney classic *Cinderella*. The integration of this familiar children’s narrative into the design of the video story was intended to activate the students’ experiences outside school and reuse it as a learning platform in the classroom. John responded to this built-in video feature and must have felt confident about the narrative connection. He persisted in vying to participate in the discussion, uttering “Cinderella” more than once (6, 8) and stopping only when Ling acknowledged his expression. Ling’s question, “Who is the lady in the picture?” might have been prompted by John’s initial, eager nomination of the topic (6). Interestingly, Ling’s response, “Ok, maybe Cinderella” (7), while acknowledging the possibility of John’s identification of the heroine, also seemed to push that knowledge into the sidelines of the discussion. Instead, Ling asked the students to restrict identification of the “maiden” in terms of the video story context, asking them “Alright, what name did the prince call the lovely maiden?” No response to this question was expressed distinctly by any of the students.

Bong is an interesting case in that Ling perceived his responses as trivial and irrelevant, and thus deserving sanction. Noticing his restlessness (11), Ling called on Bong to share what it was he was eager to say. Bong said, “This is East Park” while pointing to the screen, implying that he knew the location where the video was shot. Ling dismissed outright the comment by saying, “Ok, never mind” (13) and in the same breath challenged Bong’s confident claim that he *knows* the video setting: “Did you get to see them recording?” Bong confidently resurfaced later in the classroom exchanges (31–40) with another knowledge claim, this time in answer to Ling’s prompt for them to anticipate in the forthcoming video segment playback what the prince might do now that the glass slipper is broken (22–24). Several turns after his first vigorous bid to recite (31), Bong decided to volunteer his idea, saying “The prince go take the other shoe and drop and buy another pair.” It elicited laughter from the whole class, except Ling. She just managed a smile and then called attention from the whole class, which had burst into much animated talk.

In the preceding descriptions, we have seen how Ling acted as a gatekeeper of everyday knowledge that is taken up in the public space of the classroom. Her responses (or non-responses) to some of the students' ideas ascribed degrees of relevance to the instructional agenda at hand. Some of these ideas were appraised as irrelevant and could thus be ignored, while others were only slightly irrelevant and deserved some mention during the discussion. In contrast, student expressions that Ling deemed relevant to her instructional goal were warmly complimented. For the correct response Grace made to the question "Why do you think the slipper broke?" she received the first enthusiastic affirmation from Ling: "Glass is fragile. Very good!" (19) Ling repeated the property of glass as being *fragile* twice for the rest of this Excerpt (22, 52), perhaps as a way of reinforcing the school science content knowledge the students needed to learn. Similarly, the concept that glass is *breakable* was mentioned twice (55, 59), and must therefore be relevant and important for students to remember. In fact, when Brian nominated *hard* as a property of glass (54, 56) as if to correct an inaccurate answer, Ling was quick to refer to the previous day's discussion (57) as a source of prior knowledge. Presumably, in that discussion Ling qualified the idea that while glass is hard, it is not unbreakable. As *fragile* and *breakable* are descriptors of glass found in their textbook, Ling thus manoeuvred through the discussion intent on focusing student understanding on the properties of materials as formal scientific knowledge.

This teacher-led, whole-class discussion can be categorized as a formal type of institutional conversation [22]. It is labeled "formal" as it is more restricted than those found in casual conversations, and typically involves a large number of potential participants and an audience. The features of turns in formal exchanges are closely linked to the social roles of the participants in the institutional setting. The traditional teacher/student relationship is governed by a certain protocol for engagement: students should stay on-topic (11-15), wait to be called to recite (15), speak one at a time (16, 17), pay attention (24, 64), and listen carefully (45). Students are constrained to follow these rules and there are consequences if these are undermined: they will be ignored (15) or issued a stern warning (45). In contrast, teachers are expected to lead the discussion by asking, in this instance, all of the questions, and then evaluating student responses (19, 58). Unlike informal conversations between friends (i.e., between equals), this teaching episode exhibited asymmetry in the distribution of knowledge. The teacher constantly took an evaluative frame in her questioning, making sure that the students got their facts straight and had an accurate understanding of what was presented by the knowledge source (video). In this way, the teacher positioned herself as the arbiter of knowledge in the classroom. The

question-and-answer format persisted throughout the exchange, soliciting mostly single-word or short-phrase answers from the students.

The two teachers, Ling and Feng, used the video in different ways in their respective classrooms. Unlike Ling in Excerpt 1, Feng played the entire video before commenting on it. Despite the difference in the way the information in the video was presented, the students in both classes were intrigued when the video was played, as evidenced by the students' unwavering gaze on the projector screen. Although Feng carried out structured questioning only once, Feng's checking and questioning of the students was similar in structure and function as that presented in Excerpt 1. In this teacher-directed segment, the students were reminded of the formal scientific knowledge that they had acquired earlier so that they could make use of this prior knowledge to make sense of the scenario presented in the video.

After the teacher-directed question-and-answer session, the students in both classes were subsequently divided into groups of four or five to work on the problem. The general mood of the class during the group work can be described as excited.

Students' Learning and Interaction to Solve Problems

In this section, we illustrate the following observations: 1) students' concern with the goal of task completion overwhelms their goal to build knowledge in science; 2) students demonstrate an inability to move from everyday experience and knowledge to scientific knowledge as intended as the learning outcomes of the lesson; and, 3) students lack the skill to collaboratively make decisions as a group within a classroom context. In Excerpt 2, Jill and her group members were deciding which material is most suited to make the shoe after they have examined all the materials given. Jill expressed the idea that plastic is not a suitable material for making shoes as it would break when a heavy load is added (1). She is likely to have applied her everyday experience and knowledge with using plastic bags to make this claim. After a pause of thirty seconds, she declared with excitement that Crocs™ shoes are made of rubber and hence, rubber is the best material to make their shoes. Her reference to Crocs™ shoes was evidence of her usage of decontextualised language, suggesting that she was able to think about ideas and apply knowledge that was outside her immediate environment [13]. The causal relationship that she made (1, 3) by relating the heaviness of an object to the possibility of breakage of the plastic bag suggests that she was bridging a real-life example to the idea of breakability. Crocs™ shoes are popular among many young children and teenagers in Singapore. Her suggestion was not immediately accepted by her group members, as Bill countered that rubber shoes are not

comfortable (2). Bill was also using his everyday experience, knowledge, and personal preference to justify his claim. Jill was adamant that rubber is the choice material by telling Bill that rubber is unbreakable (as compared to plastic), and hence should be used to make the shoe (3). Jill's criterion for selecting a material to make shoes is one of strength, something that would not break under weight. Without waiting for collective agreement, Jill proceeded to make changes in the group's worksheet and handed the worksheet to the teacher. Bill and the other group members did not protest or provide counterarguments.

Excerpt 2
Crocs™ Shoes

Turn	Speaker	
1	Jill:	Plastic, if you put too heavy, it will break. (30s) Crocs shoes is rubber. Crocs. No, rubber is best.
2	Bill:	It is not comfortable.
3	Jill:	No, rubber is unbreakable. Rubber is fine.

[Jill proceeded to ask the recorder in the group to change the group decision on the worksheet and submitted it to the teacher.]

Excerpt 2 demonstrated how the students' everyday knowledge, experience, and personal preferences influenced their decision making and discussion during the group work. The difference in opinion between Jill and Bill suggests that everyday experience and knowledge varies according to the individual, and is likely to be found within their personal realm of experience. Using the variety of everyday experience to make a collective decision to solve a problem and understand the properties of material would require the students to have more in-depth discussions, and understand the intrinsic properties of the materials rather than rely on their personal preferences. The short negotiation between Jill and Bill before a final decision was made could possibly suggest that the students are not familiar with using the skills of negotiation within a group setting and/or they are more concerned with completing the task at hand rather than building collective knowledge of materials suitable to make shoes.

Excerpt 3 illustrates yet another example of how the students were keen on completing the task, but were not mature enough and sufficiently competent to negotiate their ideas within the group, so that they were able to complete the task accurately and within the time frame provided. The students in this group were examining the properties of metal to determine if it

was an appropriate material to make the shoe. Paul examined the metal ruler and declared that it was unbendable. Daniel, the scribe in the group, examined the metal ruler to confirm what he needed to record in the group worksheet. Paul, who was standing behind Daniel, added that one of the properties of metal is that it is not able to absorb water (2). He got impatient and repeated the fact that metal cannot absorb water. He directed his frustration to his three other team members whom he perceived to be clowning around and not contributing to the completion of the task. He subsequently moved away from the group. After Paul moved away, Fred added that the metal ruler is a solid (3), and Noel approached the teacher to ask if the metal ruler is fragile (4).

Excerpt 3 Unbendable

Turn	Speaker
	[Holding a metal ruler]
1	Paul: It's unbendable.
	[Daniel, who is recording, starts to pick up the object and tries to bend it before recording the observation in the group worksheet]
2	Paul: It cannot absorb water. (.5) I ALREADY said it cannot absorb water. [speaking to the other three members of the group who are playing with the ruler] Everything anyhow do, anyhow do, then how to get correct huh?
	[Paul moves away from the group]
3	Fred: Solid, made of solid.
4	Noel: [asking the teacher] Is this fragile?

In Excerpt 3, the students demonstrated uncertainty as to how they could communicate and interact with each other within their groups in order to collectively negotiate an agreed upon answer on the properties of metal. With different experiences and expectations about what group work and collective decisions are, it does not help the rest of the group members who are not ready or who are uncertain about the properties to learn about them. This particular situation was exacerbated by having a frustrated group member (Paul) who was keen to complete the task, obviously ahead, and thought he was right. The different levels of knowledge (both about group work as well as scientific knowledge) among the group members can be seen (4) when Noel actually had to turn to the teacher to ask whether metal is fragile; this indicated a lack of understanding of the word “fragile” or the properties of metal.

To further illustrate the complexity of using everyday scenarios as a starting point for grade 3 students to learn the properties of materials, Excerpt 4 shows another group of students

trying to determine the property of wood so that they can determine if it is suitable for making shoes. Seth examined the block of wood given and commented that wood comes from trees and that the block of wood is hard (1). Sabrina, another member of the group, added that it is also light. Keith sought clarification (3) about the relationship between wood and trees, but this was not built on by his team members. Seth added that the wood is strong. Mike noticed that every time they recorded that something was hard, they also commented that it was strong (5), and he is not convinced by the relationship. Indeed, during the group discussion, it was evident that many students associated hardness with strength.

Excerpt 4
Strong and Hard

Turn	Speaker
[Holding a block of wood]	
1	Seth: Wood is made up of trees. It is hard.
2	Sabrina: And light.
3	Keith: This material is wood? (.2) what made up of trees?
4	Seth: It is strong.
5	Mike: Every time you write it is strong, it is hard. Crazy ah, you? [Colloquial way of speech meaning: "Are you crazy?"]

In this Excerpt, we observe how Seth, Sabrina, and Keith built on each others' ideas relating to the properties of wood (1-4). This was done through clarification (3) and stating their ideas. Mike played the role of a critic (5) by commenting that he thought it was wrong that the property of strength is almost always related to hardness. In fact, he thought that his team members were crazy to think that way. In Excerpt 4, the rest of the group eventually ignored Mike's input which is indicative that Mike was unsuccessful in convincing his group members of his point. We argue here that this is indicative of the students' uncertainty with their knowledge of the properties "strong" and "hard," and how they should be collaborating and communicating this with the members in their groups.

All the students submitted their completed worksheets to Ling, and their work was assessed based on accurate usage of scientific terms like strength and flexibility, and on the way their arguments were presented. From the completed worksheets, Ling noticed that some students used "comfortable" and "ticklish" as properties of a material. These descriptions are common everyday expressions of materials and their personal preferences, and are not part of the stable scientific language used formally to describe the intrinsic properties of materials. This

indicated that some students were unclear on how to describe the properties of materials scientifically, and hence provided descriptions that they were familiar with from their everyday experience. As Ling commented, this form of description is not aligned with the instruction objectives spelt out in the syllabus.

The difficulties of these grade 3 students to describe the intrinsic properties of the materials and then use them for making shoes suggest that for the grade 3 students to recast their everyday experience, knowledge, and preferences to a more stable and acceptable scientific knowledge and language, they needed more explicit instruction and guidance, besides being presented with a scenario within an everyday context to solve a problem. Further, the complexity of the task given suggested that younger learners of science also need more scaffolding in order to be able to distill the multiple perspectives and then present them to their peers in a convincing manner. From Excerpts 1-4, it is noted that, while these students did support their claims with evidence (for example, Excerpt 2, lines 1 and 3), that largely comes from their everyday experience. This is a good start for more in-depth discussion which will likely happen only with more time and teacher guidance. Ling decided that an extension of the lesson by using the students' answers as building blocks to shift the students' understanding of properties of materials from an everyday perspective to a scientific perspective is necessary.

Conclusion

In this article, we set out to answer the research question, "What forms of interaction occur among grade 3 students when they work in groups to solve a science problem that is based on everyday experience?" Two key forms of interaction were observed: 1) teachers used questioning to focus students' attention and achieve instructional goals; and, 2) task completion goals took priority when the students worked in groups. There is little evidence of knowledge building goals being achieved in the classrooms observed since it requires a longer period of time to achieve. Our findings in this study concurred with Bereiter's hypothesis that knowledge building goals are likely to be the most important but least often observed in classrooms as they tended to be difficult to achieve as well as to measure [12]. He argued that task completion goals and instructional goals are likely to be most evident and observable since they are short term and more easily achieved.

Analysis of group discussions among the students showed that more needs to be done to prepare the grade 3 students to engage in open-ended problem solving in science, use dialogue to recast their everyday experience and knowledge to more rule-based scientific knowledge, and use

tools like argumentation for collaborative decision making. As shown in Excerpts 2, 3 and 4, the students were unable to sustain meaningful and focussed discussions so that they could collectively agree upon the answer to their task. Their discussions were abrupt (possibly due to the constraints of curriculum time) and were often based on their personal preferences as well as emotions. While research has shown that incorporating everyday contexts in the learning of science allows for better understanding and also increased motivation in learning, the interactions observed in the grade 3 classrooms suggest that more structure and guidance are needed for students to engage in meaningful discussions of science that use everyday context as starting points [6, 7]. The movement between everyday experience/knowledge to scientific understanding is not unidirectional, but rather dialectical, and this needs to be made explicit to the students, especially younger learners [23]. However, despite the hurdles and tensions illustrated, the grade 3 students showed that they were able to engage in both contextualised and decontextualised talk to link the present and concrete (what is presented to them) to past, future, and abstract ideas. This is an important aspect in the learning of scientific knowledge as well as science literacy. Further, students' problem solving in everyday contexts helped them reflect on and bring their own experiences to the conversation, so it made their discussions richer and more contextualized. While it was evident that they lacked communication skills, the opportunity to explore with others in more collaborative ways is a good opportunity for them to learn communication skills.

As the call for curricula to shift toward context-based instruction to provide meaningful learning in science and to produce scientifically literate citizens is addressed, the findings from this research serve as a reminder that attention needs to be paid to pedagogical structures, and that readiness of the students needs to be examined before the intended goals of context-based science curricula can be fulfilled [3, 5]. There are many issues that young learners of science need to grapple with before the learning of science can be a fruitful and meaningful experience for them. As shown in Excerpts 2, 3 and 4, the students in this study spent the bulk of their time trying to figure out how they could work with their group members to complete the task. They had to convince group members to listen to their ideas and also struggled to make themselves understood. We suggest that, for young learners of science, the development of certain skills (e.g., working in a group, ways to put forth argumentation, etc.) has to be incorporated into the context-based science curriculum and be taught explicitly before the students can work in groups effectively.

Starting with everyday experience as a context for learning science offers realistic and authentic perspectives that allow students to bring in their direct experience, making classroom

discussions richer. It can, however, be seen from our research that everyday experience can be either a hindrance to learning science or it can serve as a catalyst to speed up acceptance and understanding of abstract scientific concepts. As students with different experience come to school, sharing and merging their largely local experience to become scientific knowledge that is universal involves a process of negotiation, collaboration, argumentation, and understanding [16]. These processes are all part of the scientific inquiry process to which learners of science need to be acculturated, and the integration of everyday experience not only provides a platform, but serves as a primer to facilitate discussions, conversations, and argumentation among students.

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Appendix A Key to Excerpt Dialogue Codes

[Point of overlap onset
]	Point of overlap termination
=	(a) Turn continues below, at the next identical symbol (b) If inserted at the end of one speaker’s turn and at the beginning of the next speaker’s adjacent turn, indicates that there is no gap at all between the two turns (c) Indicates that there is no interval between adjacent utterances
(3.2)	Interval between utterances (in seconds)
(.)	Very short untimed pause
<u>word</u>	Speaker emphasis
e:r the::	Lengthening of the preceding sound
?	Rising intonation, not necessarily a question
!	Animated or emphatic tone
,	Low-rising intonation, suggesting continuation
.	Falling (final) intonation
° °	Utterances between degree signs are noticeably quieter than surrounding talk
↑ ↓	Marked shifts into higher or lower pitch in the utterance following the arrow
<>	Talk surrounded by angle brackets is produced slowly and deliberately (typical of teachers modeling forms)
(guess)	Indicates the transcriber’s doubt about a word
.hh	Speaker in breath
(())	A description enclosed in a double bracket indicates non-verbal activity. Alternatively, double brackets may enclose the transcriber’s comments on contextual or other features.
T:	Teacher
P:	Unidentified student
Ss:	Several or all students simultaneously

The Journal of Mathematics and Science: COLLABORATIVE EXPLORATIONS

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PART II: REGULAR JOURNAL FEATURES

Virginia Mathematics and Science Coalition

BUILDING A CASE FOR MATHEMATICS SPECIALIST PROGRAMS

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Introduction

In 2004, the “Mathematics Specialists in K-5 Schools: Research and Policy Pilot Study” garnered support from the Teacher Professional Continuum (TPC) of the National Science Foundation (NSF). The project’s focus was to determine the effectiveness of a school-based Mathematics Specialist program in grades K-5. Preparation, deployment, and support of twenty-four Mathematics Specialists in two cohorts of 12 was at the heart of the project, utilizing well-designed research to gauge the impact on teachers who are supported by Mathematics Specialists, and on the mathematics achievement by these teachers’ students.

Unique to this grant was the specific and significant attention to a policy component. An innovative approach of utilizing a team of policy analysts to examine policy, legislative, regulatory, and funding issues regarding the establishment of Mathematics Specialist programs was utilized from the beginning. Two policy associates with extensive government relations experience in public education at the state and local division level formed the team.

As the NSF-TPC grant ramped up in the fall of 2004, the policy team composed an initial report on policy and regulatory issues, and presented it to the grant team. This first work explained the role of state policymakers and state policymaking processes, including such issues as Virginia’s education governance and policymaking structures, legislative and regulatory processes, and Board of Education (BOE) authority. It also included some analysis of the Mathematics Specialist position itself.

Included with the report was a paper describing the then-current climates of support and lack of support for a K-5 Mathematics Specialist position and a chart of existing statutory and regulatory requirements highlighting expectations for mathematics achievement on the part of

Virginia public school students. These materials showcased the tremendous degree to which public education, in general, is grounded in policy and budgeting at the state level, and to which the case for Mathematics Specialists, in particular, could be advanced by interacting with the various policymaking processes that exist in Virginia.

The two policy associates participating in the work of this project drew on grant team members' strengths, expertise and past work, as well as relationships those members had built, to advise and help steer them through the various policymaking processes to effectuate important decisions about Mathematics Specialists, and mathematics teaching and learning. This was accomplished through team members being increasingly responsive and proactive in providing useful information to key policymakers at the appropriate time in their decision-making process.

This article describes those policy-related processes and how they work "in practice" in Virginia. It also details how involvement in and interaction with these processes, led by the policy team, was undertaken successfully by the members of this Mathematics Specialist project. In addition, separate sections address the importance of keeping policymakers and the public informed about the benefits of Mathematics Specialists and the great importance of understanding the state and local government responsibilities and processes for funding public education.

State Policymakers and State Policymaking Processes

The framework for governance of public education in Virginia is set forth in Article VIII of the Virginia Constitution. Often called the "education article," the ultimate authority for the educational system to the General Assembly, it establishes a state board of education to provide general supervision of the public school system, and vests the supervision of schools in each school division with a local school board.

The General Assembly directs education policy by approving changes to the state Code and by enacting the state budget. As directed by the Constitution, it must provide for a system of free public elementary and secondary schools for all school-age children and seek to ensure that an educational program of high quality is established and continually maintained. The Board of Education (BOE) is directed to prescribe the Standards of Quality (SOQ), which define the Commonwealth's required educational program, and to recommend any changes in such to the legislature. However, the General Assembly may enact the Board's recommendations into law or revise the existing Standards, found in the *Code of Virginia* at §22.1-253.13:1-8, as it deems appropriate.

Virginia operates with a biennial budget. In even-numbered years, the General Assembly adopts a two-year revenue and spending plan, with appropriations made for programs in the first and/or second years. Almost all major budget actions are taken in the first year, though if revenue is uncertain, legislators sometimes defer appropriations until the second year for a program adopted in the first.

The budget process and consideration of legislative bills generally are on parallel tracks, as approved policy changes may necessitate the state paying all or part of the costs associated with new and revised statutes. Approved budget provisions, which may be actual appropriations or language directing an action, take precedent over statutes and thus often are the ultimate drivers of education policy. Moreover, the legislature, through the budgeting process, apportions the costs of providing the educational program meeting these standards between the state and local governments.

The BOE has the primary responsibility and authority for effectuating state educational policy, guiding public education through such functions as promulgating regulations for accrediting schools, establishing learning objectives, and setting licensure standards for teachers. The governor appoints the nine-member Board, the Superintendent of Public Instruction, and the Secretary of Education who is a member of the Cabinet. As is the Superintendent, Virginia's Secretary of Education is an advisor to the Governor on educational matters and promotes the Governor's educational policies. The Governor, however, has considerable influence over public education policy largely through his management of the state's budgeting process.

The Constitution and the *Code* provide that the supervision of schools in each school division shall be vested in a school board. Specific school board powers and duties are stipulated in the *Code* at §22.1-79. In particular, this section states that a school board shall, insofar as not inconsistent with state statutes and BOE regulations, operate and maintain the public schools in the school division. As mandated by the SOQ, school boards have great responsibility for meeting the educational needs of diverse student populations by implementing various instructional programs, providing support services, assessing student progress and achievement, and providing support, training, and professional development for school personnel.

State policy in many program service areas, including public education, also is shaped through a defined regulatory process. State regulations in large part direct the operation of Virginia's state agencies and the programs and entities affected by the actions of such agencies.

Such regulations must be authorized by law, and they carry the force of the law. The Virginia Administrative Process Act (APA) provides the basic framework for this regulatory rulemaking, setting out the stages of the regulatory process, including notice and opportunity for public comment. Typically, each regulatory action goes through a mandatory three-stage process constructed to ensure the public has ample opportunity to participate, and that all perspectives are considered in the development of a final regulation.

The formation of education policy in Virginia often is a very deliberative process, with significant changes sometimes taking years to be realized. It is common practice for the General Assembly to establish legislative or agency studies to examine new, ongoing, or divisive issues. That process rarely is rapid and recommendations are not necessarily considered in a timely manner. Therefore, the push for significant policy changes more often than not languishes until advocates muster significant legislative interest in the issue to try again.

Recent State Policy Actions

Over the course of the TPC grant's five years (2004-2009), state policymakers approved a number of actions that are telling both in substance and in the expression of support and confidence these leaders place on the work and value of Mathematics Specialists. The most significant include the following actions:

- **Licensure Regulations**—The 2005 General Assembly approved SJR 428, which requested the BOE to include a Mathematics Specialist endorsement in its revisions to the *Virginia Licensure Regulations for School Personnel*. The BOE finalized the Mathematics Specialist for elementary and middle education add-on endorsement as part of the licensure regulations that took effect in 2007.
- **Public Commendation**—The General Assembly approved HJR 258 in 2006, which commended local school boards employing Mathematics Specialists.
- **Legislative Study**—HJR 25, also approved in 2006, established a joint subcommittee to study mathematics, science, and technology education in the Commonwealth.
- **Budget**—The 2007 General Assembly provided one-time funding of \$150,000 for salary support for certain grant-supported Mathematics Specialists so that an additional year of data could be obtained.
- **Standards of Quality for Public Education**—At the request of the BOE, the General Assembly amended the SOQ in 2007 to require school divisions to identify and assist students having difficulties in mathematics.

How Outreach, Awareness, and Advocacy Influenced Successful Outcomes

For each of these successful actions, the grant management team, members of Virginia Mathematics and Science Coalition (VMSC), and partner school divisions, their school board members and staffs all deserve credit for effectuating the positive outcomes. Success was achieved through a series of communications and outreach, awareness-building and advocacy activities, many initiated by the grant team and others undertaken as proactive responses.

These activities essentially constituted a sustained campaign over several years. Indeed, it was critical that they be ongoing and focused, due to the previously noted lengthy processes in Virginia to effectuate change in policies. Over time, these efforts and the outcomes they produced met the intended goal to increase support for the key role that Mathematics Specialists play in improving student learning in mathematics, while building awareness of their growing use and benefit.

Throughout the course of the five-year period, grant team members acted on information and encouragement from the policy associates to do the following: 1) proactively participate in specific state policy-shaping activities, including the introduction of legislation and budget initiatives, and advocacy before the BOE; 2) seize upon opportunities to provide evidence of the benefits of implementing Mathematics Specialist programs in ways that were credible to mathematics educators and policymakers at all levels; and, 3) build awareness and support for Mathematics Specialists throughout the education community which in turn could inform and influence state policymakers. For each of these successful policy actions, let's take a closer look at various strategies and approaches that were instrumental in bringing about desired outcomes. These activities, while specific to Virginia in their details, may serve as models for other advocates to undertake when opportunities are afforded in their education policy environment.

State Regulations: Licensure Regulations for School Personnel — In 2005, the General Assembly approved SJR 428, which requested the BOE to include a Mathematics Specialist endorsement in its upcoming revisions to the Virginia Licensure Regulations for School Personnel. The BOE then created the Mathematics Specialist for elementary and middle school education add-on endorsement as part of the regulations that took effect in 2007.

Background: The Virginia Mathematics and Science Coalition (VMSC) was an early advocate for this licensure endorsement for educators. In 2002, amidst growing research and evidence

linking student outcomes with teacher quality, it convened a task force to research and report to the Virginia education community how a “Teacher Specialist” would improve student learning. Its charge was to examine job description, competencies, preparation, and licensure of such specialists. The Task Force observed that “Virginia teachers and administrators reported to the Task Force that ongoing, site-based assistance is necessary to adequately support teachers in the change process. One way to provide this sustained support is to develop and maintain a cadre of Mathematics Teacher Specialists who can offer meaningful and consistent site-based guidance to their colleagues.” The group focused its work and findings on the roles and responsibilities of a school-based Mathematics Specialist, the importance of state licensure, and the necessity of quality preparation programs [1].

In June 2003, the BOE’s Advisory Board on Teacher Education and Licensure (ABTEL) proposed revisions to the licensure regulations that included a proposal to establish a Mathematics Specialist endorsement for both elementary and middle school education. Responding to the VMSC work and ABTEL recommendation, the BOE approved the following resolution:

It is the intention of the Board to proceed forthwith on establishing criteria for the new licensure endorsement of Math Specialist. It is the Board’s further intention that upon the completion of the process of establishing the Math Specialist endorsement, the Board will recommend the inclusion in the SOQ of Math Specialists at an appropriate ratio to be determined by the Board.

The BOE was continuing to review and discuss the overhaul of the licensure regulations (following some delay due to ongoing implications with the then-recently implemented federal No Child Left Behind legislation) when the General Assembly adopted SJR 428 requesting the Board to include an endorsement for Mathematics Specialist in that regulatory revision. Revised regulations that took effect September 21, 2007, and that remain current, contain a Mathematics Specialist endorsement. The endorsement requires either graduation from an approved master’s degree-level Mathematics Specialist preparation program or completion of a master’s degree-level program in mathematics, mathematics education, or a related field including at least twenty-one content hours in undergraduate or graduate-level mathematics. Corresponding *Regulations Governing the Review and Approval of Education Programs* that similarly were approved, address the same coursework competencies as highlighted in the endorsement section (knowledge, skills, application, history, technology), and speak to the school-based Mathematics Specialist as a resource in professional development, instructing children who have learning

difficulties in mathematics, curriculum development and implementation, mentoring new teachers, and parent and community education.

Policy Team and Management Team Activities: The grant management team continuously advocated, through communication with BOE members and Department of Education (DOE) officials, for the inclusion of a Mathematics Specialist endorsement in the licensure regulations. Members built relationships with BOE members and DOE staff during the early work of the Task Force, disseminated results of the Task Force report, and provided letters of support and testimony at BOE hearings.

In advancing the General Assembly resolution, members of the grant management team drafted the resolution, requested it be introduced by a legislator who at the time was the VMSC chairman, and solicited support for it in the education community. The policy team monitored and reported on its progress to passage by the General Assembly. The VMSC solicited support of SJR 428 via letter to local school divisions in late 2004, prior to the convening of the 2005 General Assembly. During the legislative session, talking points in support of the resolution and several letters of endorsement were distributed to legislators.

Commending Legislative Resolution — The General Assembly approved HJR 258 which commended local school boards employing Mathematics Specialists.

Background: At the request of the VMSC, the Speaker of the Virginia House of Delegates introduced a resolution commending Virginia school boards that employ Mathematics Specialists in order to increase student mathematics achievement by increasing the quality of mathematics instruction. The resolution directed:

...[the preparation of] a copy of this resolution for presentation to the Virginia Mathematics and Science Coalition, requesting that it further distribute copies of this resolution to the respective school boards as an expression of the General Assembly's admiration and support for their commendable initiatives directed at improving both instruction and achievement in mathematics [2].

The resolution was approved on voice votes by both the House of Delegates and Senate in February 2006. Thus, the General Assembly provided a "thumbs up" to those school divisions

implementing Mathematics Specialist programs, while also signaling to others that they look at the implemented models for establishment in their own schools.

Policy Team and Management Team Activities: The policy team suggested and drafted the resolution for the Speaker of the House that was submitted, and during the course of the legislative session, monitored and reported on its progress to passage by the General Assembly. Following approval of the resolution, the VMSC distributed copies, as requested, to local school boards, as well as to other K-12 education stakeholders. The grant team viewed this policy team recommendation as an effective way to draw legislators' attention to Mathematics Specialists, as well as to provide some recognition to local school divisions employing Mathematics Specialists, with the desire that some of their peers take notice and explore such programs themselves.

Joint Legislative Study — The General Assembly approved HJR 25 which established a joint subcommittee to study mathematics, science, and technology education in the Commonwealth.

Background: In 2006, the legislature approved HJR 25, which established a two-year joint subcommittee to study mathematics, science, and technology education in the Commonwealth at the elementary, secondary, and undergraduate levels. The resolution, which was approved unanimously, noted the importance of ensuring “that the curricula of Virginia's public schools provide an adequate foundation for students to pursue and continue successful studies of science, math, and technology at institutions of higher education.” The fourteen-member panel was charged with, among other things, reviewing and recommending “innovative ways to interest students at all education levels in science, math, and technology” [2].

The HJR 25 subcommittee membership included two citizen members, one designated by the resolution to be “a professor of mathematics-, science-, or technology-related courses at a state institution of higher education.” Acting on the policy team's suggestion, the VMSC nominated one of its members to be part of the HJR 25 subcommittee, and the Senate Rules Committee appointed this nominee to the panel. The VMSC closely followed the work of the panel, providing oral and written information about the efficacy of Mathematics Specialists. At the conclusion of its two-year stint, the study committee was continued for an additional year.

Policy Team and Management Team Activities: The policy team also monitored and reported on the progress of the HJR 25 study committee's work and legislative recommendations. The

first two legislative recommendations of the HJR 25 study (in 2007) directly supported teacher mathematics education and the employment of Mathematics Specialists. The first recommendation would qualify students agreeing to teach in a mathematics or science field for the Virginia Teaching Scholarship Loan Program; the second would create a pilot program to provide grants to six school divisions to hire an elementary Mathematics Specialist. These two recommendations were introduced during the 2008 General Assembly as HB 1165 and HB 984, respectively. Although these recommendations were not approved by the legislature, legislators were hearing Mathematics Specialists discussed more frequently.

State Budget — In 2007, the General Assembly-approved budget provided one-time funding of \$150,000 for salaries of certain grant-supported Mathematics Specialists so that an additional year of data could be obtained. In 2009, the budget included flexibility in the use of state funds to hire Mathematics Specialists.

Background: The chairman of the House Education Committee (who represents one of the project's partner school divisions), and a member of the Senate Finance Committee (who is a former VMSC chairman) each proposed a policy team-drafted amendment to the state budget. This amendment provided the five partner divisions a \$25,000 allocation for each of the Cohort I Mathematics Specialists that the divisions continued to employ in their then-current positions for the 2007-2008 school year. The \$25,000 NSF fund allocation to the partner divisions for the first twelve Mathematics Specialists was provided only for 2005-2006 and 2006-2007.

As part of the budgeting process previously explained, the House of Delegates and the Senate each prepare their own version of the budget, which then is negotiated by a team of senior legislators to reach a compromise spending plan for a given two-year period. In this particular case, the \$25,000 amendment was included in the House version of the budget, but not in the Senate plan. The compromise on this particular item was the approval of a \$12,500 one-time allocation for each Specialist, or half the amount requested. Still, the inclusion of any funding for the Mathematics Specialist cohort was deemed a major victory, as state budget writers were convinced that the research being conducted and the impact of Mathematics Specialists on student learning was of significant importance.

In a year of diminishing funding for public education at both the state and local levels, state policymakers in 2009 displayed their belief that Mathematics Specialists are effective, as the legislature and governor sought to provide authority for school divisions to flexibly use several

existing funding sources to hire Mathematics Specialists to provide intervention services. Two of these legislative efforts succeeded.

First, the governor's proposed budget for 2009-2010 contained language to allow school divisions to use state *Standards of Learning (SOL)* Algebra Readiness Initiative Funds to employ state-endorsed Mathematics Specialists to provide intervention services. The budget ultimately approved included this provision, which had been initiated by the BOE and endorsed by the State Superintendent of Public Instruction (the language also was included in the approved budget for FY11 and FY12). Second, HJR 652 (which was a 2008 recommendation of the HJR 25 study committee and which passed unanimously), requested school divisions "to consider using existing intervention, remediation, and at-risk funding to hire K-8 Mathematics Specialists as an effective means to improve the performance of low-achieving students."

It is worthy to note that a survey by the Department of Education (Summer 2009) found that 44% of the eighty-five school divisions responding (37 divisions) reported employing Mathematics Specialists in 2009-2010. Of those responding, 29% indicated they were employing Specialists with local funds, while 25% indicated use of federal funding. State funding from existing intervention, remediation, and at-risk funding was cited by 18%. In addition, 21% of those who responded indicated they utilized Algebra Readiness Initiative Funds.

Policy Team and Management Team Activities: The policy team reached out to the two legislators to request submittal of the budget amendments, and outlined a plan for local school superintendents to lobby their legislators on this budget amendment. An initial letter was sent to superintendents and mathematics supervisors in the affected divisions prior to the start of the General Assembly to request that they contact state lawmakers to support the amendments. During the legislative session, they again were encouraged to phone and e-mail members of the budget committees that were considering the proposed amendments. Position papers explaining and supporting the amendments also were distributed to the committee members, staff, and budget negotiators throughout the budget development process. Following budget approval, thank-you letters were sent to the two legislative patrons. This amendment led to an unexpected third year of collection and analysis of PDA data from the Cohort I Specialists.

The policy team also monitored progress of the Speaker of the House's independently proposed budget item to provide state funding for elementary school Mathematics Specialists in a school division he represents. While the amendment itself was not approved, the proposal was a

testament to his belief in the value of Mathematics Specialists, having witnessed first-hand their potential in one of the grant's partner school divisions. It also helped set the stage for the successful grant-initiated budget amendment.

Code of Virginia/Standards of Quality — The legislature amended the Standards of Quality to require school divisions to identify and assist students having difficulties in mathematics.

Background: As previously noted, it is a duty of the BOE to prescribe the Standards of Quality (SOQ) for review and revision by the General Assembly. Beginning with the review required in 2003, the Board has utilized an open, public process to consider changes to the SOQ. It established a standing Committee on the Standards of Quality, which holds regular meetings to deliberate potential SOQ changes and where public involvement is invited and encouraged.

The BOE indicated in 2006 that it would prepare a package of recommended changes to the SOQ for submittal to the 2007 General Assembly session. The grant team submitted a letter to the BOE and State Superintendent, which noted:

Much is known about how students learn mathematics and, with appropriate learning strategies, many more students can be successful in mathematics than is currently the case. Accordingly, we encourage the Board to include mathematics as an area where it is crucial to identify student needs at the earliest time.

The VMSC had presented a similar case and recommendation to the Board in 2004. This time, the Board seized upon this recommendation and included in its package language to direct local school boards to identify and diagnose students having difficulties in mathematics and to implement appropriate strategies practices to assist them.

In addition, the Board had proposed a new required staffing standard requiring the employment of one Mathematics Specialist per 1,000 students in grades K-8. The Board held ten public hearings across the state to solicit input on its SOQ proposal. The language and staffing standard items were included in the proposal submitted to the General Assembly, and introduced by the chairmen of the respective education committees. The SB 795 was the legislative vehicle for the SOQ changes that advanced through the legislative process. While all new staffing standards, including the K-8 Mathematics Specialist, were removed from the bill, the language amendment on early identification and assistance was included in the final, approved version of

the bill (previously, the SOQ had required such interventions only for students having difficulty with reading).

Policy Team and Management Team Activities: Concerning the SOQ changes, VMSC members on several occasions provided oral and written testimony advocating the following: 1) a requirement that local school divisions identify, diagnose, and assist students having difficulty with mathematics; and, 2) the concept of employing Mathematics Specialists in elementary schools. Remarks were made at a meeting of the Board's SOQ subcommittee (by invitation in July 2006) and submitted during the public hearing and comment period on the BOE's proposed revisions to the SOQ. The successful language amendment may be viewed as a "sleeper" amendment, as it establishes in the *Code* the importance of addressing underachievement in mathematics. In brighter fiscal days, it might be used to obtain state financial or other support for Mathematics Specialists.

Following inclusion of the one Mathematics Specialist per 1,000 students provision in the BOE recommendations, the VMSC sent a letter to the BOE President and the State Superintendent proposing establishment of a work group to examine issues surrounding implementation of such a requirement. Specifically, the letter proposed working with other stakeholders to address challenges to and develop scenarios for implementation of the staffing recommendations (the work group was not formed, as the one Specialist/1,000 was not approved).

Building the Case

Over the course of the grant period, numerous other activities recommended by the policy team were undertaken by the grant team with the goal of raising awareness of and support for Mathematics Specialists. These upbeat efforts were viewed as prime opportunities to sensitize and invigorate targeted audiences to the influential work of Mathematics Specialists:

- 1) The VMSC wrote commending letters to the relevant local and state elected officials upon the Norfolk community's winning the 2005 Broad Prize for Urban Education, awarded annually to one outstanding urban school district for increased achievement. Norfolk Public Schools, which at the time employed a Mathematics Specialist in each of its thirty-five elementary schools, had made impressive gains in mathematics achievement in its elementary and middle schools over the previous four years.

- 2) The VMSC submitted a proposal to make a presentation regarding Mathematics Specialists during the round-table portion of the Virginia School Boards Association's educational conference in Richmond in July 2005. The VSBA accepted the VMSC proposal, and the presentation was made.
- 3) Publishable articles were prepared by the policy team and specifically tailored for use by the elementary and secondary school principal associations in Virginia, as well as the school superintendents association. All versions focused primarily on the findings of parallel utilization interviews conducted by the policy team with the principals of each elementary school where Cohort I Mathematics Specialists were placed.
- 4) The grant team developed a one-page information sheet about the state of Mathematics Specialists in Virginia (2006). The paper explained preparation efforts at six state institutions of higher education and highlighted employment practices around the state. It also included the text of the HJR 25 resolution that commended local school boards employing Mathematics Specialists. The one-pager was used in various outreach activities, including widespread distribution in the K-12 and higher education communities.
- 5) On several occasions, the VMSC advocated that the BOE amend its *Regulations Establishing Standards for Accrediting Public Schools (SOA)* in Virginia, both prior to and after approval of the SOQ requirement for identification, diagnosis, and assistance for students having difficulty with mathematics.
- 6) A second one-page information sheet was developed in the summer/fall of 2009 to highlight grant research findings that Mathematics Specialists, over time, are having a significant impact on student achievement, and that Virginia preparation programs for Mathematics Specialists are of high quality. This paper also was widely distributed in the K-12 and higher education communities, as well as to BOE members and key legislative members and their staffs.

Follow the Money

As previously noted, the state budget often is the ultimate driver of education policy, as the legislature must provide state general fund dollars to support public education through the budgeting process and apportion the costs of providing an educational program between the state and local governments. It is helpful to examine these duties more closely to understand the challenges of paying for Mathematics Specialists.

While Article VIII, § 1 of the Virginia Constitution brands the General Assembly as the entity responsible for the establishment of public education in the state, Article VIII, § 2 speaks to fiscal authority. The 1971 revision to the Constitution added the following language stipulating that, while the General Assembly would apportion costs, responsibility for funding public schools would be shared with localities:

The General Assembly shall determine the manner in which funds are to be provided for the cost of maintaining an educational program meeting the prescribed standards of quality, and shall provide for the apportionment of the cost of such program between the Commonwealth and the local units of government comprising such school divisions. Each unit of local government shall provide its portion of such cost by local taxes or from other available funds [3].

State budget policy and process has significant, direct effects on local government. Local governing bodies, established by statute in Title 15.2 of the *Code*, have the “power of the purse,” as they control the funding of the state-required local portion of the SOQ and any additional items the local community deems necessary for a quality education. When the legislature adopts and funds new education initiatives, adopts and does *not* fund new initiatives, or reduces or eliminates state education funding, there are reverberations at the local level.

It is the legislature’s current practice that, overall, the state assume 55% of the statewide costs of funding the SOQ, leaving 45% of the funding to be provided collectively by the local governments. The state provides more funding to school divisions judged less capable to fund education locally than it does to those school divisions judged more able to provide local resources. These adjustments are provided through a complex and increasingly controversial formula that measures the local ability to pay—the local composite index (LCI). The LCI ranges from .2000 at the less affluent end to .8000 at the more affluent. A locality with an LCI of .2000 receives 80% of required SOQ expenditures from the state and is responsible for the remaining 20%; a local government with an index of .8000 receives 20% of its required expenditure from the state and must provide the other 80%. Thus, for example, an SOQ-mandated position estimated by the state to have an annual cost of \$36,000 requires those divisions with an index of .2000 to come up with \$7,200 in local dollars and those with an index of .8000 to find \$28,800 in local funds. For the 2010-2012 biennium, nearly 80% of the Commonwealth’s school divisions have an index below .5000.

Another funding controversy rages between the state and local governments over whether the state properly calculates the actual cost of providing the SOQ program. Local governments generally believe that the state understates the true costs of providing a public education, thus minimizing state costs at the expense of localities, chiefly through its approach to funding teacher salaries and school construction. The state recognizes salary and other operating costs in the SOQ based on “reasonable” costs, which usually are lower than a school division’s actual salary expenditures, and has played a minimal role over the years in providing dollars for local school facility needs.

In addition to providing direct aid for public education through funding the mandated SOQ, in the past the legislature provided incentive funding to offer optional money for certain educational programs it espouses. Under this incentive scenario, local school divisions received state funding for certain programs or initiatives if they matched the available state funding with required amounts of local dollars. In more recent years, as budget and revenue shortfall challenges have necessitated reductions in public education funding, the state has turned to consolidating funding streams and funding more programs with dollars allotted to education from state lottery revenues.

State dollars for education will be dwindling in the near future. While public education largely was sheltered from major funding reductions in 2008 and 2009, state funding for at least the next two years was sharply reduced. State general funds budgeted for public education fell from just under \$6.3 billion for FY10 to a projected \$5.5 billion for FY11, a three-quarters of a billion dollar decrease (*2010-2012 Appropriations Act*). General Assembly budget writers resigned themselves to the fact that reductions would have to occur, given that state dollars for schools make up over one-third of the entire state general fund budget. Moving forward over the next several years, the state will continue to face tough fiscal choices, and likely will be hard pressed to increase public education funding in the face of pressures to also adequately address other priorities and program service areas.

While state policymakers have demonstrated that they recognize the value of Mathematics Specialists, and local policymakers are convinced and confident about the value of the in-school coaching model that Mathematics Specialists bring to improving mathematics achievement, both acknowledge that the major obstacle to expanded hiring of Mathematics Specialists is insufficient state and local funding. Local policymakers do not want a mandate to employ Mathematics Specialists, as paying the required local share for these more expensive employees is costly to

localities, especially as budgets are being reduced, not enhanced. Further, any such mandate could possibly set required employment ratios at levels that do not match local needs across more than 130 local school divisions. Likewise, state policymakers are challenged by the numbers, as the estimated state cost (FY10) of one full-time Mathematics Specialist for each 1,000 students in grades K-8 was estimated at \$28.6 million (local costs were estimated to be slightly lower at \$22.8 million) [4].

Conclusion

Providing credible, useful, and timely information to policymakers for decisions concerning implementation of Mathematics Specialist initiatives during the course of this project was rewarded by those policymakers taking actions to enforce and support the benefits of implementing Mathematics Specialist programs. The key to success was using information about policy issues for implementing Mathematics Specialist initiatives to engage policymakers, the education community, and the public in dialogue to create an awareness of and stronger support for not only Mathematics Specialists, but also public education in general.

The policy associates educated the project team members in education policymaking in Virginia, found opportunities for advancement, identified the pitfalls, and initiated strategy discussions for the purpose of engaging policymakers effectively. While the process “tools” may differ from state to state, a winning formula to effectuating policy goals should include effectively interacting with and utilizing the processes at hand. Patience is also a virtue.

Acknowledgment

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RIGHT TRIANGLES OF GIAN FRANCESCO MALFATTI

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Introduction.

Every triangle circumscribes a unique triple of circles, each of which is tangent to the other two. Figure 1 shows a right triangle which circumscribes three circles as described.

B

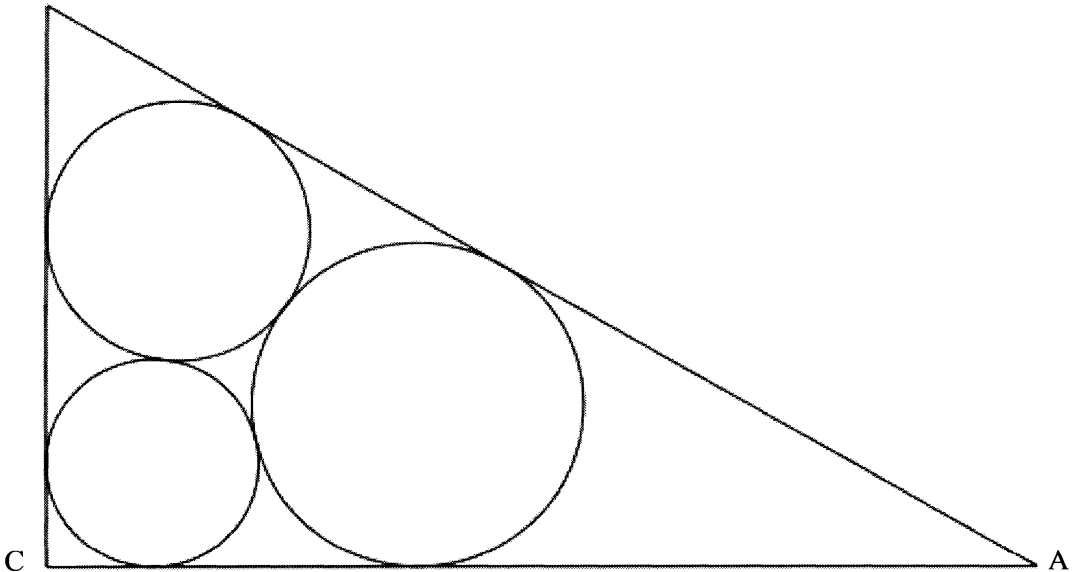


Figure 1. Right triangle with its circles.

Such circles are named Malfatti circles to honor the Italian mathematician Gian Francesco Malfatti who, in 1803, wrongly conjectured that the greatest area that can be bounded by three circles drawn within any triangular region is the area contained by the three Malfatti circles of the triangle. Using the search engine *Google*TM to search for "3 circles in a triangle" produced an enormous amount of information about the geometry of triangles and their Malfatti circles. Thus, it should be clear that no startling contributions to the subject are to follow.

Motivation

To this mathematics teacher, the most interesting problems are those that arise naturally from the material that he is teaching, that are easy to pose, and that quickly lead from the familiar to mathematical places new to him. So it was that the teacher (i. e., the author of this article)

wondered how to write a program with *Mathematica* to create a figure like the one above. It was obvious that he needed to locate his triangle in the xy -plane and then to find the coordinates of the centers and the lengths of the radii of the three circles. Figure 2 shows the triangle above with the addition of the centers of the circles and the radii to the points of tangency between the circles and the sides of the triangle.

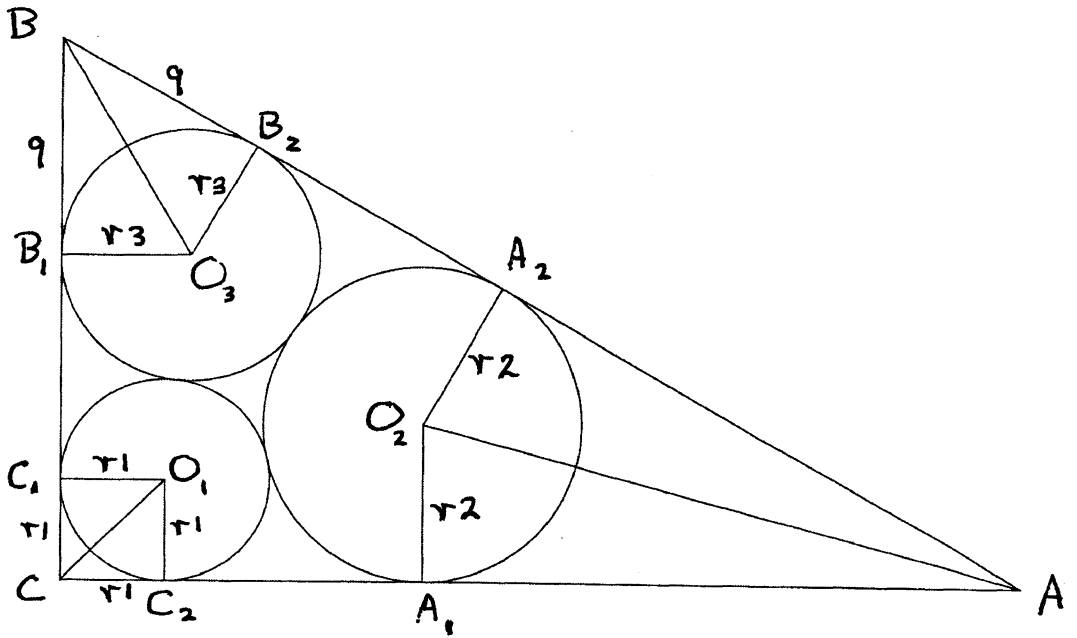


Figure 2. Right triangle with its Malfatti circles.

Facts from Grade 9 Geometry

The notation used in the statements that follow is derived from Figure 2. Although summer will remove many of these statements from the rising grade 10 memory, the facts and ideas with which the statements are concerned were once current and familiar in grade 9 geometry class. The centers of the three circles are O_1 , O_2 , and O_3 and the corresponding radii are r_1 , r_2 , and r_3 .

- 1) Tangent segments AA_1 and AA_2 have the same length. In this case, $AA_1 = AA_2 = p$. Also $BB_1 = BB_2 = q$ and $CC_1 = CC_2 = r_1$. Note that CC_1 and CC_2 will also have the same length, but that length is the same as radius r_1 only because angle ACB is a right angle.

2) Rays AO_2 , BO_3 , and CO_1 bisect their angles BAC , ABC , and BCA , respectively.

3) $B_1 C_1$, $A_1 C_2$, and $A_2 B_2$ are common external tangents for their circles and have lengths $2\sqrt{r_1 * r_3}$, $2\sqrt{r_1 * r_2}$, and $2\sqrt{r_2 * r_3}$, respectively.

If one starts with a correctly given triple of parts that determines the congruence of triangles, one (in theory) ought to be able to compute the radii and the coordinates of the centers of the Malfatti circles of a triangle. If a triangle is a right triangle as shown in Figure 6, one can write five equations which, when solved, will supply the information needed to write the program to create the figure. Under the assumption that triangle ABC of Figure 2 is a right triangle with all sides and angles known, these five equations hold true:

$$\begin{aligned} p + q + 2\sqrt{r_2 * r_3} &= AB, \\ r_1 + p + 2\sqrt{r_1 * r_2} &= AC, \\ r_1 + q + 2\sqrt{r_1 * r_3} &= BC, \\ \tan(\angle A/2) &= r_2/p, \text{ and } \tan(\angle B/2) = r_3/q. \end{aligned}$$

If the triangle is taken to represent the general case, six equations are required and an enormous amount of algebra is necessary to achieve a solution. Goldilocks might have said, "The general triangle is too hard and the equilateral triangle is too easy. The right triangle is just right."

Malfatti Circles in Right Triangles

Grade 9 geometers at the top of their game should understand the thinking that went into the five equations above. Even though the difficulty of the Malfatti circles in a right triangle is "just right", the algebra involved in solving the five equations is still quite challenging. However, *Mathematica* can do the algebra as well as draw the figures.

Here are two examples to argue the richness of the blend of analytic geometry and technology in problems on Malfatti circles.

Example 1. Find the radii and centers of the Malfatti circles in a 30° - 60° - 90° right triangle with sides of lengths 5, $5\sqrt{3}$, and 10 units. Then, draw the triangle with its circles.

Solution. Since a figure is needed in explaining the solution, it makes sense to place the cart before the horse in this instance. So here is $\triangle ABC$ with right $\angle C$ in Figure 3; the program for creating the figure will follow.

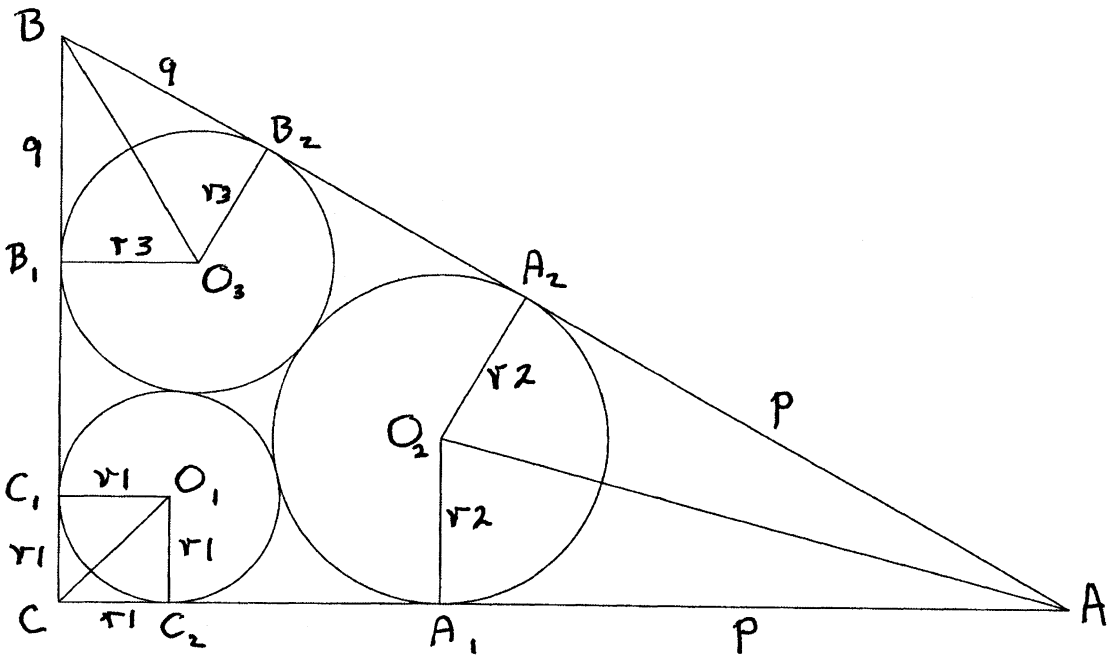


Figure 3. A 30° - 60° - 90° right triangle.

In ΔABC , $\angle A = 30^\circ$, $\angle B = 60^\circ$, and $\angle C = 90^\circ$ with $AB = 10$, $AC = 5\sqrt{3}$, and $BC = 5$. The five equations written in the symbols developed above are:

$$\begin{aligned}
 p + q + 2\sqrt{r_2 * r_3} &= 10, \\
 r_1 + p + 2\sqrt{r_1 * r_2} &= 5\sqrt{3} \\
 r_1 + q + 2\sqrt{r_1 * r_3} &= 5, \\
 \tan(\angle A/2) = \tan(30^\circ/2) &= r_2/p = 2 - \sqrt{3}, \text{ and} \\
 \tan(\angle B/2) = \tan(60^\circ/2) &= r_3/q = 1/\sqrt{3}.
 \end{aligned}$$

The last two equations may be rewritten as $p = (2 + \sqrt{3}) r_2$ and $q = \sqrt{3} r_3$. Substitution of these expressions for p and q in other equations leaves only the following three equation to be solved for the radii:

$$\begin{aligned}
 (2 + \sqrt{3})r_2 + \sqrt{3} r_3 + 2\sqrt{r_2 * r_3} &= 10, \\
 r_1 + (2 + \sqrt{3})r_2 + 2\sqrt{r_1 * r_2} &= 5\sqrt{3}, \text{ and} \\
 r_1 + \sqrt{3} r_3 + 2\sqrt{r_1 * r_3} &= 5.
 \end{aligned}$$

Mathematica gives the speedy numerical solution $r_1 = 0.928434$, $r_2 = 1.44996$, $r_3 = 1.15499$. Figure 4 lists the instructions which lead to the solution. It follows that $p = (2 + \sqrt{3})r_2 = 5.41131$ and $q = \sqrt{3}r_3 = 2.0005$.

```
NSolve[{(2 +  $\sqrt{3}$ )r2 +  $\sqrt{3}$  r3 + 2 $\sqrt{r_2 * r_3}$  == 10,
  r1 + (2 +  $\sqrt{3}$ ) r2 + 2 $\sqrt{r_1 * r_2}$  == 5 $\sqrt{3}$ , r1 +  $\sqrt{3}$  r3 + 2 $\sqrt{r_1 * r_3}$  == 5},
{r1, r2, r3}]
{{r1  $\rightarrow$  0.928434,    r2  $\rightarrow$  1.44996,    r3  $\rightarrow$  1.15499}}
```

Figure 4. Instructions for finding the three radii with *Mathematica*.

If the coordinates of the vertices of the triangle are taken to be $(5\sqrt{3}, 0)$ for A, $(0, 5)$ for B, and $(0, 0)$ for C, reference to Figure 3 will reveal the coordinates of the centers of the circles. The coordinates of O_1 are $(r_1, r_1) = (0.928434, 0.928434)$, the coordinates of O_2 are $(5\sqrt{3} - p, r_2) = (3.24894, 1.44996)$, and the coordinates of O_3 are $(r_3, 5 - q) = (1.15499, 2.9995)$. Now that the coordinates of the centers and radii of the three circles have been computed, all input information needed for *Mathematica* to draw the 30° - 60° - 90° right triangle with its Malfatti circles is available. Here is the program that produced Figure 3:

```

r1 = 0.928434; r2 = 1.44996; r3 = 1.15499;

q =  $\sqrt{3}$  1.1549879938480403
2.0005

5 - q
2.9995

p =  $(2 + \sqrt{3}) * 1.44995658969149$ 
5.41131

5  $\sqrt{3}$  - p
3.24894

list1 = {{0, 0}, {5  $\sqrt{3}$ , 0}, {0, 5}, {0, 0}};
plot1 = ListPlot[list1, PlotJoined -> True,
  AspectRatio -> Automatic, PlotStyle -> GrayLevel[0], Axes -> False];
list2 = {{r1, 0}, {r1, r1}, {0, r1}, {0, 0}, {r1, r1}};
plot3 = ListPlot[list2, PlotJoined -> True,
  AspectRatio -> Automatic, PlotStyle -> GrayLevel[0], Axes -> False];

list3 = {{0, 5 - q}, {r3, 5 - q}, {r3 (1 + 1/2), 5 - q + r3 *  $\sqrt{3}$  / 2}};
plot4 = ListPlot[list3, PlotJoined -> True,
  AspectRatio -> Automatic, PlotStyle -> GrayLevel[0], Axes -> False];
plot5 = ListPlot[{{0, 5}, {r3, 5 - q}}, PlotJoined -> True,
  AspectRatio -> Automatic, PlotStyle -> GrayLevel[0], Axes -> False];
plot6 = ListPlot[{{5  $\sqrt{3}$  - p, r2}, {5  $\sqrt{3}$ , 0}}, PlotJoined -> True,
  AspectRatio -> Automatic, PlotStyle -> GrayLevel[0], Axes -> False];

list4 = {{5  $\sqrt{3}$  - p, 0}, {5  $\sqrt{3}$  - p, r2}, {{5  $\sqrt{3}$  - p} + r2 / 2, r2 (1 +  $\sqrt{3}$  / 2)}};
plot7 = ListPlot[list4, PlotJoined -> True,
  AspectRatio -> Automatic, PlotStyle -> GrayLevel[0], Axes -> False];
plot2 = ParametricPlot[{{.928434 (1 + Cos[t]), .928434 (1 + Sin[t])}, {3.24894 + 1.44996 Cos[t],
  1.449969 (1 + Sin[t])}, {1.15499 (1 + Cos[t]), 2.9995 + 1.15499 Sin[t]}},
  {t, 0, 2  $\pi$ }, PlotStyle -> GrayLevel[0], Axes -> False];
Show[plot1, plot2, plot3, plot4, plot5, plot6, plot7]

```

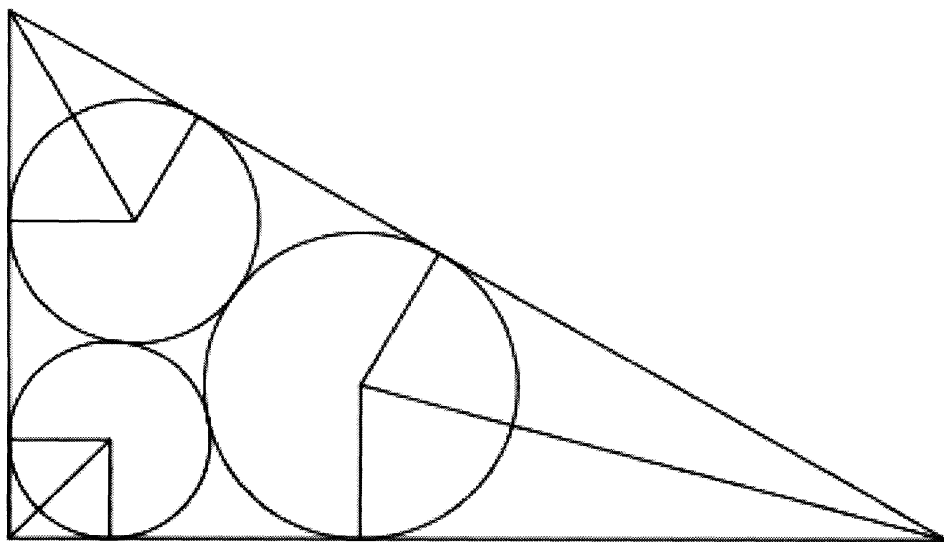


Figure 5. Program for the 30° - 60° - 90° right triangle.

Here is the second example. Since it involves an isosceles right triangle, it is quite a bit simpler than the first example.

Example 2. Find the radii and centers of the Malfatti circles in a 45° - 45° - 90° right triangle with sides of lengths 10, 10, and $10\sqrt{2}$. Then, draw the triangle with its circles.

Solution. Here is $\triangle ABC$ with right angle at C as shown below in Figure 6. The notation is the same as that in Figure 3, but the symmetry of the isosceles triangle offers significant simplifications. Thus, $AC = BC = 10$, $AB = 10\sqrt{2}$, $\angle A = \angle B = 45^\circ$, and $\angle C = 90^\circ$. Also, $AA_1 = AA_2 = BB_1 = BB_2 = p$ and $\tan(\angle A/2) = \tan(\angle B/2) = \tan 22.5^\circ = \sqrt{2} - 1$.

It follows that the radii of circles O_1 , O_2 , and O_3 are $r_1 = 1.48847$, $r_2 = 2.07107$, and $r_3 = 2.07107$, respectively. Reference to Figure 6 reveals that the coordinates of O_1 are $(r_1, r_1) = (1.48847, 1.48847)$, the coordinates of O_2 are $(10 - p, r_2) = (5, 2.07107)$, and the coordinates of O_3 are $(r_3, 10 - p) = (r_2, 10 - p) = (2.07107, 5)$. The program which produced Figure 6 is listed below.

```

Clear[r1, r2, p]
p = 5; r1 = 1.48847; r2 = 2.07207;
list3 = {{0, 0}, {10, 0}, {0, 10}, {0, 0}};
list4 = {{0, r1}, {r1, r1}, {r1, 0}};
plot5 = ListPlot[list4, PlotJoined → True,
  AspectRatio → Automatic, PlotStyle → GrayLevel[0], Axes → False];
plot3 = ListPlot[list3, PlotJoined → True,
  AspectRatio → Automatic, PlotStyle → GrayLevel[0], Axes → False];
plot6 = ListPlot[{{0, 0}, {r1, r1}}, PlotJoined → True,
  AspectRatio → Automatic, PlotStyle → GrayLevel[0], Axes → False];
plot7 = ListPlot[{{0, 10}, {r2, 5}}, PlotJoined → True,
  AspectRatio → Automatic, PlotStyle → GrayLevel[0], Axes → False];
list5 = {{0, 5}, {r2, 5}, {{(1 + 1/√2) r2, 5 + (1/√2) r2}}};
plot8 = ListPlot[list5, PlotJoined → True,
  AspectRatio → Automatic, PlotStyle → GrayLevel[0], Axes → False];
plot9 = ListPlot[{{10, 0}, {5, r2}}, PlotJoined → True,
  AspectRatio → Automatic, PlotStyle → GrayLevel[0], Axes → False];
list6 = {{5, 0}, {5, r2}, {5 + r2/√2, r2 (1 + 1/√2)}};
plot10 = ListPlot[list6, PlotJoined → True,
  AspectRatio → Automatic, PlotStyle → GrayLevel[0], Axes → False];
plot4 = ParametricPlot[{{1.48846 (1 + Cos[t]), 1.48846 (1 + Sin[t])},
  {5 + 2.07107 Cos[t], 2.07107 (1 + Sin[t])}, {2.07107 (1 + Cos[t]), 5 + 2.07107 Sin[t]}}},
  {t, 0, 2 π}, PlotStyle → GrayLevel[0], Axes → False];
Show[plot3, plot4, plot5, plot6, plot7, plot8, plot9, plot10]

```

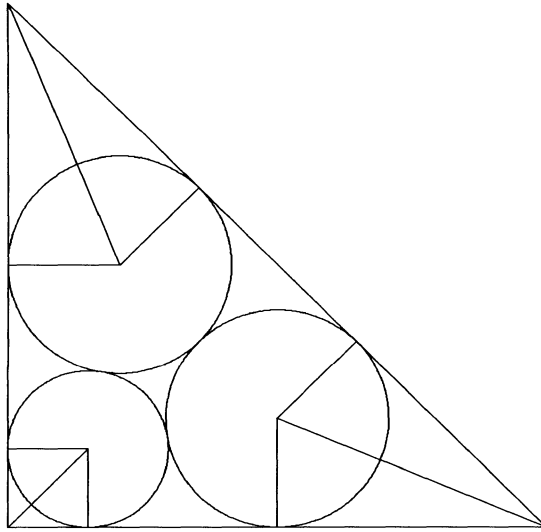


Figure 8. Program for the 30° - 60° - 90° right triangle.

Suggestions for Other Problems.

One good thing about teaching geometry is that fun and work often overlap. Such was the case with the circles and triangles of Gian Francesco Malfatti. The summer's assigned work was to use the Internet to seek enrichment material for the geometry class of 2011-12. The fun was learning more geometry (new to this teacher, old to many others), and then using the computing power of *Mathematica* to achieve the results described above. Should there be readers who found these ideas to be of interest, more fun awaits them in the 3 - 4 - 5 right triangle and in isosceles triangles with nice integer sides.

A LESSON PLAN WITH AN ARC MIDPOINT

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Abstract

The article introduces an explicit way of locating the arc midpoint in the Cartesian plane, which is consistent for both x - and y -coordinates and is technically accessible for students starting as young as fifteen. The authors give the proof of the statement using two trigonometry identities, and discuss some materials for innovative lessons on the arc midpoint computation that could enrich and enhance curriculum.

Introduction

Circumference is one of the most nearly perfect and most important lines in mathematics and science. Its segments, arcs, and their midpoints occur in thousands of theoretic and real-world problems. Along with the linear midpoint formula, the arc midpoint is beneficial for students' mathematics learning in general, and for their performance in coordinate geometry in particular. The logic conjunction “**iff**,” used in the arc midpoint statement, means “if and only if.”

Arc Midpoint Computation

Let the origin-centered arc of radius r in the Cartesian plane (see Figure 1) have the endpoints A and B with x -coordinates a , b respectively, and midpoint M with x -coordinate μ . Then,

$$2\mu = \pm\sqrt{(r+a)(r+b)} \pm \sqrt{(r-a)(r-b)}, \quad (1)$$

where the **first** radical has “ $-$ ” **iff** the arc makes a negative x -intercept, and the **second** radical has “ $+$ ” **iff** the arc makes a positive x -intercept.

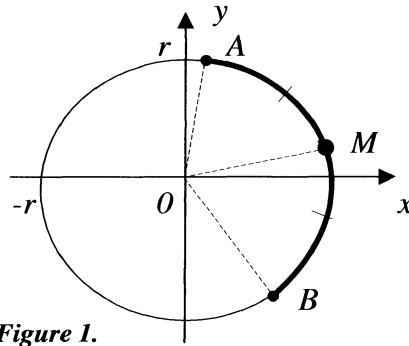


Figure 1.

The Same Relationship Holds for y -Values — Proof of this statement is shown below. Note that details of the proof are accessible only for strong mathematics students who are learning trigonometry at the advanced level. Consider additional propositions that are used in the main proof.

Two Identities

For any $p, q \in [-1, 1]$

$$\sin^{-1} p + \sin^{-1} q = 2 \sin^{-1} A, \quad (2)$$

$$\cos^{-1} p + \cos^{-1} q = 2 \cos^{-1} A, \quad (3)$$

where $2A = \sqrt{(1+p)(1+q)} - \sqrt{(1-p)(1-q)}$.

To prove identity (3), we denote $p = \cos \alpha$, $q = \cos \beta$, and $\gamma = \frac{\alpha + \beta}{2}$, where $\alpha, \beta, \gamma \in [0, \pi]$.

Then, its left side of identity (3) is simplified to $\cos^{-1}(\cos \alpha) + \cos^{-1}(\cos \beta) = \alpha + \beta = 2\gamma$.

Since $\alpha, \beta \in [0, \pi]$, then $\cos \frac{\alpha}{2} \geq 0$ and $\cos \frac{\beta}{2} \geq 0$. Using this, let us simplify its right side:

$$2 \cos^{-1} A = 2 \cos^{-1} \frac{1}{2} \left(\sqrt{(1 + \cos \alpha)(1 + \cos \beta)} - \sqrt{(1 - \cos \alpha)(1 - \cos \beta)} \right) =$$

$$2 \cos^{-1} \left(\cos \frac{\alpha}{2} \cos \frac{\beta}{2} - \sin \frac{\alpha}{2} \sin \frac{\beta}{2} \right) = 2 \cos^{-1} \left(\cos \frac{\alpha + \beta}{2} \right) = 2\gamma,$$

and identity (3) is proved. Identity (2) is a simple corollary of identity (3), indeed:

$$\begin{aligned}\sin^{-1} p + \sin^{-1} q &= \frac{\pi}{2} - \cos^{-1} p + \frac{\pi}{2} - \cos^{-1} q = \pi - (\cos^{-1} p + \cos^{-1} q) = \\ &\pi - 2 \cos^{-1} A = 2 \left(\frac{\pi}{2} - \cos^{-1} A \right) = 2 \sin^{-1} A,\end{aligned}$$

and identity (2) is also proved.

Arc Midpoint Computation Proof

Denote $p = a/r$, $q = b/r$, and $m = \mu/r$. Consider angles $\alpha = \cos^{-1} p$, $\beta = \cos^{-1} q$, and $\gamma = \cos^{-1} m$ that radii OA , OB , and OM form with positive part of x -axes, respectively.

There are four cases.

Case 1. The arc does not have x -intercepts. Then, $\gamma = (\alpha + \beta)/2$, and therefore $m = \cos \gamma = \cos \frac{1}{2}(\cos^{-1} p + \cos^{-1} q)$. Using identity (3), we get $m = A = \frac{1}{2}(\sqrt{(1+p)(1+q)} - \sqrt{(1-p)(1-q)})$. Hence, $2\mu = \sqrt{(r+a)(r+b)} - \sqrt{(r-a)(r-b)}$, and Case 1 is proved.

Case 2. The arc has a positive x -intercept, but does not have a negative one. Then, $\gamma = |\alpha - \beta|/2$, and therefore $m = \cos \frac{1}{2}(\cos^{-1} p - \cos^{-1} q)$. In addition, using identities (2) and (3), it is easy to see that $|\cos^{-1} p - \cos^{-1} q| = 2 \cos^{-1} \frac{1}{2}(\sqrt{(1+p)(1+q)} + \sqrt{(1-p)(1-q)})$ also holds for any $p, q \in [-1, 1]$. From here, we get $m = \frac{1}{2}(\sqrt{(1+p)(1+q)} + \sqrt{(1-p)(1-q)})$. Hence, $2\mu = \sqrt{(r+a)(r+b)} + \sqrt{(r-a)(r-b)}$, and Case 2 is also proved.

Case 3. The arc has a negative x -intercept, but does not have a positive one. This part of the proof is similar to Case 2 with $\gamma = \pi - \frac{1}{2}|\alpha - \beta|$.

Case 4. The arc has two x -intercepts. This part of the proof is similar to Case 1 with $\gamma = \pi - \frac{1}{2}(\alpha + \beta)$.

Proof for y -values can be achieved similarly using identity (2) or otherwise. ***Q.E.D.***

Thoughts and Materials for Lessons

The first lesson on the new topic could begin from recalling the midpoint formula and illustrating with a quick example. Then, an analogy with the arc midpoint computation and its diagram can be made. The diagram is an important part of the computation. After the theory of computation is introduced, and before considering numerical examples, it is useful to have preliminary exercises to help students understand the logic of two “ \pm decisions.” Through such exercises, the teacher ensures that students use the conjunction **iff** properly. Several diagrams, representing different locations of the arcs, may be shown on the board, and students could be asked to determine signs of both radicals in the formula (1) based on the particular location of the arc. For example, for the arc shown in Figure 1, the first radical has “+” because an arc does not have a negative x -intercept, and the second radical has “+” because an arc does have a positive x -intercept. Or, for the arc shown in Figure 2, the first radical has “-” because an arc does have a negative x -intercept, and the second radical has “-” because an arc does not have a positive x -intercept. When preliminary “ \pm practice” is finished, numerical examples could be discussed. In the following examples, we provide a selection of sample problems where the *exact answer is to be found without using a calculator*.

Example A: An origin-centered arc of radius 50, located as shown in Figure 1, has the ends at $x = 14$ and $x = 25$. Find the x -coordinate of its midpoint.

Example B: An arc, with radius 40 and the center at origin, is located above the x -axis. If it begins and ends at $x = -24$ and $x = 9$, what is the x -value of its midpoint?

Example C: An arc has its center at $(0,0)$ and radius 82. It starts at $y = 18$ in quadrant II, passes through quadrant III and ends in quadrant IV at $y = -1$. What is the y -value of the arc’s midpoint?

Solution A: We are given $r = 50$, $a = 14$, $b = 25$. As previously discussed, in this case both radicals in the arc midpoint formula (1) have “+” hence,

$$2\mu = \sqrt{(50+14)(50+25)} + \sqrt{(50-14)(50-25)} = 40\sqrt{3} + 30,$$

and $20\sqrt{3} + 15$ is the answer.

Solution B: We are given $r = 40$, $a = -24$, $b = 9$. In this case, the first radical has “+,” since the arc does not have a negative x -intercept, and the second radical has “-,” since the arc does not have a positive x -intercept. Using formula (1), we get

$$2\mu = \sqrt{(40-24)(40+9)} - \sqrt{(40+24)(40-9)} = 28 - 8\sqrt{31},$$

and $14 - 4\sqrt{31}$ is the answer.

Solution C: $r = 82$, $a = 18$, $b = -1$ are given. In this case, the first radical is “-,” since the arc does have a negative y -intercept, and the second radical has “-,” since the arc does not have a positive y -intercept. Hence,

$$2\mu = -\sqrt{(82+18)(82-1)} - \sqrt{(82-18)(82+1)} = -90 - 8\sqrt{83},$$

and $-45 - 4\sqrt{83}$ is the answer.

Applications of the arc midpoint computation to the real-world problems could be planned for the next lesson. In such problems, both exact and rounded answers could be requested, and a calculator should be used for evaluating radicals.

Problem

A water tank (T), a grain bin (B), and a storage unit (S) are located on the circle (see Figure 2). T is 0.6 km away from the center C and equidistant from S and B. If S is located 0.4 km south of center C and B is located 0.2 km north of C, how far north of C is T located?

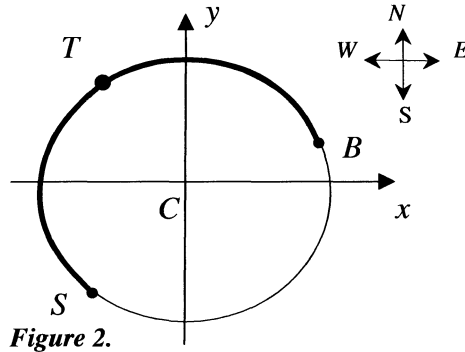


Figure 2.

Solution

Introduce the coordinate system with origin at C, x -axis pointed east and y -axis pointed north. Note that T is a midpoint of the arc STB. Using y -coordinates and 1 unit = 100 m, we have $a = -4$, $a = 2$, $r = 6$. For the first radical in (1) we chose “+,” since the arc does not have a negative y -intercept. For the second radical in (1), we chose “+” since the arc does have a positive y -intercept. Then, formula (1) gives the y -value of

$$T: \quad \frac{1}{2} \left(\sqrt{(6-4)(6+2)} + \sqrt{(6+4)(6-2)} \right) = 2 + \sqrt{10}. \quad \text{Hence, T is located}$$

$100(2 + \sqrt{10})$ m north of C (or 516 m north of C).

New problems for further practice could be prepared using various real-world situations that involve arcs and their midpoints.

UNLOCKING UNDERGRADUATE PROBLEM SOLVING

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Abstract

It is difficult to find good problems for undergraduates. In this article, we explore an interesting problem that can be used in virtually any mathematics course. We then offer natural generalizations, state and prove some related results, and ultimately end with several open problems suitable for undergraduate research. Finally, we attempt to shed some light on what makes a problem *interesting*.

Introduction

The Department of Mathematics at Lynchburg College has made a concerted effort to bring serious mathematical thinking into every one of its mathematics classes. We want our students to have the opportunity to question, explore, make conjectures, and then prove those conjectures. We want them to experience the true beauty of problem solving.

We spend a great deal of our time looking for appropriate problems that can be used at many levels. We leave no stone unturned. We examine textbooks, *Math Olympiad* and similar problem books, websites, and *Car Talk* “Puzzlers” [1-3]. During these investigations, we have come across several excellent problems. We are always looking for interesting problems that satisfy the following four criteria:

- 1) Are easy to understand, but for which the solution is not obvious;
- 2) Require some experimentation and examples to make a conjecture;
- 3) Have some higher-level mathematics lurking in the background; and,
- 4) Can be easily generalized.

In this article, we will study one such problem. This problem can be found in *Mathematical Delights*, in “From the Desk of Liong-shin Hahn” as Problem 1: “A Safe Cracking Problem” [4]. The problem is as follows:

A lock has sixteen keys arranged in a 4×4 array; each key is oriented either horizontally or vertically. In order to open the lock, all of the keys must be vertically oriented. When a key is switched to another position, all the keys in the same row and column automatically switch their positions, too (see diagram). (Only one key at a time can be switched.)

Show that no matter what the starting position, it is always possible to open this lock.

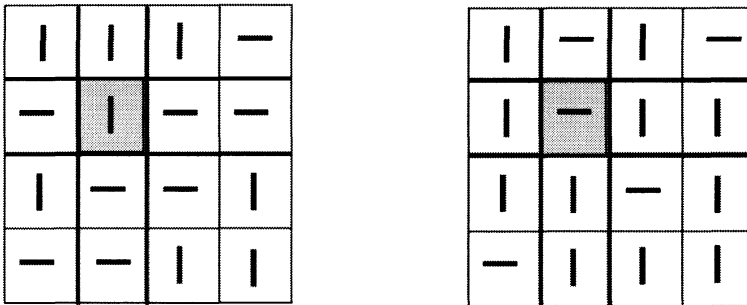


Figure 1. Original lock; lock after turning the shaded key.

This problem was given to students at many levels: to students from our liberal arts problem solving course to our upper-level students in linear algebra and experimental mathematics. All of these students agreed that the problem was easy to understand and that the solution was not at all obvious.

Problems like this force students to think differently. They spend more time practicing higher-order thinking skills than they do rummaging through their dusty old high school bag of formulas and techniques. In fact, no matter the mathematical level of the student, they immediately begin experimenting!

Results

Most mathematicians that see this problem instantly recognize the locks (in all their possible states) as elements of the vector space of 4×4 matrices over \mathbb{Z}_2 , where an entry of 0 corresponds to a vertical key and an entry of 1 corresponds to a horizontal key. In this setting, turning a key in the (i,j) position translates to adding the matrix $A_{i,j}$ that has ones in the i^{th} row

and the j^{th} column and zeros elsewhere to the matrix corresponding to the lock in question. To prove that every lock is open, one need only prove that the set of matrices A_{ij} form a basis.

Before we prove any results for lock problems such as this one, we should make a few comments. Students, even those with no background in linear algebra, quickly realize from experimentation that they can change the orientation of the key in the i^{th} row and j^{th} column while leaving all other keys in the same orientation by turning each key in the i^{th} row and the j^{th} column exactly once. This realization requires knowledge of neither linear algebra nor modular arithmetic. In fact, it turns out that students with knowledge of little other than basic parity can, with a little experimentation, come to this same conclusion. However, it is exactly this technique that can be used to prove the linear algebra version in a straightforward manner for any lock with an even number of both rows and columns:

Result 1. Any lock with an even number of rows and an even number of columns can be opened regardless of starting position.

Proof. Choose an arbitrary starting position of any $m \times n$ lock where m and n are both even. Let A be the matrix in the vector space V of $m \times n$ matrices over \mathbf{Z}_2 for which we choose each entry as follows: if the corresponding key in our given starting position is horizontal, the entry is 1, and if the corresponding key in our given starting position is vertical, the entry is 0.

Consider matrices of the following form in the vector space of $m \times n$ matrices over \mathbf{Z}_2 :

$$A_{k,l} \text{ defined by } (A_{k,l})_{i,j} = \begin{cases} 0 & \text{if } k \neq i \text{ and } l \neq j. \\ 1 & \text{if } k = i \text{ or } l = j. \end{cases}$$

$A_{k,l} + A$ produces a matrix that corresponds to the lock position we would obtain by turning the key in the k^{th} row and the l^{th} column. So, if the set $S = \{A_{k,l} : 1 \leq k \leq m, 1 \leq l \leq n\}$ spans V , every matrix in V may be written as a linear combination of elements of S , in particular the zero matrix, which will allow us to conclude that any arbitrary lock may be opened.

In order to show that S spans V , it suffices to show that any arbitrary element of the standard basis of V can be written as a linear combination of elements of S . Choose an arbitrary

element of the standard basis of V , E_{ij} , the matrix whose $(i,j)^{\text{th}}$ entry is 1 and all other entries are zero. Clearly, we can unlock any lock using the matrices E_{ij} .

We claim that
$$E_{i,j} = \sum_{k=1}^m A_{k,j} + \sum_{l=1}^n A_{i,l} - A_{i,j}.$$

First, note that
$$\sum_{k=1}^m (A_{k,j})_{i,j} + \sum_{l=1}^n (A_{i,l})_{i,j} - (A_{i,j})_{i,j} = m + n - 1 \equiv 1 = (E_{i,j})_{i,j} \pmod{2}.$$

If $s \neq i$, then
$$\sum_{k=1}^m (A_{k,j})_{s,j} + \sum_{l=1}^n (A_{i,l})_{s,j} - (A_{i,j})_{s,j} = m + 1 - 1 = m \equiv 0 = (E_{i,j})_{s,j} \pmod{2}.$$

If $t \neq j$, then
$$\sum_{k=1}^m (A_{k,j})_{i,t} + \sum_{l=1}^n (A_{i,l})_{i,t} - (A_{i,j})_{i,t} = 1 + n - 1 = n \equiv 0 = (E_{i,j})_{i,t} \pmod{2}.$$

If $s \neq i$ and $t \neq j$, then
$$\sum_{k=1}^m (A_{k,j})_{s,t} + \sum_{l=1}^n (A_{i,l})_{s,t} - (A_{i,j})_{s,t} = 1 + 1 - 0 \equiv 0 = (E_{i,j})_{s,t} \pmod{2}.$$

Hence, S spans V and therefore any $m \times n$ lock with m and n even can be opened.

In asking our students to ask interesting questions inspired by the lock problem, a natural idea students have is to question whether the results will be the same if the number of rows and columns are changed. The result we have just shown is, in fact, one such simple extension of this problem. In asking these sorts of questions, one of our students noticed that a 3×3 lock had a particular position (and then a whole class of related positions) that could not be unlocked. In fact, even an introductory student can quickly discover positions for a $1 \times n$ lock, with $n > 1$, that cannot be unlocked.

Again, as mathematicians, creating these examples is relatively simple if we treat the locks as elements of the vector space of $m \times n$ matrices over \mathbf{Z}_2 . However, students, even those at an introductory level, can quickly create “unopenable” positions of locks of various sizes, along with most of a proof that these locks cannot be opened, even if they lack any background in linear algebra. Again, an understanding of parity is all that is required to discover these ideas. However, in a class in which Martin Gardner’s famous “Mutilated Chessboard” problem is studied, students can find interesting connections between their attempts to create an unbreakable lock and that problem [5]. We will now prove a couple more results that were inspired by these students’ explorations.

Result 2. If m is odd and n is even, there exist positions from which an $m \times n$ lock cannot be opened.

Proof. Examine any starting position of this $m \times n$ lock with an odd number of horizontally positioned keys. Let A be the $m \times n$ matrix over \mathbb{Z}_2 which corresponds to this starting position as before. Further, define the matrices $A_{k,l}$ as before. Define the function σ by:

$$\sigma(B) \equiv \sum_{i=1}^m \sum_{j=1}^n (B)_{i,j} \pmod{2}.$$

An open lock which corresponds to matrix D satisfies $\sigma(D) \equiv 0 \pmod{2}$, while the matrix A for our starting position above satisfies $\sigma(A) \equiv 1 \pmod{2}$. Further, since $A_{k,l} + A$ produces a matrix that corresponds to the lock position we would obtain by turning a key in the k^{th} row and l^{th} column, $\sigma(B + C) \equiv \sigma(B) + \sigma(C)$ for any matrices B and C , and $\sigma(A_{k,l}) \equiv m + n - 1 \equiv 0 \pmod{2}$, no sequence of key turns can open a lock in a position corresponding to matrix A .

Result 3. If m and n are both odd, not both 1, there exist positions from which an $m \times n$ lock cannot be opened.

Proof. Color the position (or cell) of the key in the i^{th} row and j^{th} column of a lock black if $i + j$ is even and white if $i + j$ is odd. The cells will appear in a checkerboard pattern, starting with a black cell in the upper left hand corner as shown in Figure 2 below.

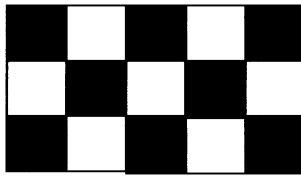


Figure 2. Colored 3 x 5 lock.

Note that each odd row and column starts and ends with a black cell, while each even row and column starts and ends with a white cell. Thus, when m (or n) $\equiv 1 \pmod{4}$, since m (or n) $= 4r + 1$, each odd row (or column) contains $2r + 1$ black and $2r$ white cells, and each even row (or column) $2r + 1$ white and $2r$ black cells. Also, when m (or n) $\equiv 3 \pmod{4}$, m (or n) $= 4r + 3$,

each odd row (or column) contains $2r + 2$ black and $2r + 1$ white cells, and each even row (or column) $2r + 2$ white and $2r + 1$ black cells.

For any position of a lock, we can define an $m \times n$ matrix A over \mathbf{Z}_2 corresponding to that position as before. Also, define the matrices $A_{k,l}$ as before. Define the functions σ_b and σ_w which sum the entries in a matrix corresponding to the black and white cells of a lock:

$$\sigma_b(A) \equiv \sum_{i=1}^m \sum_{j=1}^n x_{i,j} \pmod{2}, \text{ where } x_{i,j} = \begin{cases} (A)_{i,j} & \text{if } i + j \text{ is even.} \\ 0 & \text{if } i + j \text{ is odd.} \end{cases}$$

$$\sigma_w(A) \equiv \sum_{i=1}^m \sum_{j=1}^n x_{i,j} \pmod{2}, \text{ where } x_{i,j} = \begin{cases} (A)_{i,j} & \text{if } i + j \text{ is odd.} \\ 0 & \text{if } i + j \text{ is even.} \end{cases}$$

An open lock which corresponds to matrix D satisfies $\sigma_b(D) \equiv \sigma_w(D) \equiv 0 \pmod{2}$. Again, note that $A_{k,l} + A$ produces a matrix which corresponds to the lock position we would obtain by turning a key in the $(k,l)^{\text{th}}$ cell and $\sigma_b(B + C) \equiv \sigma_b(B) + \sigma_b(C)$ and $\sigma_w(B + C) \equiv \sigma_w(B) + \sigma_w(C)$ for any matrices B and C .

Examine the following cases.

Case 1: $m \equiv n \equiv 1 \pmod{4}$

Let $m = 4r + 1$ and $n = 4s + 1$.

If k and l are even, $\sigma_w(A_{k,l}) = (2r + 1) + (2s + 1) \equiv 0$.

If k is even and l is odd, $\sigma_w(A_{k,l}) = (2r + 1) + (2s) - 1 \equiv 0$.

If k is odd and l is even, $\sigma_w(A_{k,l}) = (2r) + (2s + 1) - 1 \equiv 0$.

If k and l are odd, $\sigma_w(A_{k,l}) = (2r) + (2s) \equiv 0$.

Choose a starting position for the lock which has an odd number of white horizontal cells. Then, the corresponding matrix A to this lock satisfies $\sigma_w(A) \equiv 1 \pmod{2}$. Since $\sigma_w(A_{k,l}) \equiv 0$ for any choice of k and l , no sequence of key turns can open a lock in a position corresponding to matrix A .

Case 2: $m \equiv n \equiv 3 \pmod{4}$

Similar to Case 1.

Case 3: $m \equiv 1 \pmod{4}$ and $n \equiv 3 \pmod{4}$

Let $m = 4r + 1$ and $n = 4s + 3$.

If k and l are even, $\sigma_b(A_{k,l}) = (2r) + (2s + 1) - 1 \equiv 0$.

If k is even and l is odd, $\sigma_b(A_{k,l}) = (2r) + (2s + 2) \equiv 0$.

If k is odd and l is even, $\sigma_b(A_{k,l}) = (2r + 1) + (2s + 1) \equiv 0$.

If k and l are odd, $\sigma_b(A_{k,l}) = (2r + 1) + (2s + 2) - 1 \equiv 0$.

Choose a starting lock position which has an odd number of black horizontal cells whose matrix A then satisfies $\sigma_b(A) \equiv 1 \pmod{2}$. Again, since $\sigma_b(A_{k,l}) \equiv 0$ for all k and l , no sequence of key turns can open such a lock.

Case 4: $m \equiv 3 \pmod{4}$ and $n \equiv 1 \pmod{4}$

Similar to Case 3.

Conclusion

As we mentioned earlier, this problem satisfies the four criteria that makes a problem interesting. We have proven a few results so that students might have some ideas on how to start on other generalizations. Like all interesting problems, generalizations abound! We end this paper with the following versions of lock problems:

- 1) Start with an $m \times n$ lock as studied above. Change the rules for which keys change when a particular key is turned. For instance, what if only the keys sharing a border with the turned key changes? What size locks can be opened?
- 2) Start with a locked 3-dimensional rectangular $m \times n \times l$ box, each face of which is covered by two $m \times n$, two $m \times l$, and two $n \times l$ keys similar to those studied above. In this 3-D version, turning one key changes the positions of each key in the same row and column around the entire box.
- 3) Start with a locked 3-dimensional rectangular $m \times n \times l$ box containing mnl cubes each containing a key. Turning any key (even those in the interior of the box) changes the position of every key sharing a horizontal or vertical plane with the key turned. Alternately, turning any key might change the position of every key sharing a horizontal or vertical row with the key turned.
- 4) Start with an $m \times n$ lock that corresponds to an $m \times n$ matrix over \mathbb{Z}_r . That is, a lock where each key has r intermediate positions between the horizontal and vertical positions.

- 5) Start with a locked 3-dimensional rectangular $m \times n \times l$ box that works as in version 1 or version 2 above, but with keys that have r intermediate positions between horizontal and vertical positions as in version 3 above.

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REFORM TEACHING IN MATHEMATICS AND SCIENCE COURSES—A FOLLOW-UP EVALUATION

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Introduction

The history of educational reform at all levels surely shows that significant and long-lasting change is not easy. Influencing change in college courses can be especially difficult because of the independent nature and disciplinary expertise of the professors who teach those courses. While external grants from prestigious foundations can certainly help convince college professors to modify their courses, a continuing question is whether those changes continue after that external funding and support disappear. What characteristics of those redesigned courses will continue after the initial reform effort ends?

The purpose of this article is to present the results of a follow-up evaluation on a six-year project to develop more effective introductory college mathematics and science courses, especially for those students planning to become elementary and middle school teachers. Faculty at seven Virginia higher education institutions collaborated to develop introductory mathematics, science, and education courses that offered a broad-based core of knowledge taught through “best teaching practices” to enhance student learning. The mathematics and science faculty were also asked to focus especially on the most important disciplinary knowledge for those students who planned to become K-8 teachers.

From 1993 to 2000, the National Science Foundation funded the Collaboratives for Excellence in Teacher Preparation (CETP) program to encourage educational institutions to reform the initial training of K-12 teachers in order to produce future teachers well prepared in mathematics, science, and technology. One of the main CETP goals was to encourage arts and sciences college faculty to work with education faculty and local school teachers to develop mathematics and science instructional experiences that help students learn in-depth subject matter and essential teaching skills.

The theoretical framework for reform programs such as CETP can be clearly found in the mathematics and science standards-based reform efforts of the past ten years. Twelve years ago, the American Association for the Advancement of Science began Project 2061 with the explicit,

long-term goal to reform K-12 education to produce science literate graduates. Their 1989 report, *Science for All Americans*, identified what all students should know and be able to do in mathematics, science, and technology after thirteen years of schooling [1]. In 1993, Project 2061 published *Benchmarks for Science Literacy* that translates the literacy goals of *Science for All Americans* into explicit learning objectives by the end of grades 2, 5, 8, and 12 [2]. The National Science Education Standards released in December 1995 provided a series of standards for the following: 1) science teaching; 2) professional development of teachers; 3) teachers' development of professional knowledge and skills; 4) science education assessment; 5) content standards organized by K-4, 5-8, and 9-12 grade levels; 6) school district science program standards; and, 7) the science education system beyond the school [3]. Among the six science teaching standards presented in that report, three—the calls for inquiry-based science programs, for the teacher to become a facilitator of student learning, and for the ongoing assessment of teaching and student learning—are especially important to reforming college science courses.

Methods

The Virginia Collaborative for Excellence in the Preparation of Teachers (VCEPT) was established in May 1996 and originally consisted of the following: 1) four-year institutions (Virginia Commonwealth University, Norfolk State University, Mary Washington College, and Longwood College—faculty from UVA and the College of William & Mary joined VCEPT in later years); 2) two-year institutions (J. Sargent Reynolds Community College, Tidewater Community College, and Germanna Community College); 3) community-based educational institutions (the Science Museum of Virginia and the Virginia Mathematics and Science Center); and, 4) local school systems. The Virginia Collaborative for Excellence in the Preparation of Teachers (VCEPT) was engaged in formal project activities for six years until May 2002. As part of a more extensive CETP impact study, the National Science Foundation funded a three-year evaluation follow-up in 2002 on the effects of the VCEPT activities. This three-year follow-up study examined the impact of VCEPT (in terms of both influence and sustainability) on college professors, teacher graduates, professional teachers in the field, and the policies of the Virginia Department of Education. Only the impact on higher education faculty will be examined in this article.

One of the main VCEPT project goals was to facilitate a re-examination of introductory college mathematics, science, and education courses taken by students preparing to be K-8 teachers. Typically, these introductory courses were also used to satisfy the general education requirements of other students not planning to become teachers. While a few of these students

would choose to major in mathematics and science, these were normally the final mathematics or science course for most students in these courses.

Teams of college and K-8 faculty worked on the redesign of specific courses at each of the VCEPT institutions. They were guided by course development principles which the entire VCEPT project working group had approved by consensus. The choice of specific courses' goals, activities, and assignments were to be guided by the following fifteen instructional characteristics:

- 1) active student learning
- 2) up-to-date teaching technologies
- 3) connections to other related disciplines
- 4) connections to the natural world
- 5) mixture of breadth and depth in coverage
- 6) interesting and intellectually involving concepts
- 7) critical thinking about current events
- 8) practical applications to students' own lives
- 9) effective interactions among students
- 10) opportunities to collect pertinent information
- 11) opportunities to organize information
- 12) opportunities to analyze information
- 13) opportunities to communicate conclusions and ideas
- 14) ethical and social implications in the world
- 15) different methods of assessing student performance

Fifty-eight VCEPT "reformed" courses were developed at five of the original VCEPT project institutions—Longwood University (LWU); Norfolk State University (NSU); University of Mary Washington (UMW); Virginia Commonwealth University (VCU); and J. Sargeant Reynolds Community College (JSRCC)—using these guiding principles. Throughout the original six-year VCEPT project, these courses were regularly evaluated through classroom visits by project evaluators, interviews with course instructors, and end-of-course evaluations by students. The results of these efforts were shared with course instructors through individual feedback reports. Combined course evaluations were also shared with VCEPT project members and the National Science Foundation through annual VCEPT reports.

For the follow-up evaluation, a sample of these courses was selected to investigate to what degree the courses still exhibited those principles after the original VCEPT project ended. In addition, the evaluation examined how well those reform course characteristics enhanced students' learning. During the fall and spring semesters of the 2003-2004 academic year, eighteen different courses (with 1-5 different sections of each course) were evaluated using an end-of-course student questionnaire (see Appendix A) that asked students to rate to what degree the course exhibited these fifteen VCEPT course development principles and the degree to which they contributed to their learning in the course.

The number of courses (and sections of the same course) at each institution was the following: one course (6 sections) at JSRCC; two courses at UMW (1 and 2 sections); two courses at VCU (1 and 4 sections); five courses at NSU; and, seven courses (1, 2, 3, 4, 4, 4 and 5 sections) at LWU. The number of students completing the follow-up VCEPT course evaluations was 112 at JSRCC, 73 at UMW, 237 at VCU, 129 at NSU, and 459 at LWU for a total of 1,010 students. The courses were chosen by institutional VCEPT coordinators to be representative of the "typical" VCEPT reform course. This purposeful sampling method would adequately represent the type of mathematics, science, and education VCEPT reform courses still being taught at each institution.

Results

The students taking the VCEPT reform courses at all five of the institutions provided remarkably consistent feedback about their course experiences. At all five VCEPT institutions, the students identified "active student learning" as the most frequently encountered characteristic of the fifteen identified VCEPT course characteristics and also the most valuable characteristic for their learning in the course. Typically, about 85% of the students indicated that "active student learning" occurred systematically or customarily in all of their classes. On a 5-point scale—where 1= Systematic use (100% of classes); 2= Customary use (75%-99% of classes); 3= Frequent use (50%-74% of classes); 4= Moderate use (25-49% of classes); and, 5= Occasional use (0-24% of classes)—"active student learning" averaged a 1.91 rating for the degree to which it occurred in their classes. While the use of a mean rating with these five ordinal categories can be misinterpreted, the mean rating is included here because it provides a helpful indication of the distribution of the students' responses among the choices.

Other most frequent VCEPT course characteristics that students reported being a part of their courses did vary somewhat among institutions, but there was still much consistency in the

students' ratings. At Longwood University, the second through fifth most frequently noted course characteristics were "assessment of student performance in different ways," "connections to the natural world," "mixture of breadth and depth in coverage," and "opportunities to organize information." At Norfolk State University, the second through fifth most frequently noted course characteristics were "interesting and intellectually involving concepts," "opportunities to organize information," "up-to-date teaching technologies," and "opportunities to analyze information." At the University of Mary Washington, the second through fifth most frequently noted course characteristics were "effective interactions among students," "up-to-date teaching technologies," "practical applications to students' own lives," and "opportunities to communicate conclusions and ideas." At Virginia Commonwealth University, the second through fifth most frequently noted course characteristics were "effective interactions among students," "opportunities to analyze information," "connections to the natural world," and "opportunities to communicate conclusions and ideas." At J. Sargeant Reynolds Community College, the second through fifth most frequently noted course characteristics were "connections to the natural world," "interesting and intellectually involving concepts," "opportunities to analyze information," and "mixture of breadth and depth in coverage." While the students' reported use of these course characteristics did vary among the different types of mathematics, science, and education courses, students were quite consistent in reporting "customary use" (defined as occurring in 75% to 99% of their classes) for these top five characteristics.

These students were also asked to rate the importance of these fifteen VCEPT course characteristics in helping them to learn in their course. The number one rated characteristic by the students across all VCEPT institutions was "active student learning" with a mean rating for all forty-two VCEPT courses/sections sampled of 1.47 on a 5-point scale, where 1= Very Important, 2= Important, 3= Unimportant, 4= Detrimental to Your Learning, and 5= Not Applicable or No Opinion. Again, the mean rating is used for these five nominal categories to represent the overall ranking of the students for each characteristic.

"Interesting and intellectually involving concepts" was rated the second most valuable course characteristic for student learning at LWU, NSU, and JSRCC while being rated third most valuable at VCU and fifth most valuable at UMW. "Assessment of student performance in different ways" was rated second most valuable at VCU, third most valuable at LWU, fourth most valuable at UMW, and fifth most valuable at JSRCC. "Practical applications to students' own lives" was rated second most valuable at UMW and fourth most valuable at LWU. Two other course characteristics made the top five for their value to student learning in three different

institutions: “effective interactions among students” and “up-to-date teaching technologies.” “Opportunities to analyze information” and “opportunities to communicate conclusions and ideas” made the top five at two of the VCEPT institutions.

There was again much consistency among the students’ ratings of the least frequently encountered course characteristics. These four course characteristics were always rated the least frequent components of the VCEPT courses, although the exact twelfth to fifteenth order did differ among the VCEPT institutions: “critical thinking about current events,” “ethical and social implications in the world,” “connections to other related disciplines,” and “practical applications to students’ own lives.” The three lowest-rated course characteristics on value to students’ learning were also the same among all the four-year VCEPT institutions with the exact order at the bottom again differing slightly: “ethical and social implications in the world,” “critical thinking about current events,” and “connections to other related disciplines.”

Discussion and Conclusions

The VCEPT course evaluation follow-up data support the conclusion that project-initiated changes to mathematics, science, and education courses are still reflected in students’ perceptions three to five years after the initial course modifications. These new students’ end-of-course evaluations of their reform mathematics, science, and education college courses show that the class activities and assignments have continued to exhibit most of the VCEPT instructional characteristics that faculty put into their redesigned courses.

“Active student learning” has continued to be the most important course element for both instructors and students. While the exact nature of these activities differs among the courses, students do perceive an overall instructional commitment for student-centered learning rather than teacher-centered lecturing. While there was some variation among the rest of students’ rankings at different institutions, the course characteristics of “opportunities to analyze information,” “connections to the natural world,” “interesting and intellectually involving concepts,” “mixture of breadth and depth in coverage,” “effective interactions among students,” “up-to-date teaching technologies,” and “opportunities to communicate conclusions and ideas” were typically seen as customarily used in the reform courses.

When students were asked to indicate which course characteristics contributed most to their learning, “active student learning” was the highest ranked instructional component. Since this was also the one course characteristic most frequently identified with the reform courses, this

finding suggests that students' learning was indeed enhanced by the project-based course changes. "Interesting and intellectually involving concepts" and "assessment of student performance in different ways" were the next two highest-ranked contributions to students' learning. "Effective interactions among students," "up-to-date teaching technologies," "practical applications to students' own lives," "opportunities to analyze information," and "opportunities to communicate conclusions and ideas" were the other highest-ranked contributors to student learning. All of these except assessment were also perceived as frequently occurring in the reform courses.

Examining the least frequent and least valuable course characteristics students identified, at least two interpretations of these findings are possible—the less frequent use of these characteristics made them less valuable to the students or the students did not find inclusion of these issues helpful to learning the basic content of the courses. Interviews with faculty did reveal that instructors found including course material that provided "ethical and social implications in the world," "critical thinking about current events," and "connections to other related disciplines" the most challenging of the instructional characteristics to address.

While this follow-up evaluation provides positive evidence that the VCEPT reform courses have consistently retained the VCEPT course principles, additional kinds of evidence could have strengthened that conclusion. Most of the instructors who redesigned the courses are still the instructors-of-record. When new professors start teaching these courses, will they continue the same objectives, activities, and assignments? Whether the current professors mentor their colleagues and convince them of the value of these reform course characteristics remains an open question.

This follow-up evaluation used students' judgments because they were the target consumers for the course changes. However, the evaluation would have been stronger if an objective measure of student learning was available for students taking the VCEPT reform courses. While each instructor did formally assess and grade each student's learning, the changes in the courses made comparisons with earlier students in the pre-reform courses impossible. The use of any standardized assessment measure given as a pre-test and post-test was also not an evaluation strategy that the instructors embraced.

In conclusion, this follow-up evaluation has shown that college course development initiated by a formal NSF-funded project can be maintained after that funding ceases. Since the

sustainability of project-initiated changes is an important goal of such foundation-funded projects, this evaluation should encourage future efforts to help mathematics, science, and education faculty reconsider the way they help undergraduate students learn the core concepts and principles that help them learn—and, in some cases, teach—those fundamental disciplinary ideas.

References

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Appendix A

Virginia Collaborative for Excellence in the Preparation of Teachers Fall 2003 Evaluation Questionnaire

Your instructors have been participating in a National Science Foundation project to identify and implement “best practices” for college mathematics and science instruction. Please complete the following questionnaire so that we can use your feedback in the future development of this course. Your anonymous opinions will be returned to the project evaluator who will summarize them for the instructors and the National Science Foundation. Since we will be summarizing your responses as group data, your individual opinions will remain confidential. However, we are asking for some biographical information to see how students’ views are influenced by their year in school or career aspirations. Thank you in advance for taking the time to respond thoughtfully to these questions.

Please use a No. 2 pencil to fill in the appropriate circle on the General Purpose Answer Sheet to record your answers. In the Last Name space print the abbreviation for your course and section number, such as MATH 106-01, CMSC 128-03, or BIO 121-02, but you do NOT need to mark the circles under those letters and numbers.

Feedback on Course

Please use the 5-point rating scale on the right for items 1-15 as you describe the following characteristics of this course.

To what degree did classes in this course include

- | | |
|--|--|
| 1. active student learning | A = Systematic use (100% of classes) |
| 2. up-to-date teaching technologies | B = Customary use (75%-99% of classes) |
| 3. connections to other related disciplines | C = Frequent use (50%-74% of classes) |
| 4. connections to the natural world | D = Moderate use (25-49% of classes) |
| 5. mixture of breadth and depth in coverage | E = Occasional use (0-24% of classes) |
| 6. interesting and intellectually involving concepts | |
| 7. critical thinking about current events | |
| 8. practical applications to students’ own lives | |
| 9. effective interactions among students | |

10. opportunities to collect pertinent information
11. opportunities to organize information
12. opportunities to analyze information
13. opportunities to communicate conclusions and ideas
14. ethical and social implications in the world
15. assessment of student performance in different ways

Please use the 5-point rating scale on the right for items 16-30 as you assess the value of these course characteristics to help you learn math and/or science content.

To what degree are these course characteristics important in helping you learn in this course?

- | | |
|---|----------------------------------|
| 16. active student learning | A = Very Important |
| 17. up-to-date teaching technologies | B = Important |
| 18. connections to other related disciplines | C = Unimportant |
| 19. connections to the natural world | D = Detrimental to your learning |
| 20. mixture of breadth and depth in coverage | E = Not Applicable or No Opinion |
| 21. interesting and intellectually involving concepts | |
| 22. critical thinking about current events | |
| 23. practical applications to students' own lives | |
| 24. effective interactions among students | |
| 25. opportunities to collect pertinent information | |
| 26. opportunities to organize information | |
| 27. opportunities to analyze information | |
| 28. opportunities to communicate conclusions and ideas | |
| 29. ethical and social implications in the world | |
| 30. assessment of student performance in different ways | |

Biographical Information

31. What was your academic classification at the beginning of the Fall 2002 semester?
 A = Freshman B = Sophomore C = Junior D = Senior E = Graduate or Unclassified

32. Do you plan to become certified to teach? [If unsure of the grade level, mark all of those that might apply.]

A= No, B = Yes, grades K-5, C= Yes, grades 6-8, D = Yes, grades 9-12, E= Undecided

If you are planning to teach, please also answer questions 33 to 35.

Use the 4-point scale on the right to indicate your opinion about each of these statements:

33. This course experience increased my motivation to try a variety of mathematics/science teaching strategies in my own teaching.

A = Strongly Agree

B = Agree

C = Disagree

D = Strongly Disagree

34. This course experience increased my understanding of how to use different mathematics/science teaching strategies.

35. I will likely share teaching ideas from this course with classmates.

STRONG SUPPORT FOR MATHEMATICS SPECIALISTS IN VIRGINIA

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Introduction

Strong, consistent support from state and local policymakers is essential to the establishment of effective Mathematics Specialists programs in local school divisions. When policymakers and policy leaders understand that there is a positive relationship between school-based Mathematics Specialists and significantly improved student mathematics achievement, they are likely to take legislative, regulatory, and budget actions that initiate, nurture, and sustain successful programs. This article presents specific state and local policy actions that have contributed to Virginia's nationally-recognized accomplishments in implementing and supporting Mathematics Specialist programs in elementary and middle schools.

In 2004, the National Science Foundation (NSF) awarded a consortium of three Virginia universities and five partner school divisions a five-year Teacher Professional Continuum (TPC) grant having as its overall goal determining the effectiveness of a school-based Mathematics Specialist program in grades K-5. The program core has been a pilot program to prepare, deploy, and support—with NSF and local funding—twenty-four Mathematics Specialists in elementary schools for two years each. Twelve Cohort I Mathematics Specialists started their school assignments at the beginning of the 2005-06 school year; twelve Cohort II Mathematics Specialists, with the 2007-08 school year.

From its inception, the NSF-TPC grant has focused on identifying and taking into consideration the state and local policy climates that underlay the successful implementation of Mathematics Specialist programs across Virginia. The grant's project management team has included two policy associates who have analyzed policy, legislative, regulatory, and funding issues at the state and local levels, and also guided the team and the partner divisions in understanding the relationships between policymaking and establishing effective, sustainable Mathematics Specialist models.

In the fifty states, education policy is established and funded, to a greater or lesser extent, by the state legislative body. For Virginia, this body is the Virginia General Assembly, advised by the gubernatorially-appointed Virginia Board of Education. State public education policy is set by the legislatively-enacted Standards of Quality (SOQ) found in the *Code of Virginia*, the biennial budget's appropriation of elementary and secondary education funding based on the SOQ and various other legislation, such as laws regarding personnel, transportation, and health.

Virginia's local school divisions are creations of the General Assembly and, in almost all instances, follow the political boundaries of counties, cities, and towns. The local school boards are given specific limited powers in the Virginia Constitution and are to be either popularly elected or appointed by the local elected governing body; that is, the county board of supervisors or the city (or town) council. Local school boards carry out state education policy, and adopt congruent policies for employing instructional staff and addressing local priorities. The school board determines the school division budget, subject to the approval and appropriations of the local government.

For the purposes of this article, *policymakers* are considered to be those state and local government legislators, elected officials, and local school board members who are empowered by law to set and, in some cases, fund education policy. *Policy leaders* include the superintendent and administration of local school divisions who are key influencers of the policies adopted or not adopted by the *policymakers*. *Policy leaders* initiate policy recommendations to the school board, analyze policy suggestions and directives, inform the school board's policy decisions, and carry out these decisions. In this same manner, at the state government level, the members of the Virginia Board of Education are seen as important *policy leaders*, while the Governor and General Assembly are seen as *policymakers*.

While the terms *policymakers* and *policy leaders* are used more or less interchangeably in this article, sometimes, for simplicity, *policymakers* may refer to either. However, as described above, the makers and the leaders, while working closely together, differ markedly in terms of actual authority and responsibilities.

Support from Policymakers and Policy Leaders

Throughout the five years of the NSF-TPC grant, state and local policymakers and policy leaders have strongly and consistently backed the preparation and support programs provided for the grant's elementary school Mathematics Specialists. School administrators have enthusiastically endorsed the in-school implementation model developed and used for the NSF-TPC grant. As this article will detail, the policymakers have funded as well as endorsed the program.

This on-going support is rooted in two bases: 1) the direct positive experiences of school divisions employing Mathematics Specialists either in locally-developed programs or through participation in NSF Mathematics Specialist grants; and, 2) the convincing body of evidence which has emerged from grant-supported quantitative research. This research has determined that, over time, K-5 Mathematics Specialists contribute directly to raising the mathematics achievement of the student populations they serve.

While this article draws on interviews and interactions with policymakers and policy leaders, it does not specifically address research findings. Let it be noted that the research conducted for this grant shows that overall, students in schools having elementary Mathematics Specialists in place for three years had statistically significant higher scores on the Virginia Standards of Learning mathematics assessments than did students in the control schools without such Specialists.

At all levels of government, policymakers and policy leaders are, by necessity, financial realists. They know that funding constraints may understandably limit the expansion and/or retention of the numbers of Mathematics Specialists employed by local school boards as Virginia struggles during the current economic recession. Moreover, they are aware that funding shortfalls may determine how the role of a Mathematics Specialist develops within a school division or in a specific school.

This article reports actions and interview statements from partner division policymakers and policy leaders. Also, it expresses the conclusion of policymakers and policy leaders that the key obstacle to employing Mathematics Specialists is not unwillingness but insufficient funds.

State Policymakers and Policy Leaders

State policymakers and policy leaders quickly recognized the value of Mathematics Specialists in increasing student mathematics achievement by enhancing the quality of mathematics instruction. For more than six years, the General Assembly and the Virginia Board of Education have taken actions in support of Mathematics Specialists. These have included creating a Mathematics Specialist add-on endorsement, recommending requirements and appropriations for mandated K-8 Mathematics Specialists in public schools, providing funding in support of a third year of employment for Cohort I Mathematics Specialists, and amending the Virginia Standards of Quality to require specialized assistance for students evidencing problems in learning mathematics. Recall that the Standards of Quality are the sections of the *Code of Virginia* which govern public elementary and secondary education, and drive its funding. It should be noted, not surprisingly, that the actual funding formulas are a source of continuing controversy between the Commonwealth and the local governments.

Endorsement — As a result of amendments recommended by the Virginia Board of Education to the *Virginia Licensure Regulations for School Personnel*, an add-on endorsement for a Mathematics Specialist for elementary and middle school education became effective in September 2007. In 2005, the General Assembly had requested the Board to consider such an endorsement in its licensure regulations revision in order to improve student achievement in mathematics. As of March 2010, 229 individuals had achieved this endorsement.

Legislative Mathematics Education Study — During its 2006 session, the General Assembly commended several Virginia school boards for both recognizing the value of Mathematics Specialists and taking the initiative to employ them to help elevate both teacher and student performance. In that same session, the legislature created the Joint Subcommittee Studying Science, Math and Technology Education, stating in its resolution that increased emphasis on science, mathematics, and technology education is necessary at the elementary and secondary level. In 2007, this Joint Subcommittee introduced legislation for a pilot program providing grants to six school divisions to hire Mathematics Specialists. The proposed legislation was not enacted.

Mathematics Specialist Position Requirement — In 2006, the Virginia Board of Education recommended that the Commonwealth of Virginia include requirements and appropriations for K-8 Mathematics Specialists in the public schools through the Standards of Quality which drive funding for many instructional positions. Enabling legislation was introduced during the 2007

legislative session to provide one, full-time Mathematics Specialist for each 1,000 students in grades K-8. Its failure may be largely attributed to its very large costs. The FY10 financial impact estimate of the state share of the cost for K-8 Mathematics Specialists at the proposed ratio was \$28.6 million. The local share, also based on the controversial state funding methodology, was \$22.8 million.

Mathematics Specialist Grant Support — For FY07, the General Assembly did provide one-time funding for salary support for some NSF-TPC grant-supported Mathematics Specialists so that an additional third year of research data could be obtained. The NSF grant had provided \$25,000 per year to the partner school divisions for each of the Cohort I Specialists employed during 2005-06 and 2006-07 only. The General Assembly provided \$12,500 to the partner divisions per Specialist employed during 2007-08 and the partner divisions provided the additional funding for each of the twelve Specialists. This third year of data proved to be key to the positive findings of the quantitative research component of the grant.

Standards of Quality Amendment — At the request of the Virginia Board of Education, the 2007 General Assembly amended the Standards of Quality to require school divisions to identify and assist students having difficulty with mathematics. Previously, the Standards of Quality had required such interventions only for students having difficulty with reading. This amendment codifies the legislative intent to improve student mathematics achievement.

Flexibility Budget Amendment — In advance of the termination of the NSF-TPC grant's funding with the 2008-09 school year, the Virginia Board of Education submitted a budget amendment to the Governor to authorize local school divisions to draw from certain existing funding sources, which had been established for different but complementary educational purposes, to employ Mathematics Specialists. The Governor and the 2009 General Assembly accepted this amendment, a token of their continued support for Mathematics Specialists during a gloomy budget cycle. Local school divisions have used this authority.

Local Policymakers and Policy Leaders

Local policymakers and policy leaders are convinced and confident about the value of the in-school coaching model that Mathematics Specialists bring to improving mathematics achievement. These widespread views were particularly evidenced at three points during the NSF-TPC grant's course when the two policy associates interviewed key local policy leaders and

policymakers regarding their perceptions and intentions regarding the employment of Mathematics Specialists.

During July and August 2006, the policy associates interviewed the principals of the schools in which the first cohort of twelve Specialists had begun their assignments in September 2005. During the summer of 2008, they interviewed the principals of the schools in which the second cohort of twelve Specialists had begun in September 2007. In the intervening year, they interviewed division policy leaders, including division superintendents, directors of instruction, and a school board member.

The thirty-six individuals interviewed were similar in their views of the effectiveness of the Mathematics Specialists and the effectiveness of the in-school model. Principals quickly homed in on the Specialists' value in improving inexperienced and weak classroom teachers. In addition, the Specialists were directed to teachers with a range of diverse learners because the principals recognized their ability to help with accelerated as well as special education. Division-level policy leaders appreciated the rigorous mathematics content courses taken by Specialists, the focus on classroom teacher education, and the daily imbedded on-site assistance; they saw these as essential components of the model. One noted that resident expertise was a big positive for teachers, for instruction, and ultimately, for the students.

Retention — Beyond the voluminous anecdotal information, those interviewed offered the fact that *all* five partner divisions retained *all* Mathematics Specialists beyond the two years of NSF grant support for each Specialist is proof of the division policymakers' belief in the efficacy of Mathematics Specialists. Despite downward-trending budgets, the partner divisions have provided *all* funding to continue Cohort I Specialists for the fourth and fifth years and Cohort II Specialists for the third year. In all years, no matter the existence or level of grant or state assistance, the divisions have voluntarily borne a significant part of each Specialist's salary and benefits.

For the 2009-2010 school year, twenty-two of the twenty-four original TPC Specialists continued to be employed by their partner divisions as Mathematics Specialists, despite the cessation of all grant-related funding. One Specialist retired and one moved to a non-participating division for employment in a school mathematics instruction supervisory role.

Grant Requirements Fulfilled — The five partner school divisions fulfilled all requirements under the NSF-TPC research and policy study over its five years. In addition to employing the Specialists for the required periods, the divisions provided access to schools, staff, and data. The divisions were agreeable to numerous visitors, technology requirements for transmitting research data, and release time for Mathematics Specialists and other staff. The mathematics supervisors in each partner division were able to devote many hours to supporting their Specialists and were of great value during the grant period. The building principals were gracious, persistent, and innovative in adapting their faculties and communities to the Specialists' presence, as well as in guiding the Specialists in their new placements.

Participation in New NSF Mathematics Specialist Grants — Nineteen local school divisions are participating in one or both of two new NSF-supported Mathematics Specialist research studies awarded in 2009. One division already participated in the NSF-TPC grant.

Sixteen divisions are involved in the Middle School project which has as a prime goal preparing a group of fifty exemplary middle school teachers (grades 6-8) with a profound understanding of mathematics studied in the middle grades in order to provide intellectual leadership as school-based Mathematics Specialists. All NSF-TPC grant divisions had expressed a need for help at the middle school level.

Thirteen divisions are involved in the Rural K-5 Schools project which is dedicated to extending Mathematics Specialists to the rural settings where the majority of Virginia's divisions are located. This grant addresses the challenges of delivering course content via distance learning and providing induction and on-the-job support to beginning Specialists in divisions with few or no mathematics support personnel.

Numerous Other Local Mathematics Specialist Programs — More than forty local school divisions in Virginia, in addition to the five TPC partner divisions, currently employ Mathematics Specialists who fit the criterion of specially-trained teachers released to work with other teachers. This number is approximately 30% of the Commonwealth's school divisions.

Some of these local programs have existed for several years and pioneered the use of Mathematics Specialists in elementary schools. They all demonstrate a variety of position responsibilities, support models and preparation programs, and have been a great source of ideas

and experiences for the NSF-TPC grant model, as well as the Rural K-5 Schools and Middle School research projects now underway.

Funding—The Key Obstacle

Policymakers and policy leaders acknowledge that the key obstacle to the employment of Mathematics Specialists is insufficient state and local funding. Budget pressures that emerged a few years ago have worsened, not abated. Revenues are down, spending is down, and new or expanded instructional programs have become rare.

The fact is that Virginia's biennium budget for FY11 and FY12 slashes general operating funds to FY06 levels. Almost all state funding for K-12 public education comes from the state's General Fund. Moreover, the adopted K-12 public education budget for FY11 is nearly three-quarters of a billion dollars (\$773 million) below the FY10 base adopted in 2009.

Another funding impediment which makes local school division employment of Mathematics Specialists challenging at this time stems from the Commonwealth's funding methodology for mandated versus non-mandated instructional positions. Mandated positions are those that are required by the Standards of Quality. Local school divisions are obligated to share the mandated costs with the Commonwealth on the basis of their ability to pay, as determined by a complex and controversial formula.

The Standards of Quality (SOQ) require local school divisions to employ elementary classroom teachers at legislatively-established ratios; but, the SOQ does not require local school divisions to employ Mathematics Specialists. Accordingly, since required instructional costs are shared between the Commonwealth and the local divisions, the Commonwealth shares the cost of employing mandated classroom teachers, but not the costs of non-mandated Mathematics Specialists. Financially-strapped local school divisions are less likely to create new instructional positions in the absence of a state requirement and funding support to do so. Moreover, they are more likely to discontinue instructional positions for which the costs are entirely locally borne.

Conclusion

While the current financial situation is difficult, the future of Mathematics Specialists is not dark. Mathematics Specialist programs are established in Virginia, the economy is expected to eventually improve, and federal policy will continue to stimulate state and local governments to raise mathematics achievement.

The more than forty Mathematics Specialist programs in Virginia school divisions, the growing number of endorsed K-8 Mathematics Specialists, the several established preparation programs at institutions of higher learning throughout the Commonwealth, and the nineteen divisions participating in the new grant programs have created a synergy in which Mathematics Specialists will continue to thrive. Mathematics Specialists are now widely known and well regarded in the public schools and their communities.

The National Science Foundation's award to Virginia of three Mathematics Specialist grants has not only encouraged the building of a state-wide infrastructure, but also enabled a growing number of school divisions to establish footholds for growth. The Rural K-5 and Middle School projects recently funded are helping to sustain the drive for program expansion and improvement.

The federal No Child Left Behind legislation has unarguably motivated public elementary and secondary education to examine instructional delivery systems, scrutinize teacher performance and preparation, and use assessment data to focus instruction and intervention. The reauthorization of the Elementary Education and Secondary Education Act with its promised focus on readiness for college and career will continue to drive the quest for strong mathematics achievement throughout the country.

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