

The Journal of Mathematics and Science:

COLLABORATIVE EXPLORATIONS

Volume 15, Spring 2015

PART I: SPECIAL ISSUE

The Virginia Initiative for Science Teaching and Achievement (VISTA)

PART II: REGULAR JOURNAL FEATURES



Virginia Mathematics and Science Coalition

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SPECIAL ISSUE

The Virginia Initiative for Science Teaching and Achievement (VISTA)

Coordinating Editor
for this Special Issue

Donna Sterling
George Mason University

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Virginia Mathematics and Science Coalition

In Memory of Donna Sterling, Ph.D.

This issue of *The Journal of Mathematics and Science: Collaborative Explorations* is dedicated to the memory of Dr. Donna Sterling.

A professor of science education at George Mason University, Dr. Sterling was nationally recognized for her work to improve the teaching of science and technology in elementary and secondary schools. She was a pioneer in science education, and her research formed the basis for the Virginia Initiative for Science Teaching and Achievement (VISTA), a \$28.5 million U.S. Department of Education i3 validation grant-supported program that is among the largest U.S. federal research grants ever awarded with a focus on STEM education.

By inspiring teachers to inspire students, Dr. Sterling encouraged countless numbers of young people to unlock the mysteries and wonders of the world through scientific discovery. She tapped into students' curiosity and advocated for approaches that involve teaching that is rooted in problem-based and inquiry-based learning. Her visionary work will impact generations to come.

SCIENCE EDUCATION IN VIRGINIA

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Introduction

The revision and adoption of the *Science Standards of Learning for Virginia Public Schools* in 1995 reinforced the Commonwealth’s longstanding emphasis on high-quality science programs and student achievement [1]. Virginia is fortunate to have a highly integrated system of standards, regulations, public processes, and rigorous course pathways that is the foundation to educate science-literate graduates. This system has necessarily functioned in concert with a respected *tradition of practice* within Virginia’s science education community and its shared vision for science for all students beginning at the earliest grades. There is much to be proud of in Virginia, but we must understand that challenges remain abundant.

Status of Science Program Quality/Performance Indicators

Objective measures of inputs and outcomes are required for framing a clear perspective on science education in the Commonwealth—but what are those measures? It is at this point that we consider the quote (often misattributed to Albert Einstein), “Not everything that counts can be counted, and not everything that can be counted counts.” Data are often difficult to obtain on many important measures, but the following samples can serve as indicators that are objective, can be used in comparisons, and/or were systematically developed.

The State Science Standards — The 2013 Thomas B. Fordham Institute report on the *Next Generation Science Standards* concluded that Virginia’s science standards were superior to the recent national effort [2]. In the Institute’s earlier state-by-state review of science standards, Virginia’s *Science Standards of Learning* were rated among the very best in the nation with only two states having higher rankings:

The Old Dominion’s science standards are among the few that we would cheerfully recommend as models for other states (and for drafters of “common” standards for this field). They are thorough and rigorous, particularly in the areas of mathematical applications and evolution, and they clearly provide a solid foundation for a rigorous K-12 science curriculum [3].

Science Graduation Requirements and Diplomas Awarded — Virginia’s two college- and career-ready diplomas, the Standard Diploma (SD) and the Advanced Studies Diploma (ASD), require three and four laboratory science credits for graduation, respectively. These credits must be distributed among the biological and physical sciences [4]. In 2013, 47,872 students achieved the ASD, while 35,357 students achieved the SD, indicating that 58% of students earning one of these college- and career-ready diplomas had completed four or more science credits [5]. National data indicate that only two states require four science credits of all students [6].

National Assessment of Education Progress (NAEP) Performance — The NAEP is the largest nationally representative and continuing assessment of what students in the United States know and can do in various subject areas. Assessments are conducted periodically in mathematics, reading, science, writing, the arts, civics, economics, geography, and U.S. history. The NAEP results serve as a common metric for all states and selected urban districts. The assessment difficulty level stays essentially the same from year to year, with only carefully documented changes. This permits NAEP to provide a clear picture of student academic progress over time.

The last NAEP assessment released for grade 4 science (2009), Virginia fourth graders ranked at the top of the national assessment. Virginia achievement exceeded all but two states [7].

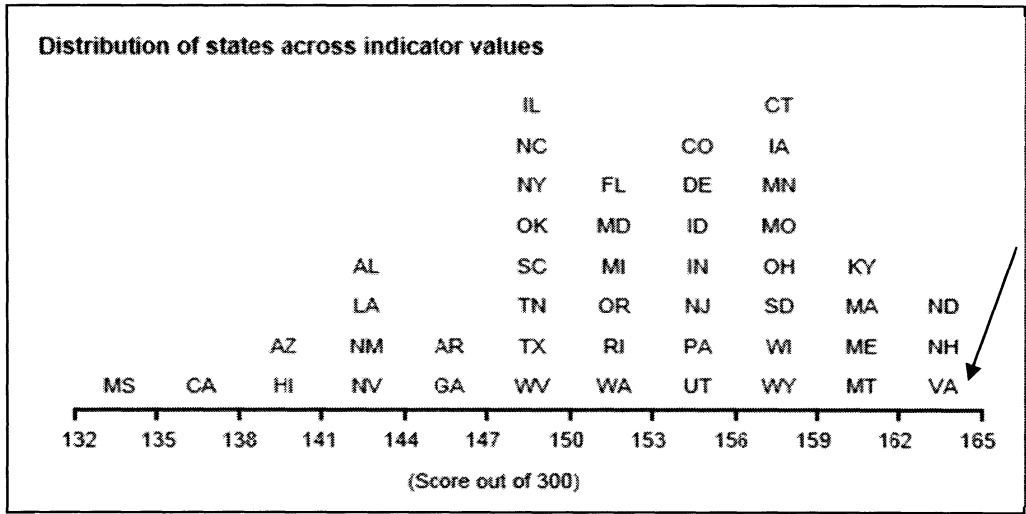


Figure 1. The NAEP “Fourth Grade Science Performance”(2009), as reported on the National Science Foundation website.

In the most recent NAEP assessment released for grade 8 science (2011), Virginia eighth graders ranked among the highest performing states on the national assessment. Achievement exceeded all Southern and Mid-Atlantic states [8].

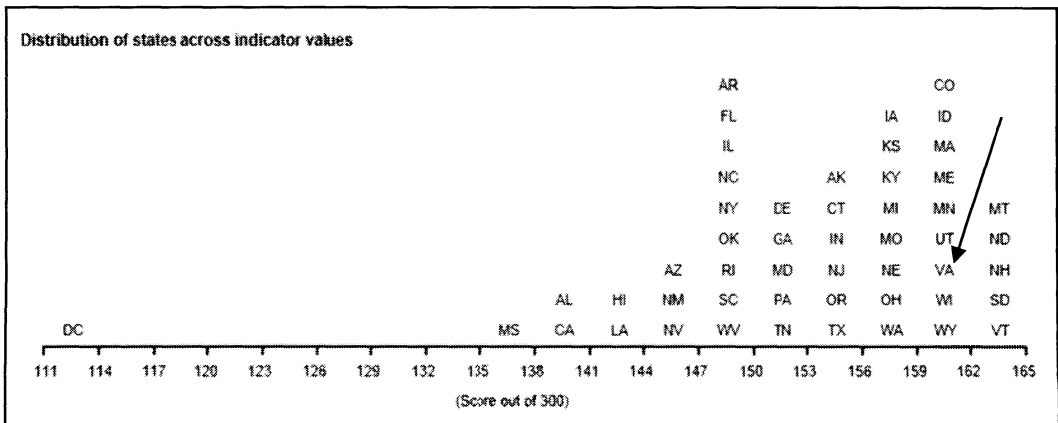


Figure 2. The NAEP “Eighth Grade Science Performance” (2011), as reported on the National Science Foundation website.

International Science Assessment Linking Study: TIMSS and NAEP — The October 2013 release of a major international linking study, *U.S. States in a Global Context*, by the National

Center for Education Statistics connected science scores of U.S. students on the 2011 NAEP with results from the 2011 Trends in International Mathematics and Science Study (TIMSS) [9]. The study concluded that Virginia's eighth graders achieved at a statistically higher level in science than students in thirty-seven countries and systems. Students in only four countries—Singapore, Taiwan, South Korea, and Japan—scored statistically higher. Virginia's average grade 8 science score was only six points below the TIMSS benchmark for high achievement and 69 points above the intermediate achievement benchmark [8].

Advanced Placement Science Courses — The number of Virginia students taking Advanced Placement (AP) courses and tests has increased significantly since 2004, as have their scores on AP science tests. In February 2014, The College Board's *AP Report to the Nation* announced that Virginia again boasted the nation's third-highest percentage of public high school seniors qualifying for college credit on Advanced Placement (AP) examinations [10]. Only two states had higher percentages of seniors earning qualifying scores. The College Board, in its *Virginia Student Achievement Report 2012-2013*, showed that the number of Virginia students taking Advanced Placement Tests for AP Biology, AP Chemistry, and AP Physics B *and* achieving qualifying scores for college credit exceeded 50% and had noteworthy year-over-year gains [11].

Science*	2004	2010	2011	2012	2013
Total Tests Taken	2,829	14,725	16,809	19,137	20,356
Total Scores 3 or Above	1,849	7,316	8,398	9,662	11,132

*Science includes Biology, Chemistry, Environmental Science, Physics B, and Physics C.

Figure 3. Advanced Placement Tests in Virginia, 2004-2013.

State Science Accreditation — Accreditation status is provided by the Virginia Department of Education (VDOE) based on the *Science Standards of Learning* assessments at grades 3, 5, and 8 and at end-of-course in Earth science, biology, and chemistry for high schools. Schools that did not achieve an aggregate student pass rate of at least 70% in science had the status of “Accredited with Warning.” Accreditation information for 2013-2014 (based on assessments taken during the 2012-2013 school year) is posted on the VDOE website for over 1,800 elementary, middle, and high schools [12]. Among these, there are four high schools, eight middle schools, and twenty-nine elementary schools that are “Accredited with Warning” in science.

Review of Partnership and Collaboration Indicators

It is clear from the data from various external sources that science education in Virginia has great potential. However, it is important for all of the stakeholders to realize that there must be continuous focus and effort made to retain and improve science education for Virginia's students. Since the person who makes the difference in a student's academic career is the teacher, much of the focus and effort is on teacher professional development [13]. Members of the science education community work collaboratively to provide high-quality professional development for teachers of science in Virginia.

Professional and Leadership Organizations — Virginia's science education professional organizations are an integral component of the science education community. The Virginia Association of Science Teachers (VAST) and the Virginia Science Education Leadership Association (VSELA) are critical to the success of science education. Over the past several years, each organization has been a key player in the development and implementation of Virginia's *Science Standards of Learning*. Their members have provided expertise in grade-level and subject areas during the standards revision process, as well as provided the VDOE important time during their meetings to allow for sessions to build coherence around the goals of the standards and other important implementation matters. Over the past several years, thousands of teachers of science and science educator leaders attend their annual professional development institutes. These institutes allow teachers to connect in a setting that encourages professional learning and growth.

Another organization that provides leadership in the area of science education is the Virginia Mathematics and Science Coalition (VMSC). The mission of the VMSC is "to bring together education, scientific, corporate, and public policy leaders committed to the sustained elevation of mathematics and science education to ensure that all Virginia's students and citizens have the foundation required for lifelong success in their daily lives, careers, and society." The VMSC supports efforts by school systems, teachers, parents, students, the Commonwealth of Virginia, and other interested parties to achieve and sustain excellence in Science, Technology, Engineering, and Mathematics (STEM) education for Virginia's K-12 and higher education students. Over the past several years, the VMSC has focused efforts on communicating the importance of science education through identifying highly effective science programs through "Programs That Work" which was initiated by the Honorable Mark Warner during his tenure as the president of the VMSC. The VMSC provides an important perspective and research-based information to the science education community and its stakeholders through its white papers and

journal. Recently, the VMSC developed and is implementing a strategic plan, “Achieving Excellence in Mathematics and Science Education,” which outlines goals, objectives, and strategies in four key areas:

- 1) Curriculum and Assessment
- 2) Instructional Delivery
- 3) Human Capital
- 4) VMSC Organizational Structure

Mathematics and Science Partnership Program — The Mathematics and Science Partnership (MSP) program is intended to increase the academic achievement of students in mathematics and science by enhancing the content knowledge and teaching skills of classroom teachers. Annually, partnerships between high-need school divisions and the Science, Technology, Engineering, and Mathematics (STEM) faculty in institutions of higher education collaborate to focus on improving science teaching and learning through intense, sustained professional development.

Each state determines priorities for the use of MSP funds based on statewide needs. In recent years, Virginia has had the following priorities:

- Nature of Science and Scientific Inquiry;
- Discourse and Argumentation in Science;
- Conceptual Modeling Instruction; and,
- Integration of Mathematics and Science using Interdisciplinary Strategies.

Since 2008, many partnerships among Virginia school divisions and institutions of higher education have been developed, resulting in nearly 2,000 science teachers having received intensive professional development through the MSP program.

These MSP grant-funded projects have also resulted in the sharing of professional development models and materials, as well as curriculum materials such as lesson and unit plans, developed as a result of the projects. These materials serve as a starting point for school divisions, schools, and teachers as they work toward improving science education.

The Virginia Initiative for Science Teaching and Achievement (VISTA) — VISTA is a statewide partnership among more than eighty Virginia school divisions, six Virginia universities (George

Mason University, The College of William & Mary, Virginia Commonwealth University, Virginia Tech, James Madison University, and the University of Virginia), and the Virginia Department of Education. This partnership has leveraged the established partnerships within the science education community in order to provide a multifaceted approach to science education reform. Elementary and secondary science teachers, school division science leaders, and university science education faculty all experience the impact of VISTA programs through professional development.

The initiative is funded by a five-year, \$34 million grant from the U.S. Department of Education through the Investing in Innovation (i3) program, which includes a \$5.7 million private sector matching requirement. Oregon State University directs the independent evaluation of the VISTA program. The objectives of VISTA include the following:

- Increasing student learning in science, including students with special needs and Limited English Proficiency (LEP);
- Enhancing the quality of elementary science teaching by including inquiry-based teaching;
- Enhancing the quality of teaching of new, underprepared secondary science teachers, including having their students conduct inquiry-based activities;
- Increasing the number of certified middle school and high school science teachers;
- Increasing access for rural teachers to professional development;
- Building the state infrastructure to support effective science teaching and learning; and,
- Conducting research to determine what makes the most significant difference in helping teachers to help students learn.

The VISTA professional development programs are empowering hundreds of science educators across Virginia to use an active style of teaching that engages students in the classroom and beyond. These science educators (science teachers, school division science leaders, and science education faculty) collectively impact around 625,000 students statewide [14]. The impact of VISTA will likely continue long after the grant funding from the U.S. Department of

Education runs its course. The partners have clearly taken the opportunity to leverage relationships and resources to impact science teaching and learning in the Commonwealth.

The Virginia science education community has systematically leveraged relationships and resources to ensure that the goals of Virginia's *Science Standards of Learning* are enacted by science educators. Processes and systems are in place to ensure that students exiting Virginia public schools are scientifically literate and prepared to be career and college ready. However, it is imperative that the science education community, the policymakers, business leaders, and the community only consider changes to this system that will ultimately improve the outcome: a scientifically literate society.

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EXPERIENCES WITH PROBLEM-BASED LEARNING: VIRGINIA INITIATIVE FOR SCIENCE TEACHING AND ACHIEVEMENT

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Abstract

The Virginia Initiative for Science Teaching and Achievement (VISTA) provides high-quality professional development for teachers and administrators to enhance the quality of their science instructional programs. One emphasis of this program is helping teachers learn to implement Problem-Based Learning in the elementary science classroom. Problem-Based Learning (PBL) has the potential to produce significant positive outcomes for students, such as increased student engagement, and opportunities for in-depth critical thinking [1]. Teachers find PBL challenging because it does take additional time for planning and material acquisition, but experience has shown that the benefits outweigh these challenges. Setting clear goals, identifying specific learning objectives, and developing big questions that tie these together help increase the success of the unit. Additionally, administrators can help teachers succeed in implementing a Problem-Based Learning unit by understanding the dynamic nature of the PBL environment, providing flexibility with unit pacing, and setting aside time for refining, reflection, and revision of the unit.

Introduction

Teaching science seems simple, right? Actually, it is! After attending a summer professional development program for elementary teachers sponsored by the Virginia Initiative for Science Teaching and Achievement (VISTA), we now have a clearer understanding of research-based best practices in science teaching. We are two elementary teachers and a district science coordinator from a public school division in southeastern Virginia. The practical experience and instruction provided by the VISTA professional development program helped us understand why students need hands-on, real-world experience in order to learn significant science content. We discovered that learning science through inquiry develops critical thinking and engages students in learning unlike other instructional practices. Here is a brief summary of our experience with Problem-Based Learning, along with an analysis of the successes and challenges of implementing the unit.

A Unique Professional Development Experience

Training for VISTA began at the end of June when teams were assigned to a cohort of teachers from around the geographic region. Teachers engaged in instruction for a total of twenty days, over a five-week period during the summer. The first day was somewhat overwhelming because the room was filled with over fifty teachers from all over the area, and from all different grade levels. After about a week, everyone learned to work together, plan together, and gain useful feedback from each other's unique perspectives. The participants' weekly experience during the elementary teacher summer program is outlined below.

Weeks 1-2 — Learn about the VISTA program, and become a student yourself. Instructors engaged us in activities that modeled effective instructional strategies for teaching the nature of science. We greatly benefited from the peer interaction and getting to know one another during these first two weeks. During this time, we were assigned to a summer camp. Then, we began learning how to plan engaging lessons based on the Problem-Based Learning (PBL) format.

Weeks 3-4 — In the next two weeks, we became an instructor at a science summer camp for area students. We put into practice what we had learned throughout the training process, and experimented with new instructional strategies. A group of panel teachers observed and collected data on the instruction. Each teacher was assigned to a team and taught for two days. On our days off, we became part of the panel that observed and collected data on other assigned teachers. At the end of each day, we used discourse to discuss strengths and weaknesses. This was the moment when theory turned into practice as we learned how to improve the science instruction in our own classrooms. At the end of the camp, all students put on a culminating activity to present what they had learned to their friends and families.

Weeks 4-5 — When we were not observing or instructing at the camp, we were back in class. During this time, we had the opportunity to develop our own PBL unit while working with experts in both science and education. We had the pleasure of working with physics and biology professors from The College of William & Mary.

Problem-Based Learning: Theoretical Framework

Problem-Based Learning is a research-based instructional method that has been shown to increase student interactions and promote problem-solving skills [1]. With its origins reaching as far back as John Dewey in 1944, Problem-Based Learning focuses on students learning by doing the work in an authentic setting through solving real-world problems [2]. Students work collaboratively, which simulates experiences in the workplace and builds communication skills.

During this collaborative work, the teacher acts as facilitator to guide the students to the knowledge they need in order to solve a unique, open-ended problem [3]. Driven by the students' own need-to-know list, the classroom learning environment becomes student-centered and goal-oriented. Students that learn through problem-based methods tend to develop enhanced critical thinking skills and have higher intrinsic motivation to learn [4]. Introducing this instructional methodology to our grade 4 students created an atmosphere of excitement and intrigue for the students, but also took much thought and pre-planning.

Problem-Based Learning: Planning and Implementation

Planning for a Problem-Based Learning (PBL) unit takes time, careful planning, reflection, and revision. During the fall semester, our grade 4 students engaged in a playground design project. The students were asked the question, "How can you create a playground that is safe and fun for children with special needs?" This question initiated a cycle of scientific inquiry. Students were immediately engaged in thoughtful questioning. Using these questions as the foundation for the planning process, we developed lessons that would help achieve the goals of the unit. We focused on significant content that would drive each lesson, and provide students with the information they needed to solve the problem. At the beginning of each lesson, students engaged in a hands-on activity using real science equipment. These mini-lessons provided instruction in the significant content, while tying in themes from the Nature of Science. Engaging students in specific instruction regarding the nature of science was important to help students develop a clear understanding of the scientific process [5]. For example, students were asked the question, "How does the surface of a playground impact safety based on friction?" The students then completed an activity that helped them draw a conclusion about the question, and led them to determine how they wanted to build the floor of the playground. During the playground design process, our students engaged in numerous experiments. These experiments helped students understand that scientific knowledge is empirical and must be based on experimental data, a key aspect of the nature of science. To help students think critically about the topic, it was important to get them to think about safety for *all* children, including those with special needs. The students were taught a lesson on friction using real science friction boards, which helped focus on the significant topic of friction from the fourth grade Virginia *Standards of Learning*.

Similar lessons followed, with a culminating activity of building a model playground made for children with special needs. Students utilized Skype™ to communicate with an expert

in playground safety, and used that information to further refine their project. Students then presented their final model to parents and members of the school board. This provided students an audience for the project, and allowed them to gain a sense of accomplishment from their hard work.

Successes with Problem-Based Learning

Increases in student engagement and the amount of critical thinking were two main areas of success with this project. Keeping students engaged in the big question helped ensure all students were involved in the process of solving the problem. The school where this unit was implemented has a high number of children with special needs requirements. This made the big question of playground safety for students with special needs relatable and engaging for the students. They also played the role of scientist as they engaged with hands-on experiments and activities. On many days, the learning truly felt like playing. Problem-Based Learning also made varying the instructional methods to meet the needs of diverse learners quite easy. One example of this was an experiment on the effect of different materials on the speed of objects going down the slides. Students rolled a marble down a slide and tested different materials to be the landing platform. The object was to figure out which landing material slowed the marble down the most. Students used that information to safely construct platforms for their model playground. Visual acuity, fine motor skills, and creativity were needed to successfully complete this experiment and, no matter what their learning style, all students were able to stay focused and engaged in the project.

Another success of the unit was the increase in opportunities for students to think critically. The professional development provided by VISTA on the Nature of Science and how to engage students in real scientific processes, helped us understand that Problem-Based Learning creates the platform for critical thinking to occur. The project's big question required students to be creative and logical in the construction of their playground. Near the end of the unit, they learned through the safety expert from the National Network for Playground Safety that equipment had to be a certain distance apart, and certain restrictions applied to wheelchair slides. At this point, students had already begun constructing their playground models. Students then had to incorporate the information they learned, and make necessary adjustments to their playground models. Students also engaged in critical thinking as they encountered experiments that had a different outcome than expected. In one experiment, students were testing the impact of falling on different materials (mulch, sand, rubber). The students thought that mulch would be the best material to use during their hypothesis. At the end of the experiment, they found that

sand was actually better than the other materials they had tested. Students were required to form a reason for this or create another experiment to test, and re-think why their hypothesis was not accurate. Students realized that scientists change ideas and must re-test to get a more accurate result. Promoting critical thinking became natural as students engaged in achieving a solution to the proposed problem.

Overcoming Challenges with Problem-Based Learning

The biggest challenge in planning and implementing the PBL unit was finding the necessary resources. Planning for the first PBL unit took four hours a day for a week. After that, more time was spent gathering materials and resources, finding someone to communicate with on Skype™, and lining up an authentic audience for the student presentation. Another challenge encountered by project planners was underestimating the time needed to complete the project. With high-stakes testing just around the corner, it was tempting to skip lessons or shorten the project. Ultimately, time was found, but taking the time to create and implement such a large unit was very difficult. Although these challenges were tremendous, the project was implemented successfully with only a few modifications along the way.

Advice for Teachers

Many lessons were learned from the implementation of a Problem-Based Learning unit. The first was, keep it simple. In the beginning, a great deal of time was spent planning, but during the unit, adjustments were made to lessons and experiments to fit the schedule and materials available. Testing the experiments ahead of time with the available materials is essential. Several experiments did not work because the equipment selected was inadequate or the quantity of supplies was limited. Some real science equipment could not be substituted for normal classroom materials. Planning ahead and making a list of needed materials and sources for science equipment is essential. Another reason to keep it simple is because students are driving the solution to the problem. Teachers will not be able to pre-plan for every great student idea. For example, when doing one experiment on kinetic and potential energy, the students came up with another idea for their playground involving potential and kinetic energy. So, another experiment was added to help students incorporate this component into their model. This helped us learn that the project does not have to be as big as some might think. We have since developed several more PBL units for other topics. These have been short projects, lasting about a week and a half. The students still received high quality, engaging instruction using scientific best practices, but the culminating projects were less intense. Finally, it is beneficial to make the project cross-curricular. This helps ease the time constraints. While it may seem intimidating to

plan and implement a PBL in science, it can be quite fun, and students become better problem solvers and critical thinkers through this engaging form of instruction.

Advice for Administrators

Successful implementation of Problem-Based Learning units in science takes careful planning, professional development, and support from district and school level administrators. Administrators should be prepared to support a dynamic classroom environment, provide flexibility for pacing and cross-curricular connections, and allow teachers time to review, reflect, and revise their units.

School administrators may find it shocking to walk into a classroom during a PBL unit. It will not look normal. Classes are often messy, full of movement, and loud in volume as students use communication and collaboration skills to solve problems. This dynamic learning environment is unlike many traditional classrooms, and adjustment to this may take time. Administrators will also need to understand that Problem-Based Learning is best suited for combining related learning objectives into a cohesive unit of study. Sometimes these learning objectives are cross-curricular or are from multiple units of study throughout the course. Researchers recommend that PBL units be designed to “embody a multitude of science” standards [6]. Careful consideration should be given to provide teachers flexibility with course pacing to ensure standards can be grouped together as needed. If strict pacing is expected, teachers will struggle to identify enough related standards to make it worth taking the time to complete the investigation.

In-depth projects take students on a journey to discover the content of the course themselves, but careful planning must be done to guide them to learn the significant content and not veer too far off course. Administrators can help teachers through this process, by providing them time to refine their big questions, identify intended learning objectives, reflect, and revise their unit. Introducing teachers to a set procedure for revision and reflection, and providing them time to complete it, is an integral component to the success of Problem-Based Learning.

Conclusion

Problem-Based Learning has the potential to produce significant positive outcomes for students. Increased student engagement and opportunities for in-depth critical thinking are natural products of the PBL process. Teachers find PBL challenging because it does take

additional time for planning and material acquisition, but experience has shown that the benefits outweigh these challenges. Setting clear goals, identifying specific learning objectives, and developing big questions that tie these together help increase the success of the unit. Additionally, administrators can help teachers succeed in implementing a Problem-Based Learning unit by understanding the dynamic nature of the PBL environment, providing flexibility with unit pacing, and setting aside time for refining, reflection, and revision of the unit.

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NEW VISTAs IN SCIENCE EDUCATION

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Abstract

In the summer of 2012, a colleague and I attended the four-week Virginia Initiative for Science Teaching and Achievement (VISTA) Elementary Summer Science Institute where we were trained to conduct inquiry-based science teaching in a problem-based learning setting. We then implemented our training in our own academic classrooms by developing a Problem-Based Learning unit meeting the objectives of our Virginia standards-based science curriculum and selecting a topic with ties to our local community. Toward demonstrating that students, teachers, and educational systems stand to benefit from the implementation of this methodology, this article clarifies the following aspects: 1) outlines the problem, scenario, and process of developing a Problem-Based Learning unit; 2) explains the delivery in the classroom; 3) analyzes ongoing formative and summative assessments; 4) and, discusses the influence on students, teachers, and instruction as a whole.

Introduction

In the summer of 2012, my colleague and I had no idea what we were getting into when we applied to attend the Virginia Initiative for Science Teaching and Achievement (VISTA) Elementary Summer Science Institute. We were both relatively new to our grade 4 team, and the opportunity to receive science professional development while being paid was appealing. During Week One of the four-week Institute, we learned how to conduct inquiry-based science teaching in a problem-based learning setting, improve science instruction by developing scientific literacy, and provide a broader view of science for our students, including scientific knowledge, methods of science, and the Nature of Science. In Weeks Two and Three, we taught inquiry-based science collaboratively with other area elementary teachers to high-needs students in a summer science camp. Our theme was space exploration. Week Four brought the real test: how do we take what we learned over the summer and implement inquiry-based science instruction in our own academic classrooms in Middlesex County, Virginia?

The Problem, the Proposal, and the Process

Middlesex County is a rural area nestled among several waterways boasting 135 miles of linear shoreline along the Rappahannock River, the Piankatank River, Stingray Point, and the Chesapeake Bay. So, when tasked with developing a Problem-Based Learning unit to deliver to

our students, it was only natural that we chose one that not only met the objectives of our curriculum, but also was indigenous to our area. We read in the local newspapers that, at the time of our Summer Institute, some of our area waterways had been closed to shellfish harvesting. The amount of harvestable water acreage had decreased from 100,000 to 50,000 acres. With so many watermen and women in our area and others with ties to the local waterways, we chose natural resources and watersheds as the theme for our unit.

The Virginia Initiative for Science Teaching and Achievement (VISTA) defines Problem-Based Learning (PBL) as students solving a problem with multiple solutions over time like a scientist in a real-world context. The first step in writing our PBL unit was to establish the overarching question or problem. It had to be a real scientific problem with multiple solutions stated as a question to be solved over time. Since our unit of study was natural resources and watersheds, we chose the question, “How can we improve the health of our local waterways?” Problem-Based Learning provides authentic problem solving and hands-on, self-directed learning with the teacher serving the role of coach. According to Gallagher, “Fundamental to PBL is the ill-structured problem that drives the learning experience” [1]. Gallagher goes on to define an ill-structured question as one where elements of the problem are unclear or missing. It can change with additional information. It is authentic in that it is modeled on circumstances in the real world. It is flexible and sometimes ambiguous as it offers multiple possible solutions and, like real-world problems, it permeates many disciplines [1]. A PBL unit is designed around a core curriculum, in our case VISTA’s Nature of Science (see Figure 1) and Virginia’s *Standards of Learning (SOL)* (see Table 1), and addresses specific content learning goals [2]. Because of its “fuzzy” or ill-defined structure, however, teachers may initially feel apprehensive, especially as the teacher’s role changes to that of a facilitator or coach and students direct their own learning; but as teachers see students employing higher-level thinking skills and cognitive sophistication, their apprehensions are assuaged. Although Problem-Based Learning involves an ill-structured question, it actually requires quite a lot of planning.

Secondly, we developed our question map using the Virginia’s *Science Standards of Learning*, pens, a pad of sticky notes, and a wall of sheet glass windows [3]. We had to anticipate where students would go with their thinking, what resources and background knowledge they would need, what problems or misconceptions they might have, and how we would assess their progress along the way. After hours of rearranging and replacing questions on sticky notes

placed on window panes, we created the question map and the proposal (see Figure 2 and Table 2) and transferred our thoughts from glass to paper to computer, and on to the classroom.

NATURE OF SCIENCE (NOS)
*Science demands evidence
*Science uses a blend of logic and imagination
*Scientific ideas are durable yet subject to change
*Science is a social activity
*Scientists attempt to avoid bias
*Scientific knowledge is the product of observation and inference
*Scientific laws and theories are different kinds of scientific knowledge
*Scientists use many methods to develop scientific knowledge

Figure 1. Nature of Science from the Virginia Initiative for Science Teaching and Achievement (VISTA).

Table 1
Virginia's Standards of Learning 2014

Subject	Grade Level	Standard
Science 2010	3	<p>3.1The student will demonstrate an understanding of scientific reasoning, logic, and the nature of science by planning and conducting investigations in which</p> <ul style="list-style-type: none"> a) observations are made and are repeated to ensure accuracy; b) predictions are formulated using a variety of sources of information; c) objects with similar characteristics or properties are classified into at least two sets and two subsets; d) natural events are sequenced chronologically; e) length, volume, mass, and temperature are estimated and measured in metric and standard English units using proper tools and techniques; f) time is measured to the nearest minute using proper tools and techniques; g) questions are developed to formulate hypotheses; h) data are gathered, charted, graphed, and analyzed; i) unexpected or unusual quantitative data are recognized; j) inferences are made and conclusions are drawn; k) data are communicated; l) models are designed and built; and, m) current applications are used to reinforce science concepts.
		<p>3.4The student will investigate and understand that adaptations allow animals to satisfy life needs and respond to the environment. Key concepts include</p> <ul style="list-style-type: none"> a) behavioral adaptations; and, b) physical adaptations.

		<p>3.5 The student will investigate and understand relationships among organisms in aquatic and terrestrial food chains. Key concepts include</p> <ol style="list-style-type: none"> producer, consumer, decomposer; herbivore, carnivore, omnivore; and, predator and prey.
		<p>3.6 The student will investigate and understand that ecosystems support a diversity of plants and animals that share limited resources. Key concepts include</p> <ol style="list-style-type: none"> aquatic ecosystems; terrestrial ecosystems; populations and communities; and, the human role in conserving limited resources.
		<p>3.8 The student will investigate and understand basic patterns and cycles occurring in nature. Key concepts include</p> <ol style="list-style-type: none"> patterns of natural events such as day and night, seasonal changes, simple phases of the moon, and tides; animal life cycles; and, plant life cycles.
		<p>3.9 The student will investigate and understand the water cycle and its relationship to life on Earth. Key concepts include</p> <ol style="list-style-type: none"> there are many sources of water on Earth; the energy from the sun drives the water cycle; the water cycle involves several processes; water is essential for living things; and, water on Earth is limited and needs to be conserved.
		<p>3.10 The student will investigate and understand that natural events and human influences can affect the survival of species. Key concepts include</p> <ol style="list-style-type: none"> the interdependency of plants and animals; the effects of human activity on the quality of air, water, and habitat; the effects of fire, flood, disease, and erosion on organisms; and, conservation and resource renewal.
		<p>3.11 The student will investigate and understand different sources of energy. Key concepts include</p> <ol style="list-style-type: none"> energy from the sun; sources of renewable energy; and, sources of nonrenewable energy.
	4	<p>4.1 The student will demonstrate an understanding of scientific reasoning, logic, and the nature of science by planning and conducting investigations in which</p> <ol style="list-style-type: none"> distinctions are made among observations, conclusions, inferences, and predictions; objects or events are classified and arranged according to characteristics or properties; appropriate instruments are selected and used to measure length, mass, volume, and temperature in metric units; appropriate instruments are selected and used to measure elapsed time; predictions and inferences are made, and conclusions are

		<p>drawn based on data from a variety of sources;</p> <ul style="list-style-type: none"> f) independent and dependent variables are identified; g) constants in an experimental situation are identified; h) hypotheses are developed as cause and effect relationships; i) data are collected, recorded, analyzed, and displayed using bar and basic line graphs; j) numerical data that are contradictory or unusual in experimental results are recognized; k) data are communicated with simple graphs, pictures, written statements, and numbers; l) models are constructed to clarify explanations, demonstrate relationships, and solve needs; and, m) current applications are used to reinforce science concepts.
		<p>4.4The student will investigate and understand basic plant anatomy and life processes. Key concepts include</p> <ul style="list-style-type: none"> a) the structures of typical plants and the function of each structure; b) processes and structures involved with plant reproduction; c) photosynthesis; and, d) adaptations allow plants to satisfy life needs and respond to the environment.
		<p>4.5The student will investigate and understand how plants and animals, including humans, in an ecosystem interact with one another and with the non-living components in the ecosystem. Key concepts include</p> <ul style="list-style-type: none"> a) plant and animal adaptations; b) organization of populations, communities, and ecosystems and how they interrelate; c) flow of energy through food webs; d) habitats and niches; e) changes in an organism's niche at various stages in its life cycle; and, f) influences of human activity on ecosystems.
		<p>4.9The student will investigate and understand important Virginia natural resources. Key concepts include</p> <ul style="list-style-type: none"> a) watersheds and water resources; b) animals and plants; c) minerals, rocks, ores, and energy sources; and, d) forests, soil, and land.
		<p>5.6The student will investigate and understand characteristics of the ocean environment. Key concepts include</p> <ul style="list-style-type: none"> a) geological characteristics; b) physical characteristics; and, c) ecological characteristics.
		<p>5.7The student will investigate and understand how Earth's surface is constantly changing. Key concepts include</p> <ul style="list-style-type: none"> f) weathering, erosion, and deposition; and, g) human impact.

	6	<p>6.1 The student will demonstrate an understanding of scientific reasoning, logic, and the nature of science by planning and conducting investigations in which</p> <ol style="list-style-type: none"> observations are made involving fine discrimination between similar objects and organisms; precise and approximate measurements are recorded; scale models are used to estimate distance, volume, and quantity; hypotheses are stated in ways that identify the independent and dependent variables; a method is devised to test the validity of predictions and inferences; one variable is manipulated over time, using many repeated trials; data are collected, recorded, analyzed, and reported using metric measurements and tools; data are analyzed and communicated through graphical representation; models and simulations are designed and used to illustrate and explain phenomena and systems; and current applications are used to reinforce science concepts.
		<p>6.7 The student will investigate and understand the natural processes and human interactions that affect watershed systems. Key concepts include</p> <ol style="list-style-type: none"> the health of ecosystems and the abiotic factors of a watershed; the location and structure of Virginia's regional watershed systems; divides, tributaries, river systems, and river and stream processes; wetlands; estuaries; major conservation, health, and safety issues associated with watersheds; and, water monitoring and analysis using field equipment including hand-held technology.
		<p>6.9 The student will investigate and understand public policy decisions relating to the environment. Key concepts include</p> <ol style="list-style-type: none"> management of renewable resources; management of non-renewable resources; the mitigation of land-use and environmental hazards through preventive measures; and, cost/benefit tradeoffs in conservation policies.
VA Studies 2008	4	<p>VS 2 The student will demonstrate knowledge of the physical geography and native peoples, past and present, of Virginia by</p> <ol style="list-style-type: none"> locating and describing Virginia's Coastal Plain (Tidewater), Piedmont, Blue Ridge Mountains, Valley and Ridge, and Appalachian Plateau.
		<p>VS 2 The student will demonstrate knowledge of the physical geography and native peoples, past and present, of Virginia by</p> <ol style="list-style-type: none"> locating and identifying water features important to the early history of Virginia (Atlantic Ocean, Chesapeake Bay, James River, York River,

		Potomac River, Rappahannock River, and Lake Drummond and the Dismal Swamp).
		VS 10The student will demonstrate knowledge of government, geography, and economics by b) describing the major products and industries of Virginia’s five geographic regions.

Question Map

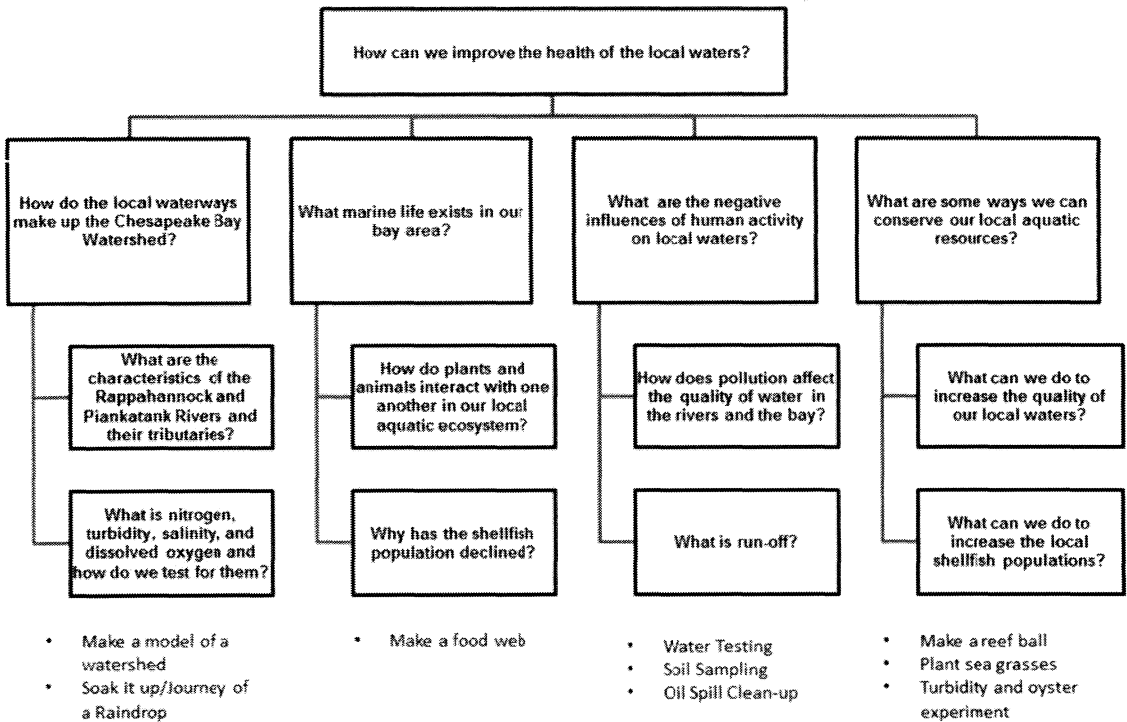


Figure 2. Question Map from the VISTA template.

Table 2**Problem-Based Learning Unit Proposal**

Theme <i>(Science Topic)</i>	Natural Resources
Problem <i>(Real scientific problem with multiple solutions stated as a question that will be solved over time)</i>	How can we improve the health of the local waters?
Student Roles <i>(Authentic scientist roles for students)</i>	C.R.A.B.S.—Conservation, Research and Bay Scientists Science Investigators for the Virginia Department of Health.
Scenario <i>(Real situation and setting that is interesting and plausible)</i>	Area waters in Gloucester, Matthews, and Middlesex have been closed to shellfish harvesting. The amount of harvestable water acreage has decreased from 100,000 to 50,000 acres in the past 12 months. The Virginia Department of Health has commissioned you as science investigators—CRABS—to help the local watermen regain and restore their fishing grounds.
Resources <i>(Identify and evaluate likely places students will seek information to solve the problem - Internet, books, expert)</i>	Local oyster farmers, Chesapeake Bay Foundation, VIMS (Virginia Institute of Marine Science), Reedville Fisherman’s Museum, Waterman’s Museum, Christchurch School, Middlesex High School, Internet, VISTA coach, Chesapeake Bay Governor’s School
Culminating Project/Assessment <i>(Develop a final project that poses a solution)</i>	Presentation of investigations at Urbanna Oyster Education Day.
Safety <i>(Identify safety issues that</i>	Water testing, proper instruction on cutting tools for watershed

might arise as students gather information)

and reef construction.

The Delivery

The delivery came next. Students were informed of a threat that was facing their community. Area waters in Gloucester, Mathews, and Middlesex have been condemned from shellfish harvesting. The amount of harvestable water acreage had decreased from 100,000 to 50,000 acres in the past twelve months. The Virginia Department of Health commissioned them as science investigators—Chesapeake Research and Bay Specialists (C.R.A.B.S.)—to help the local watermen regain and restore their fishing grounds. Since some of the waters had been condemned, students had to determine how they could improve the health of the local waterways. Students were introduced to VISTA's definitions of the Nature of Science, and told that they would assume the role of real scientists using the tenets of the discipline to tackle this real-world issue in their community. Many students have family members who are watermen and women who make their living from the water; others live on or near the local waterways, have enjoyed water activities, such as boating, fishing, etc., and were concerned about the impact of this issue on their community and their lives. Students living or traveling near the waterways began to form hypotheses for why the waterways had been condemned. Several students mentioned concern over bridge construction near the Piankatank River. The Piankatank was one of the waterways recently closed to shellfish harvesting. Could human impact be the cause of condemned waters? One student whose father is an oyster farmer was concerned that the lack of oysters was negatively affecting the waters. Students contemplated the relationship between the oyster population and the health of the

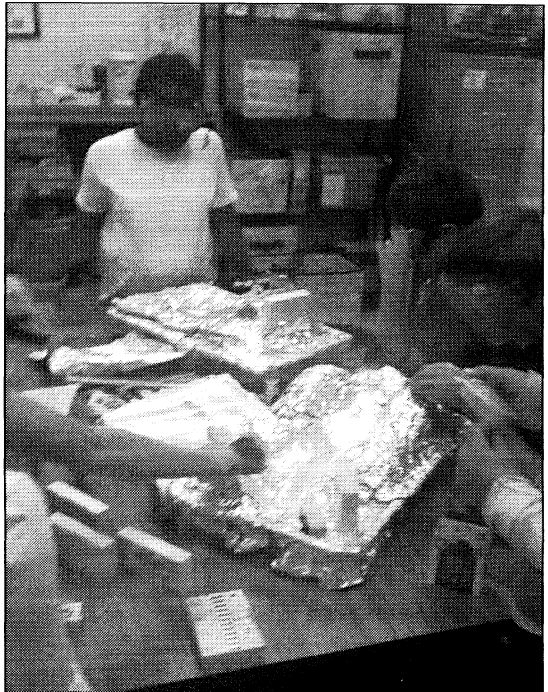


Figure 3. Students making models of watersheds.

waterways. They began to form questions. There are many waterways in the area. Are all waterways equally impacted? Are some healthier than others? How can they test the health of the waterways? Beaton and I had anticipated many of their questions on our question map, but the students raised some questions that we didn't consider. We weren't aware of the bridge construction when we were developing the lesson. We needed to include these new questions as students began their investigations.

Using key concepts from the Virginia Grades 3-6 *Science Standards of Learning* and the Nature of Science, students began to research and understand the interdependency of plants and animals in an aquatic environment. They learned that a food web shows the complex relationships between plants and animals, and how energy flows from producers to consumers to decomposers and back to producers. Bay food webs extend out of the water because land animals and humans eat from the Bay. The Nature of Science states that scientists use many methods to develop scientific knowledge, so students not only researched and investigated, but they also created models of a watershed to better understand their own local watershed, its tributaries, water resources, and characteristics. Students continued their investigations by conducting water and soil testing on samples from three local waterways: the Rappahannock River, the Piankatank River, and the Urbanna Creek.

Again, using Virginia's *Science Standards of Learning*, students studied runoff and contemplated human impact on the watershed. In the surrounding rural area, there are businesses, many farms (both animal and crop producing), wooded areas, and residences. Students noted a large paper mill on a nearby tributary. Are fertilizers and animal waste affecting the health of the local waterways? Another student mentioned a water treatment plant near her home on the Urbanna Creek. Several students referred again to the bridge construction on the Piankatank. What is the impact of the ongoing projects and businesses located directly on the waterways? Are there better practices that businesses and people in the community can employ to help improve the health of the local waterways? Science is a social activity. As students wrestled with questions and issues and then conducted investigations, they worked together cooperatively offering new insights and providing checks and balances.

One of the strengths of the VISTA program is that teachers receive ongoing support throughout the academic year as they return to their respective schools to implement their

Problem-Based Learning unit and the VISTA teaching methods into their science instruction. Our coach, Sara Beam, proved to be an invaluable resource both for her support and knowledge in our content area. Our coach is a teacher at the Chesapeake Bay Governor's School for Mathematics and Marine Science, and taught students how oyster farming can help clean area waters.

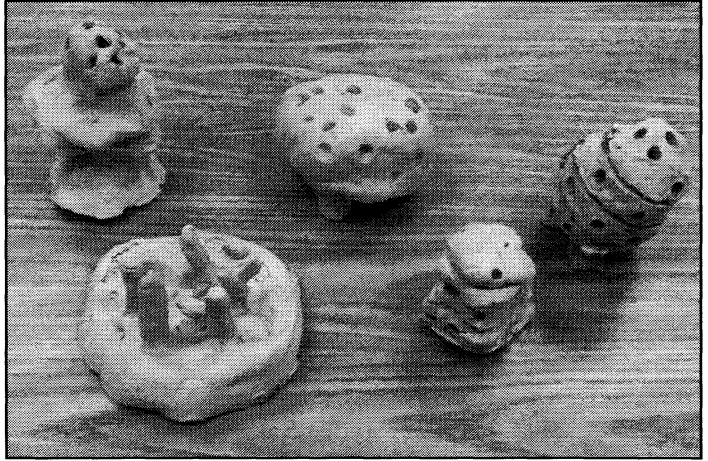


Figure 4. Students' models of reef balls.

We also partnered with VIMS (The College of William & Mary's Virginia Institute of Marine Science) to learn how to grow sea grasses and how the use of reef balls can encourage the growth of oyster populations. Students incorporated the engineering process as they researched, designed, and made their own reef ball models out of clay.

Through the process of the Problem-Based Learning unit, students learned that some of the area waters had increased algal bloom, most likely from runoff, which had adverse effects on the health of the water. They suggested that this was one of the reasons for the condemned waters, and better conservation practices would help keep contaminants and pollutants out of the water.



Figure 5. Culminating Project: student presenter on food webs at Urbanna Oyster Education Day.

Assessments were ongoing throughout the Problem-Based Learning unit. Formative assessments, such as discussion circles, classroom discussions, journal writings, investigation sheets, design briefs, and teacher observations provided constant feedback and learning checks. Models, diagrams, investigations, and oral presentations were scored according to rubrics, and used as summative assessments. Unit tests, benchmarks, and *Standards of Learning* tests were also used to assess student progress.

We concluded our unit with an exhibition. Each year in Middlesex County, the town of Urbanna holds the *Oyster*

Festival. Part of the weeklong celebration includes the Oyster Education Day which, in cooperation with the Virginia Marine Legacy Program, provides educational opportunities for schools. As their culminating project, fourth grade students from Middlesex Elementary School manned a booth and shared the findings from their Problem-Based Learning unit with other students from area schools. They explained aquatic food webs, conducted water testing, and demonstrated with models the effect of runoff in a watershed.

The Results

The first group of C.R.A.B.S. to participate in this PBL unit began as fourth graders and have just completed fifth grade. Although the sample size was small and select, and this first group of C.R.A.B.S. received subsequent science instruction from teachers who did not receive training from VISTA, it is interesting to note that this group had a 100% pass rate on the Grade 5 science *SOL*, with 78% receiving scores of Pass/Advanced and 33% receiving perfect scores, while the grade level as a whole had a pass rate of 82% with a Pass/Advanced rate of 23%. While initial results were positive, there is still little quantitative, longitudinal data yet available to comprehensively assess students' progress. Qualitatively, the next grade-level teachers receiving C.R.A.B.S. noted high science interest levels, as well as quicker concept attainment and retention in those students who participated in the Problem-Based Learning unit. Students participating in the problem-solving unit were highly engaged and enthusiastic toward learning science. In Ericson's book, *Concept-Based Curriculum and Instruction*, Caine & Caine and Perkins suggest that "if knowledge is going to be retained and understood, then students must use it in a demonstration or complex performance" [4]. The VISTA method places students at the center of hands-on, inquiry-based learning. Additionally, students are introduced to science in an authentic, real-world application operating as a professional in the field. They become well versed in the Nature of Science and are able to transfer concepts to other areas of science. They view science through the lens of a scientist.

According to Gallagher, the power of Problem-Based Learning units, such as the one described above, "is not solely in its power to deliver content but also because it delivers content in a way that opens the door to other cognitive and affective outcomes" [1]. Employing teaching and learning methods as demonstrated and exacted in the VISTA model teaches students to think conceptually and critically. Ericson suggests that to develop the thinking abilities of students systematically, educators need to develop an idea-centered model of curriculum design. Idea-centered curricula focus on deeper, conceptual ideas and use facts to support the understanding.

The Nature of Science states that science demands evidence and as such, teaches students that facts are not only critical for building content knowledge, “but are also tools for gaining insight into conceptual ideas that transfer across time and culture” [4]. The VISTA method trains teachers how to emphasize key concepts and principles, and build deeper understanding, rather than just covering a myriad of topics and facts to be learned. The Nature of Science also tells us that scientific principles are durable yet subject to change. Principles are enduring, but should be viewed in context and may be refined with new knowledge and discoveries:

Principles are key conceptual relationships that are always true and have significant roles in a discipline. They stand the test of eternal time, they will never change, and they are the cornerstones for understanding and applying the knowledge of a discipline [4].

Science is a blend of both logic and imagination. The Virginia Initiative for Science Teaching and Achievement (VISTA) encourages students and teachers to employ both while exploring new vistas. The National Research Council recognizes the *National Science Education Standards* as the most comprehensive and sound treatment of a discipline from the conceptual design perspective, and consequently provides an excellent model for writing essential conceptual understanding in other content-based disciplines [4]. The VISTA training has been transformative in our science teaching and beyond. It has given us the tools and the confidence to provide engaging, high-quality science instruction to our students. Moreover, this method of teaching is applicable to more than just science, and helps develop not just good science teachers, but good teachers overall.

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IMPACT OF A SCIENCE METHODS COURSE ON PRE-SERVICE ELEMENTARY TEACHERS' KNOWLEDGE AND CONFIDENCE OF TEACHING WITH SCIENTIFIC INQUIRY AND PROBLEM-BASED LEARNING

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Abstract

The purpose of this study was to measure the impact of an elementary science methods course on pre-service teachers' knowledge and confidence of teaching with inquiry and problem-based instructional strategies. Changes in pre-service teachers' knowledge and confidence were measured before and after completing the course activities using a pilot survey entitled "Science Pedagogical Content Knowledge & Confidence (PCKC) Survey." An integrated lecture/laboratory elementary science methods course engaged participants with hands-on activities designed to increase their pedagogical content knowledge: including theory, planning and implementation of inquiry, and problem-based learning. The results indicated that pre-service teachers' knowledge and confidence improved as a result of enrollment in the elementary science methods course. This article validates reform movements to incorporate scientific inquiry and problem-based learning into coursework.

Background

The 2012 "Program for International Student Assessment" (PISA) ranked U.S. students average in science and below average in mathematics among the world's most developed countries [1]. Similarly, the "Trends in International Mathematics and Science Study" (TIMSS) rank U.S. students behind many other developed nations [2]. Advocates for educational reform focus on teacher preparation as essential to improving the quality of science teaching and learning.

The essential components of teaching elementary science are pedagogical skills, content knowledge, and the confidence and willingness of teachers to assume responsibility for student learning. The 2002 National Science Teachers Association (NSTA) position paper recommends that “inquiry science must be a basic in the daily curriculum of every elementary school student at every grade level” [3]. Although the NSTA and other science professional organizations advocate use of inquiry in teaching science, very few elementary school teachers, especially beginning teachers, engage in this teaching strategy [4]. Zeichner and Tabachnick found that beginning teachers switch from progressive, student-centered strategies and attitudes formed during pre-service training to traditional, teacher-centered approaches when faced with the difficult realities of teaching [5]. Such difficulties include the following areas:

- 1) Unfamiliarity with science as a discipline;
- 2) Lack of science content knowledge;
- 3) Low self-efficacy with respect to science teaching;
- 4) Difficulties in assessing results of inquiry learning;
- 5) Classroom management issues; and,
- 6) Dominant commitment to preparing students for standardized testing [6].

Of these reasons, the first five are interconnected, and can be addressed by modifying the way in which pre-service teachers are trained in preparation programs. Appleton and Kindt found that beginning teachers are prone to undertake “safe” activities first (e.g., activities with predictable outcomes and/or drawn from personal experience or that of colleagues) [4]. Therefore, if such individuals have experienced science as largely book research and memorization in their own schooling, they will tend to see these activities as safe and effective. In comparison, those individuals exposed to the excitement of hands-on, inquiry-based science activities would likely see these activities as safe and effective. One of the recommendations from the Appleton and Kindt study is that education curriculum should focus on providing pre-service teachers with a repertoire of activity ideas that develop science pedagogical content knowledge [4].

Pre-service teachers who have had positive, authentic inquiry experiences during their school years and/or teacher preparation programs demonstrate improved dispositions and self-efficacy for science teaching [7-10]. In 2004, the Association for Science Teacher Education (ASTE) issued their publication, “Position Statement: Science Teacher Preparation and Career-long Development” which made the following recommendations for pre-service teachers:

...engage in activities that promote their understanding of science concepts and the history and nature of science; experience strategies for effective science teaching and inquiry, including meaningful laboratory and simulation activities using contemporary technology tools; question and evaluate evidence and justify assertions scientifically; and, develop science-specific pedagogical knowledge grounded in contemporary scholarship [11].

Unfortunately, the literature indicates that training in inquiry and problem-based instructional strategies is not consistently incorporated into the education curricula for pre-service teachers. Most teachers have never been exposed to actual inquiry unless they have previously engaged in scientific research [12, 13]. For these reasons, the authors infused a science methods course for pre-service elementary teachers with science-specific pedagogical content knowledge, including the theory, planning, and implementation of inquiry and problem-based learning.

Participants and Context

This study was facilitated during a 15-week instructional period during the Fall 2013 semester at a small liberal arts college in southeastern Virginia. All of the participants were enrolled in the science methods course and were in their junior or senior year of college. Each student was seeking a four-year Bachelor of Science degree that leads to teacher licensure. The elementary science methods course integrated the lecture and laboratory activities, met twice weekly for 2.5 hours, and included a practicum experience. The demographic of the participants included 17 African-American females, 2 Hispanic females, 1 Caucasian female, and 1 African-American male.

Two of the authors participated in the Virginia Initiative for Science Teaching and Achievement (VISTA) Science Education Faculty Academy (SEFA) during the summers of 2012 and 2013. Prior to the Academy, the science methods course involved pre-service teachers with the investigation of and participation in the science process skills. Investigatory activities were completed each week in the scientific areas of earth sciences, biology, chemistry, and physics. Other course activities included science safety in the classroom and integrated teaching.

As a consequence of the training, the science methods course was revised to adopt the VISTA goal of exposing elementary teachers to “scientific, problem-based learning and student-centered inquiry as they work in teams to conduct inquiry-based science for children” [14]. As indicated by the syllabus, the revised course emphasized SEFA topics, including hands-on learning, inquiry, Problem-Based Learning, Nature of Science, Next Generation Science Standards, scientific discourse, and engineering design briefs. The authors selected the course textbook *Ready, Set, Science!: Putting Research to Work in K-8 Science Classrooms*, and many of the assigned journal readings were based on their SEFA experiences [15].

Table 1
Science Methods Course Schedule

Dates	Topics	Journal Readings
Week 1	Introduction and Course Overview and Expectations	
Week 2	STEBI-B, PCKC Survey, Science Content Assessment, and Focus Groups	
Weeks 3 & 4	Nature of Science, Hands-on activities; Inquiry-based learning; National, state, and local science standards;	<i>The Nuts and Bolts of Introducing Science Notebooks Into Your Science Teaching Practice</i>
Week 5	Teaching the Nature of Science; Scientific Discourse	<i>Executive Summary on the Nature of Science; Talking Science; Establishing Classroom Norms for Discussion</i>
Week 6	Science process skills; 5E Learning Cycle; Assessing Science Learning	<i>Engaging Elementary Students in STEM Summer Camp; How Classroom Assessments Improve Learning</i>
Week 7	Problem-Based Learning; Integrating Science across the Curriculum; midpoint PCKC Survey; Midterm Exam Assessment	<i>Modeling Problem-Based Instruction; Weather Tamers; Motor Mania: Revving Up For Technological Design</i>
Week 8	Science and Engineering	<i>Science and Engineering</i>
Week 9 & 10	Problem-Based Learning Unit Presentations	
Weeks 11 - 14	Class suspended for Practicum	
Week 15	Post-STEBI-B, Post-PCKC Survey, Focus Groups Practicum Reflections Final Exam Assessment	

At the start of the semester, pre-service teachers were provided with the VISTA definition of Hands-on Learning as “Students purposefully manipulating *real science materials* when safe and appropriate in a way *similar to a scientist*,” and Inquiry as the “careful and systematic method of asking questions and seeking explanations” [16, 17]. The National Science Education Standard (NSES) model of the essential five features of inquiry in the classroom was utilized as a guideline for development of inquiry activities [18].

Table 2
NSES Essential Features of Inquiry

Essential Features of Classroom Inquiry and Their Variations				
Essential Feature	Variations			
1. Learner engages in scientifically oriented questions	Learner poses a question	Learner selects among questions, poses new questions	Learner sharpens or clarifies question provided by teacher, materials, or other source	Learner engages in question provided by teacher, materials, or other source
2. Learner gives priority to evidence in responding to questions	Learner determines what constitutes evidence and collects it	Learner directed to collect certain data	Learner given data and asked to analyze	Learner given data and told how to analyze
3. Learner formulate explanations from evidence	Learner formulates explanations after summarizing evidence	Learner guided in process of formulating explanations from evidence	Learner given possible ways to use evidence to formulate explanation	Learner provided with evidence
4. Learner connects explanations to scientific knowledge	Learner independently examines other resources and forms the links to explanations	Learner directed toward areas and sources of scientific knowledge	Learner given possible connections	
5. Learner communicates and justifies explanations	Learner forms reasonable and logical argument to communicate explanations	Learner coached in development of communication	Learner provided broad guidelines to use sharpen communication	Learner given steps and procedures for communication
<i>More</i> ←----- <i>Amount of Learner Self-Direction</i> -----→ <i>Less</i>				
<i>Less</i> <----- <i>Amount of Direction from Teacher or Material</i> -----> <i>More</i>				
<i>Source: National Research Council, 2000. Inquiry and the National Science Education Standards: A Guide for Teaching and Learning. Washington, DC: National Academy Press, 29.</i>				

The goal of the science methods course was to provide science pedagogical content knowledge. Although students take twelve credit hours of science during this program, time

limitations did not allow the instructor to address specific gaps in science content knowledge during this one-semester course. It is well accepted that relevant coursework in science and teacher content knowledge is a strong indicator in predicting science achievement of their students [19]. If teachers do not know the Science, Technology, Engineering, and Mathematics (STEM) content, then most students will not learn it [20].

The science content discussed in this methods course was broad and encompassed physical, chemical, and biological science. Pre-service teachers were given the tools to identify and remediate specific areas of science content weakness. At the beginning of the semester, the pre-service teachers were given a science content assessment based on Virginia's grade 5 *Standards of Learning (SOL)* science test release items. As a follow-up activity, pre-service teachers registered for and explored the resources on the NSTA Learning Center [21]. They were advised to complete the professional development indexers to diagnose specific science content needs and remediate areas of weakness using SciPacks.

The semester began with a pendulum inquiry experiment in which pre-service teachers were given one of two investigative questions: "What is the effect of string length on the period of a pendulum?" and "What is the effect of bob mass on the period of a pendulum?" Working in teams of four, they were challenged to propose a hypothesis and then develop the experimental design that would test the effect of string length and mass on the period of the pendulum. Assistance provided by the instructor was intentionally limited to allow the pre-service teachers to brainstorm ideas. The experimental design was an enormous challenge because their only prior experience with science had primarily been following "cookbook labs." These very prescriptive labs teach basic skills, such as using scientific equipment, measuring, observing, inferring, etc., but they rarely support inductive reasoning, inquiry, or the authentic nature of science [22]. The pre-service teachers were further challenged to determine the type of data needed to address their hypothesis, to analyze their data beyond superficial observations, and to make relevant conclusions. Initially, class discussions were limited to "my results support my hypothesis" or "my results do not support my hypothesis." They struggled with understanding the significance of their results and were obsessed with knowing whether their results or answers were "right or wrong."

In a follow-up activity, the pre-service teachers were randomly given existing cookbook lab exercises and tasked with converting them into inquiry, student-centered activities following

the method of Corder and Slykhuis, i.e., replace, retain and modify, and remove [23]. The pre-service teachers replaced standard introductory descriptions and background information with investigative questions. The class definition of an effective investigative question was one that has something to measure and/or compare. Next, they modified the procedure by simplifying the directions, but retained the investigative parameters and safety guidelines. Finally, they removed the results tables to allow students to create their own methods for organizing data. For each converted lab, the pre-service teachers had to anticipate their students' potential responses by developing procedures for each investigative question and data tables for the results. Table 3 is an example of a converted lab. The pre-service teachers seemed to appreciate learning that developing inquiry labs from existing lab procedures need not be complicated or intimidating.

Table 3
From Cookbook Lab to Inquiry Lab

Example Cookbook Lab – Static Electricity

Background: Rubbing a balloon creates a buildup of negatively-charged electrons on the surface called static electricity. Electrons can pull very light positively-charged items toward them. Specific procedure:

1. Place an empty aluminum can on its side on a table.
2. Blow up a balloon, and rub it back and forth through your hair really fast.
3. Hold the balloon close to the can without actually touching the can. Static electricity will roll the can toward the balloon.
4. Measure and record the distance moved in millimeters.

Example Inquiry Lab – Static Electricity

Demonstrate the cookbook lab to students during the anticipatory set to promote student-directed development of investigative questions.

Potential investigative questions that might be developed by students:

- What effect does balloon size have on the power of the pull?
- Are there materials other than hair that cause static electricity?
- Will all types of hair cause static electricity?
- Will the balloon pull all types of cans?
- Will the balloon pull other items?
- How strong is the pull of the balloon?
- Can water be added to the can? How much water can be added until the balloon can't pull it anymore?

Materials

- Assortment of materials to test for developing static electricity: wool, cotton and other fabric materials; human and artificial hair.
- Assortment of materials to test the strength of the pull: cans of different sizes and materials, packing peanuts, tissue paper, etc.
- Water.

Directions:

1. Design and conduct an experiment to answer your investigative question.
2. Be mindful of all the class safe laboratory procedures.
3. Record the data in a manner that allows you to share with the class.

At the semester midterm, the pre-service teachers were tasked with individually developing lesson plans aligned with a Virginia Science *SOL* and incorporating the NSES essential five features of inquiry. They were encouraged to examine existing lesson plans on specific websites and modify them to meet the assignment. Similarly, as noted in the findings of Yoon, Joung and Kim, the pre-service teachers were uncertain in their “decision making in when and what to guide, and what to leave open” in the development of these inquiry lessons, particularly for K-3 lesson plans [24]. The pre-service teachers struggled most with creating inquiry lessons in which the actual answer to investigative questions might not be immediately known, or for which multiple solutions were possible. This discomfort undoubtedly stems from the fact that many of their prior laboratory experiences had been cookbook lab activities, where there was only one predetermined, possible answer to the “research” question. During in-class constructive feedback from the authors, they were able to make improvements to their lesson plans. Unfortunately, time limitations of the course did not allow the pre-service teachers to teach their lesson plans.

The science methods course utilized Problem-Based Learning (PBL) as a curricular approach or framework for structuring science content into a unit of study. The pre-service teachers were given the VISTA definition of PBL as “Students solving a problem with multiple solutions over time like a scientist in a real-world context” [17]. Examples of Problem-Based Learning were introduced to the pre-service teachers using the VISTA journal articles, “Modeling Problem-Based Instruction,” “Weather Tamers,” and “Motor Mania: Revving Up For Technological Design” [25-27]. A great deal of time was spent on examining the essential elements of effective PBL lessons. Emphasis was placed on making the PBL lessons authentic and meaningful to students, using community settings and/or partners, and embedding Virginia *SOL* science content into a course of study over two to five weeks.

As a classroom project, pre-service teachers worked in teams composed of three to four students to create a PBL unit appropriate for an elementary grade science class. The assigned VISTA articles served as the template for development of these PBL lessons. Groups were encouraged to use any curriculum resources and materials available. Inquiry activities did not have to be original; however, they had to allow students to ask scientific questions, collect evidence, develop explanations, and communicate solutions justified by evidence. In groups, pre-service teachers presented the components of the PBL unit to the science methods class for evaluation and feedback.

Pre-service teachers were placed into local elementary school settings for a four-week practicum during the last one-third of the science methods course. They were instructed to observe science lessons, and determine the degree to which the mentoring teachers incorporated the instructional strategies discussed in the science methods class. Each pre-service teacher interviewed his/her mentor teachers to determine what s/he believed are the key factors and challenges of teaching science. They interviewed the students to find out what students like or dislike in learning science. A course written assignment required the pre-service teachers to summarize their observations and interviews, and to reflect on how the practicum impacted their feelings on teaching science in elementary school. Practicum experiences and reflections were shared with peers during the last week of the science methods class.

Methodology—Analysis of Results

Instrumentation — In this study, the participants completed a pilot survey entitled, “Science Pedagogical Content Knowledge & Confidence (PCKC) Survey,” developed by the authors of this study. The purpose of this Survey was to evaluate self-reported levels of confidence in the pre-service teachers’ ability to teach science and their knowledge for science teaching. This Survey was developed around the idea that the two constructs, confidence and knowledge, are needed for successful science teaching (see Appendices A and B). The items were written and selected based on the information presented in the elementary science methods course. The Survey contained twenty items related to the pre-service teachers’ *knowledge* of the content and twenty items related to *confidence* in their ability to teach the subject. The Survey asked participants to rate themselves on a 5-point Likert scale, ranging from 1 (strongly disagree) to 5 (strongly agree). A pre-test administration of the Survey occurred in August, while the post-test occurred in December of the same semester. Initial reliability measures were calculated. The

construct of *knowledge* had a Cronbach's alpha of $\alpha = .78$, while the construct of *confidence* provided a result of $\alpha = .77$. An overall measure of internal consistency was also calculated and the instrument was found to have a reliability measure of $\alpha = .88$.

Procedures — In the first week of the course, the participants received a briefing about the study, and were asked to provide consent for participation. The pre-test administration of the PCKC Survey served as a benchmark indicating the participants' belief in their confidence for teaching with scientific inquiry and Problem-Based Learning. In the semester course, the pre-service teachers were exposed to various tasks and activities that were designed to expose them to these instructional strategies. The coursework was explained in a previous section. The post Survey was given before midterm because these activities were held in the first half of the semester. The author wanted to make sure the pre-service teachers completed the Survey in a time period close to their actual experience with these specific instructional strategies in the methods course.

Analysis of Results— Results of the PCKC Survey were examined by individual construct and then in its entirety. The twenty items related to participants' *knowledge* in teaching science were examined to determine differences between pre-test and post-test results. Of the twenty items, only one (item 19) did not demonstrate an increase in the overall mean from pre-test to post-test. This item asked pre-service teachers to rate their knowledge in effectively utilizing technology (in addition to *PowerPoint*) when teaching. The pre-test mean for item 19 was 4.37, while the post-test mean was 4.33. However, the standard deviation did decrease, which would indicate that the spread of scores varied less in the post-test than in the pre-test administration (pre-test SD = .831, post-test SD = .730). This result may not be surprising as millennial-age college students are believed to have an advanced understanding of the use of technology. An examination of overall standard deviations for the twenty items related to *knowledge* found that two items (items 10 and 14) demonstrated an increase in the variance of responses as indicated by the standard deviation. The standard deviation pre-test for item 10 was .702, while the post-test was .921. For item 14, the standard deviation in the pre-test was .653 while the post-test was 1.065. The remaining eighteen items demonstrated a decrease in the variance in scores from the pre-test to post-test.

Next, the twenty items for the construct of *confidence* were examined for differences from pre-test to post-test. For the twenty items specific to *confidence*, all demonstrated an increase in ratings from the pre-test to post-test. Similar findings occurred when reviewing

differences in the standard deviations from pre-test to post-test. Figures 1 and 2 denote the differences in means from pre-test to post-test for selected Survey items.

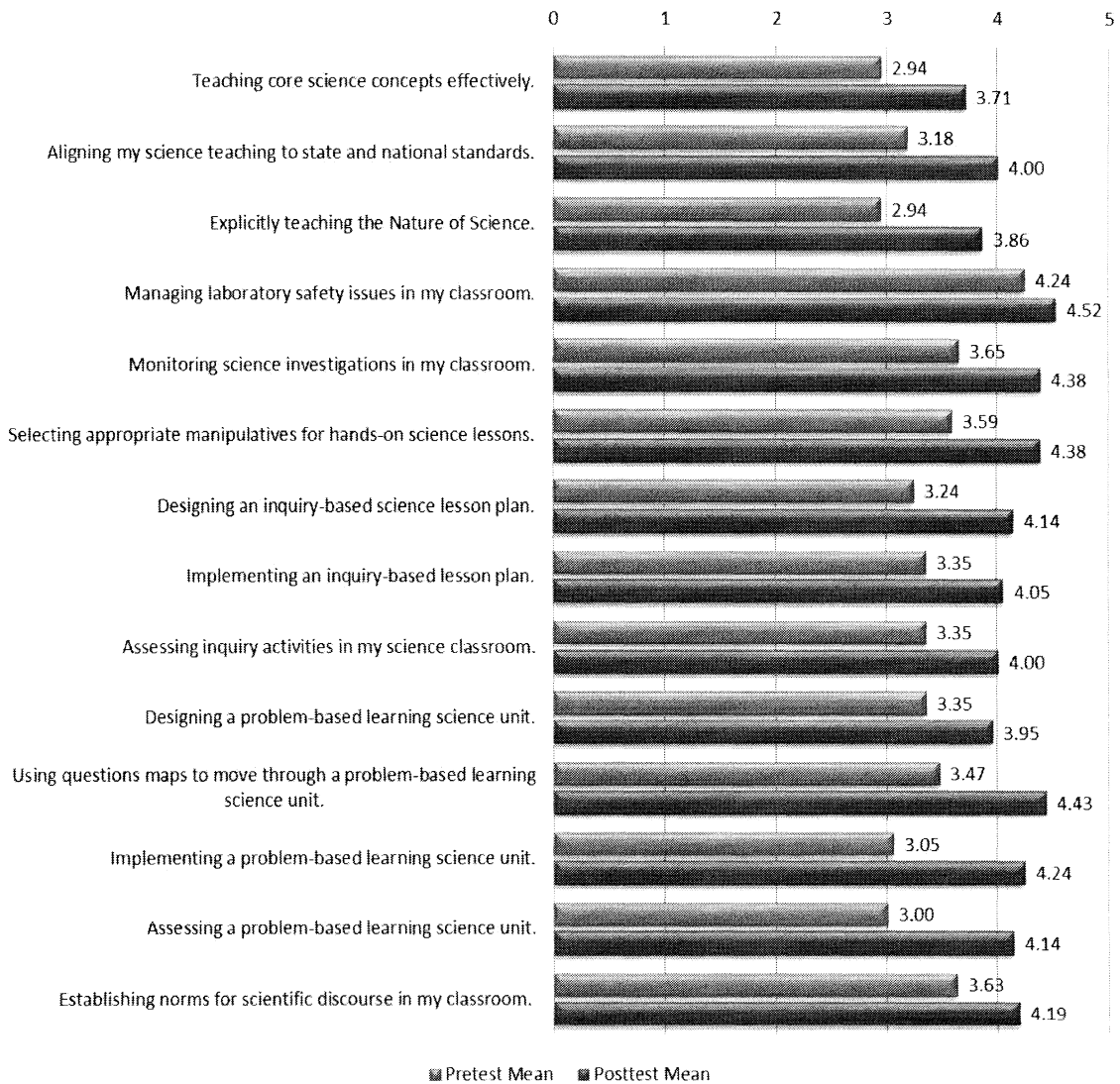


Figure 1. Likert scale ratings for completion of the phrase “I am knowledgeable about...”

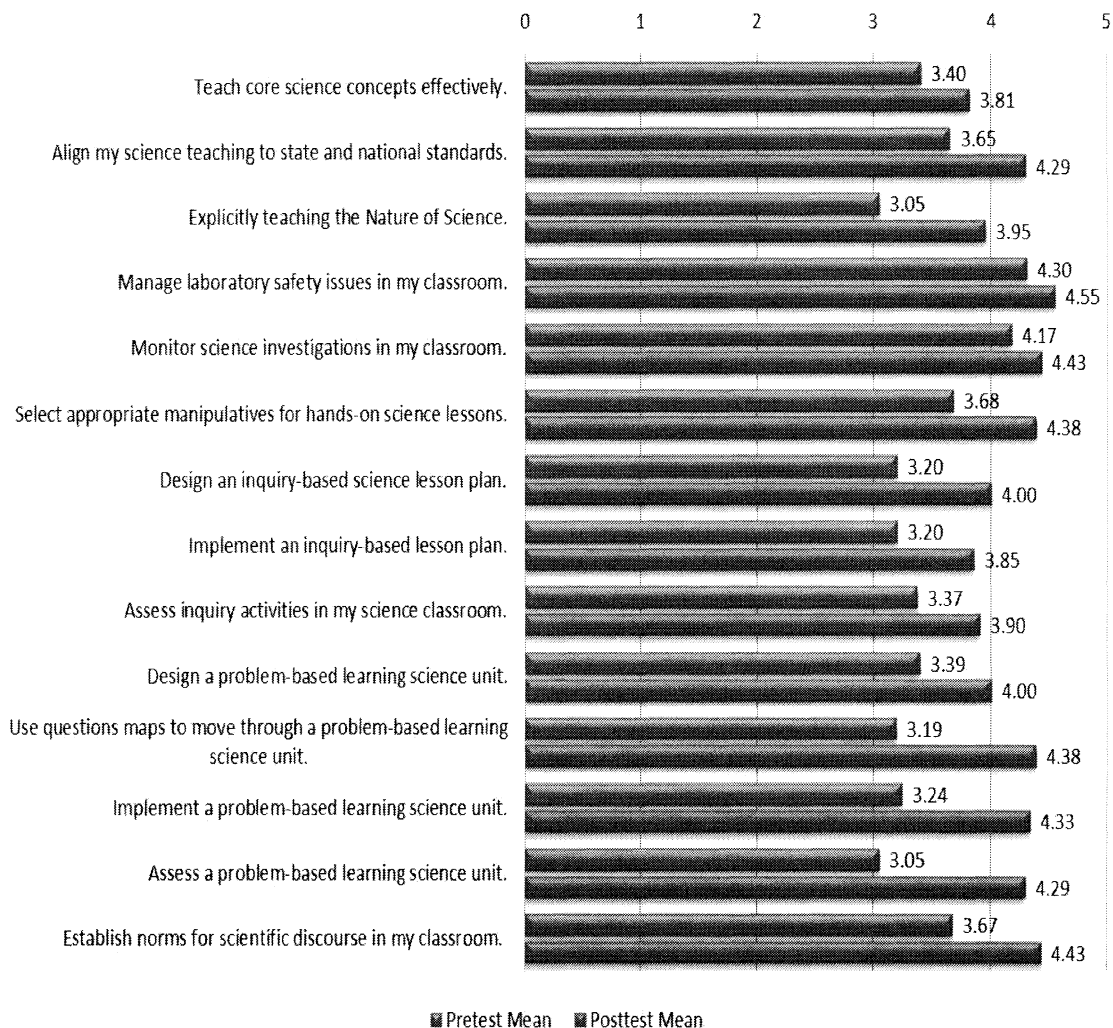


Figure 2. Likert scale ratings for completion of the phrase “I am confident in my ability to...”

The next analysis completed was the paired samples *t*-test. The paired samples *t*-test is run when comparing the means from a pre-test and post-test for the same group of participants. First, a paired samples *t*-test was run for the Survey items by construct. Results of the *t*-test for *knowledge* indicated a statistically significant difference between pre-test and post-test scores for the twenty items: $t(19) = -10.226, p = .000$. A second *t*-test was run for the items associated with the construct of *confidence*. Again, statistically significant results were found:

$t(19) = -9.866$, $p = .000$. Finally, a third t -test was run which was inclusive of all forty Survey items. Results indicated a significant result for the entire Survey, indicating that the participants' scores from the pre-test to the post-test had increased ($t(39) = -14.403$, $p = .000$). The mean for pre-test scores was calculated to be $M=3.29$, with $SD=.549$. Post-test scores were $M=4.10$, $SD = .281$.

Table 4
 t -Test Results

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Knowledge Pre-test Score- Post-test Score	-.86300	.37740	.08439	-1.03963	-.68637	-10.226	19	.000
Confidence Pre-test Score- Post-test Score	-.76250	.33718	.07540	-.92031	-.60469	-10.113	19	.000
Overall Pre-test Score- Post-test Score	-.81275	.35689	.05643	-.92689	-.69861	-14.403	39	.000

Overall, reliability measures confirmed internal consistency of the constructs, as well as the overall instrument. Individual means for the forty items for knowledge and confidence demonstrated gains from the pre-test administration to the post-test administration except for one item related to the construct of *knowledge*. The one item that did not produce a higher mean for the post-test was related to students' knowledge of the use of technology when teaching.

Discussion

Consistent with the literature, this study indicates science methods courses can improve the knowledge and confidence of pre-service elementary teachers to teach science. On the first

day of class, the pre-service teachers expressed anxiety about their science knowledge and/or pedagogy. Their lack of confidence aligns with current research on the reluctance of elementary teachers to teach science [28, 29]. The overall results of the PCKC Survey do indicate significant differences from the pre-test scores to the post-test scores for the pre-service teachers enrolled in the science methods course. The pre-service teachers demonstrated enhanced knowledge and confidence of teaching with scientific inquiry and Problem-Based Learning. There was no initial assumption by the authors that pre-service teachers' knowledge would be higher or lower than confidence prior to the start of the study, or as a result of training received in the science methods course.

The pre-service teachers were introduced to the pedagogical content knowledge and then participated in group and/or partner activities that helped them “unpack” these concepts. As noted earlier, they were involved in creating specific activities on authentic scientific inquiry and problem-based learning. This pedagogy impacted the pre-service teachers' science thinking and learning because it encouraged them to engage in problem solving, decision making, collaboration, and critical thinking. Learning these skills enhanced their knowledge and confidence for future science teaching. These experiences, which incorporated the Virginia elementary science *SOL*, could easily be taught in an elementary school classroom. This format promoted learning that helped pre-service teachers see the practical applications of the content pedagogy, and understand the theory behind the practice.

Qualitative statements collected from participants as part of the Survey helped the authors discern the pre-service teachers' perceptions of their knowledge and confidence for teaching science in elementary school. One participant noted during the pre-test Survey, “[I don't] think I have enough knowledge about science to teach it effectively.” At the end of the semester after participation in the PBL activities, she then stated, “I have been exposed to more effective methods of teaching.” Another pre-service teacher initially felt, “I do not think I know enough to teach another person,” but at the end of the semester, told the authors that “I can do anything I set my mind to.” The authors feel that these changes were due to the interactive and “hands-on” nature of the course.

Simply providing educational theories or instructional strategies is insufficient to develop the necessary Pedagogical Content Knowledge (PCK) and skills [30]. Yoon and Kim demonstrated the importance of an inquiry-based teaching practicum for the development of

elementary science teachers [24]. Following a four-week teaching practicum, pre-service teachers had the opportunity to reflect on their experiences. With few exceptions, most reported observing little or no inquiry science teaching in the elementary classrooms. Problem-Based Learning was not utilized in any of the school settings. The pre-service teachers found the practicum experience to be a weakness of the science methods course. This finding supports literature that indicates pre-service teachers often do not observe appropriate models of the inquiry-based science pedagogy during field base experiences [31]. The pre-service teachers wanted to observe implementation of the science methods course instructional strategies in the elementary school classrooms. As a recommendation for course improvement, they requested practicum placements in classrooms with mentoring teachers that have been trained in the VISTA program. They also wanted to develop inquiry lesson plans that could be implemented during their practicum. Findings by methods course instructors support allowing pre-service teachers to design PBL units for implementation in the classroom with the cooperation of veteran K-12 teachers [32]. It is expected that placement of pre-service teachers in classrooms with highly effective science teachers will be simplified once more teams of elementary teachers in the surrounding school districts participate in VISTA.

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Appendix A
Construct of Knowledge

Sample constructs of the questionnaire: "I am knowledgeable about..."

1. teaching core science concepts effectively.
2. aligning my science teaching to state and national standards.
3. explicitly teaching the Nature of Science.
4. managing laboratory safety issues in my classroom.
5. monitoring science investigations in my classroom.
6. selecting appropriate manipulatives for hands-on science lessons.
7. designing an inquiry-based science lesson plan.
8. implementing an inquiry-based lesson plan.
9. assessing inquiry activities in my science classroom.
10. designing a problem-based learning science unit.
11. using question maps to move through a problem-based learning science unit.
12. implementing a problem-based learning science unit.
13. assessing a problem-based learning science unit.
14. establishing norms for scientific discourse in my classroom.

Appendix B

Construct of Confidence

Sample constructs of the questionnaire: “I am confident in my ability to...”

1. teach core science concepts effectively.
2. align my science teaching to state and national standards.
3. explicitly teach the Nature of Science.
4. manage laboratory safety issues in my classroom.
5. monitor science investigations in my classroom.
6. select appropriate manipulatives for hands-on science lessons.
7. design an inquiry-based science lesson plan.
8. implement an inquiry-based lesson plan.
9. assess inquiry activities in my science classroom.
10. design a problem-based learning science unit.
11. use question maps to move through a problem-based learning science unit.
12. implement a problem-based learning science unit.
13. assess a problem-based learning science unit.
14. establish norms for scientific discourse in my classroom.

SCIENCE LEADERSHIP: IMPACT OF THE NEW SCIENCE COORDINATORS ACADEMY

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Abstract

This article discusses the impact of the New Science Coordinators Academy (NSCA) on two cohorts of participants. The NSCA is one of four components of the Virginia Initiative for Science Teaching and Achievement (VISTA), a United States Department of Education (USED) science education reform grant. The NSCA is designed to support new school district science coordinators (with less than five years of experience) and to continue building the state science education infrastructure. Research in education leadership traditionally focuses on teacher leaders, principals, and district office personnel. Interestingly, research on district office personnel rarely distinguishes between the different roles of district personnel. This article seeks to inform the field by sharing the impact of an academy designed for new science coordinators on their learning, and to begin to understand their role and impact in their district. The five-day Academy engaged participants in a variety of experiences designed to facilitate the following: 1) build leadership skills; 2) build a common understanding and vision for hands-on science, inquiry, problem-based learning, and nature of science in the science classroom; 3) investigate data to improve student learning goals; 4) and, develop a science strategic plan. The data indicate that the NSCA was successful at meeting its goals to support the participants and to build a common language among these new coordinators. Initial data also support the variety of responsibilities of these participants and the positive impact of the Academy on their district work.

As education professionals continue to investigate strategies to improve teaching and learning in schools, an important question arises: Does leadership matter? According to Leithwood and Wahlstrom, leadership does matter [1]. Another important question arises as to the types of leadership needed to make the desired improvements. Studies of leadership typically

focus on teacher leaders, principals, and central/district office leadership [2-7]. Studies in science education typically focus on the role and impact of science teacher leaders.

Research examining principals and central/district office leadership has occurred predominately in the field of education leadership, and focuses on their activities and their role as an aggregate group when examining their impact on schools. Reports, such as those by Bottoms and Schmidt-Davis, do not distinguish between leadership levels or job responsibilities [3, 8, 9].

The lack of research on the various leadership levels raises an important question for educators of science and other content areas. Is pedagogical expertise sufficient, or is specific content and pedagogical content support necessary to impact student learning in particular content areas, such as science [10]? The literature provides no insight into the importance of content expertise for district leaders. As science educators, we believe that content knowledge is important for teachers. Like Spillane, Diamond, et al., we believe that science leaders in schools and at the district level must have a “sufficient” level of science content and science pedagogical content knowledge to provide the expertise and support teachers need [11].

The recently released *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*, as well as *Next Generation Science Standards*, call for science leaders to be active within their districts to support the changes proposed by these documents to curriculum, instruction, and assessment [12, 13]. The release of the 2011 “Trends in Mathematics and Science Study” shows that we are still not achieving at the levels of many countries [14]. As a nation, there is a strong push to increase the number of highly prepared Science, Technology, Engineering, and Mathematics (STEM) professionals. To improve student achievement and interest in science, we must have skilled science leaders at the district/central office level working with principals and teachers to improve instruction. In order to justify their positions and to support their work, we must understand their role and impact on improving student learning which is currently missing from educational research. Without an understanding of their role and impact on improving student achievement, we cannot justify their work and the necessity of their expertise.

Individuals in these positions come from a variety of backgrounds. They may be trained in science or assigned science as an area of focus for the district. The positions also range from district office positions, such as science coordinators and science directors, to school-level science leaders or science liaisons. To advance work on the role of science coordinators, this

article will examine the impact of a five-day science leadership academy on a group of new science coordinators from district/central offices across the Commonwealth of Virginia. Our focus is the work accomplished inside the Academy and in the districts because of the Academy.

The Virginia Initiative for Science Teaching and Achievement_(VISTA) is a five-year Investing in Innovation (i3) grant funded by the U.S. Department of Education. One component of the project is a five-day leadership academy to build, support, and sustain district-level staff for district/central office personnel newly designated (under five years in their position) as the science coordinator.

Review of the Literature—Overview of Educational Leadership Research since the 1970s

Over the last forty to fifty years, the focus of research in the educational leadership arena has shifted. In the 1970s and 1980s, Fullan characterized the role of district leadership as assisting with the “innovation implementation” era of change [15]. The research during this time focused on how districts could support the implementation of new programs and practices. As some schools within a district showed improvement and others did not, the focus of research shifted to the school level. District-level impact was seen as minimal on implementing new practices and programs.

This ushered in a period of research on effective schools. The “effective schools” movement focused on the school as the unit of change for impact on teaching practice and student achievement. Studies during this time, such as Floden, Porter, et al., indicated that district influence on instructional decisions and classroom practices were minor [16]. Only a few studies highlighted the role of school districts on educational change [17]. However, the research did not focus on linking student interventions and student learning. Case studies conducted by researchers in the late 1990s on school district transformation (such as Spillane in Michigan and by Elmore and Burney in New York City) brought the role of the district back to the forefront [18-20]. As noted by Leithwood, Louis, Anderson and Wahlstrom, some districts can and do have a positive impact on schools, teachers, and student achievement [21].

Review of the Literature—Characteristics of Effective or Successful School Districts

Two studies of effective or successful school districts provide insight into characteristics or features common across the districts. The first study, a 2005 review of the research by the American Institute for Research (AIR), identified seven primary themes (see Table 1) based on analyzing twenty studies [22]. They found that effective districts focused on student achievement and learning. This focus was supported by having a theory of action, committing to professional development, and using data to improve and consider policies that are comprehensive and coherent.

Table 1
Comparison of Characteristics of Effective Districts from 2005 AIR Report

Successful districts focus first and foremost on student achievement and learning. All leadership is instructional leadership.
Successful districts have a theory of action for how to effect improvements, and they establish clear goals.
Commit to professional learning at all levels and provide multiple, meaningful learning opportunities.
Use data to guide improvement strategies.
Enact comprehensive, coherent reform policies.
Have educators who accept personal responsibility for improving student learning and receive support to help them succeed.
Monitor progress regularly and intervene if necessary.

In a synthesis study of districts serving a high proportion of underserved students, Leithwood found ten characteristics across thirty-one studies of high-performing districts (see Table 2) [5]. No one characteristic was overwhelmingly identified or significant in its impact. While there are limitations to this study, it does provide suggestions for districts to consider while realizing that systemic reform is complex, nonlinear, and requires leaders who are flexible, with the advantage of feedback loops that allow for alterations in alignment and changes in roles within the district [5].

Table 2
Comparison of Characteristics of Effective Districts from Leithwood Study

Districtwide focus on student achievement.
Identified approaches to curriculum and instruction.
Use of evidence for planning, organizational learning, and accountability.
Districtwide sense of efficacy.
Building and maintaining good communications and relations, learning communities, district culture.
Investing in instructional leadership.
Targeted and phased orientation to school improvement (targeting interventions on low performing schools/students).
Districtwide, job-embedded professional development for leaders and teachers.
Strategic engagement with the government's agenda for change and associated resources.
Infrastructure alignment.

The two studies point to the need for districts to have a unified focus on student learning and achievement, have professional development across all levels, monitor progress, and use data.

Review of the Literature—Science Coordinators as Leaders

St. John and Pratt in 1997 reported on the characteristics of the “best” cases of science education reform in states and districts [23]. In these “best cases,” they found leadership that committed to long-term work, connected to many sources of support (local, state, and national), focused on educational substance, and used standards as a vision to guide their reform efforts. Few studies can be found that examined the impact of science-specific coordinators on the work of principals, teachers, and student achievement. This finding is confirmed by other researchers who have noted this missing area in the literature [24, 25]. The lack of knowledge on the impact of content specificity—science in this case—on principals, teachers, and students may be a critical missing link in improving student achievement.

Structure of the Academy

The Academy was designed to occur over a five-day period. This article will report on the second and third years of the Academy. Participants convened for three days in the fall and then again for two days in the spring, with additional networking and support at the Virginia Science Education Leadership Association (VSELA) meeting in the fall (two days) and spring (two days). The New Science Coordinators Academy (NSCA) has six goals for participants:

- 1) Learn to make improvements in leadership, teacher learning, quality teaching, and student learning.
- 2) Develop a common understanding of hands-on science, inquiry, problem-based learning, and nature of science.
- 3) Identify aspects of effective science teaching and learning.
- 4) Compare district models of creating standards-based science curricula.
- 5) Investigate data sources available to use in order to provide a focus to improve district science programs.
- 6) Develop a science program strategic plan.

Our aim is to meet the needs of new science coordinators. These goals also match those identified by research on supporting policy implementation and instructional reform conducted by Marsh and colleagues, as well as the National Science Teachers Association's "Position Statement: Leadership in Science Education" [26-28]. The facilitators address these goals by weaving a variety of activities and opportunities to revisit the goals throughout the five days.

The sequence of activities during Year Two and Year Three were almost identical (see Appendix A). Day 1 of the NSCA engaged the participants in an introduction to VISTA, an introduction to the other participants and VISTA staff, and then a daylong simulation, "Building Systems for Science Literacy." Kathy Stiles of WestEd facilitated this simulation, which is under development by WestEd. The game is based on the ideas and principles of *Designing Professional Development for Teachers of Science and Mathematics* [29]. The simulation allows players to "discover what activities and resources have the greatest impact on teacher and student learning, why some teachers struggle to improve their instructional practices, and how much it 'costs' in time, materials, and commitment to provide effective professional development" [30]. These activities promote Goals 1, 5, and 6.

Day 2 of the NSCA began by engaging the participants in a model Problem-Based Learning lesson. After participating as learners in the lesson, the participants discussed the question, “How can we identify effective teaching?” This led to the introduction of the VISTA definitions for Hands-on Science, Inquiry, Problem-Based Learning (PBL), and Nature of Science (NOS). Science educators in Virginia developed the definitions for Hands-on Science and PBL to be used in common across the VISTA program. The definition for Inquiry came from *Inquiry and the National Science Education Standards*, and focuses on the five essential features of inquiry [31]. Virginia has added specific aspects on the NOS into its state standards, hence an increased interest in NOS since it now can be tested on state standardized tests. These aspects are the focus of the discussion and work of VISTA. The second half of the afternoon focused on examining different data sources and developing an action plan. The participants examined data from TIMSS, NAEP, AAAS, as well as school district data [14]. This examination of data led to a discussion of what the data tells us are gaps in student learning. The participants received a multistep strategic planning tool to identify and organize the gaps from their data. From this tool, the participants began to identify actions to take in the future. Then, these actions were organized and prioritized into tasks on a timeline. These activities promote Goals 1, 2, 3, 5, and 6.

Day 3 focused on engaging participants in expanding the action plan into a more detailed teacher professional development plan. In addition, we wanted to provide the participants with the opportunity to get ideas from other science coordinators from across Virginia. To accomplish this, we brought a group of experienced science coordinators, from districts of varying sizes, to share their insights as science coordinators and to help the participants with their strategic plan. These activities promote Goals 5 and 6.

When they returned in the spring, Day 4 began with small groups of participants sharing how they were progressing with their strategic plan by considering what was going well, what needed improvement, and what components they need for the future. Afterward, participants were provided an introduction to the basics of the NSTA “Science Program Improvement Review” (SPIR) tool to help with evaluation of their work [32]. The coordinators were then given an opportunity to explore classroom discourse, misconceptions in science, and the nature of science or engineering practices. This provided the coordinators with an opportunity to consider additional instructional strategies and supports for use in their districts. The day finished with an update presentation by the state science supervisor. These activities promote Goals 1, 2, 3, and 6.

Day 5 began with the introduction of a protocol for analyzing student work. The participants requested this professional development approach at the end of Day 3 in the fall. The participants examined several different protocols and then practiced using a common set of work, as well as work that they brought with them from their districts. A session on the development of curriculum followed the student work analysis session. The participants looked at their curriculum guides, and were provided analysis prompts that had them map their curriculum to determine whether it was aligned to the *SOL* and supported instruction and assessment. Next, the participants revisited inquiry by examining a tool developed by Volkman and Abell to convert cookbook labs into inquiry labs [33]. The last session of the day dealt with the evaluation of strategic plans and professional development using the SPIR results and the introduction of Thomas Guskey's book, *Evaluating Professional Development* [34]. As a final task, the participants completed an evaluation survey by the outside evaluator. These activities promote Goals 1-6.

Methods—Participants

Thirty-four individuals have participated in the Academy. The participants included ten males and twenty-four females ranging in age from 28-59 years of age from thirty different school districts in Virginia. There were 5 African-American and 29 Caucasian participants. All of the participants held a M.Ed. or M.S. degree, and fourteen participants held or are in the process of earning an Ed.D. or Ph.D. in Education. All participants are currently in leadership positions in their respective school divisions (K-12 science coordinator, science lead teacher, science specialist, instructional coach, vertical team leader, beginning teacher advisor coordinator, elementary principal), and all of the participants have led science professional development. Participants' years of experience in their current leadership roles ranged from two months to five years.

Methods—Measures

For this article, we collected four types of data: 1) participant exit slips; 2) demographic data; 3) agenda and handouts; and, 4) participant activity logs. The daily exit slips were developed by the VISTA NSCA implementation team to align with the goals of the Academy. The questions on the daily exit slips asked participants to reflect on the sessions presented each day, to link their learning to their work, and to track the impact of the sessions. The responses were examined by the lead author to determine the impact of the NSCA on their work. Grounded

theory drove the determination of themes or categories from the participant reflections [35]. The exit slips were read several times. Then, each question was read and the responses were categorized by emergent themes [36]. Next, a comparison of the themes to the NSCA goals for alignment occurred. Finally, the themes and their alignment to the goals allowed us to develop answers to the research questions.

The participant logs were participant self-reports of their activities outside of the Academy that involved using their new understandings and resources, and their continued efforts on their strategic plans. These logs were analyzed using the same strategies described for the exit slips. The analysis allowed us to learn from the participants the extent to which the science coordinators used their new knowledge in their district work and to answer research question 5.

Artifacts such as the agenda and handouts from daily activities were collected. In order to analyze if the goals were met, the agenda was correlated with the activities that were conducted, exit slips, and the goals.

Research Questions

The following questions guided assessment of the impact of the New Science Coordinators Academy (NSCA):

- 1) To what extent do the science coordinators gain knowledge with respect to each of the NSCA goals during the five-day Academy?
- 2) Which goals of the NSCA were viewed by science coordinators as most beneficial to the science coordinators?
- 3) What science coordinator needs are not met by the NSCA?
- 4) To what extent do the science coordinators use the new knowledge in their district work?

Results/Findings

In this section, we are not able to report on findings from the first cohort, since we had not had the opportunity to develop research questions and feedback questions to provide insight into those research questions. These findings will reflect those of participants in Cohorts II and III. To better understand their roles in their districts, we asked the Cohort II and III participants

several questions. The science coordinators have a wide variety of roles, including coordinating professional development of science teachers, working in classrooms with teachers, and working on district science curricula. Not all coordinators had the same responsibilities (see Table 3).

Table 3
Potential Impact on Science Instruction in District

Role of Participant in the School District	Cohort II Number of responses (n=15)	Cohort III Number of responses (n=17)
Professional and staff development	10	12
Working directly w/teachers	9	2
Curriculum development	6	5
Instructional coaching	4	0
Working directly w/administrators	3	1
Ordering supplies and textbooks	2	3
Hiring and recruitment	2	0
Teacher evaluations	2	0
Teaching in the classroom	2	0
Working w/supervisors	1	0
School improvement planning	1	1
Creating shared mission and goals	1	2
<i>Vague or unclear</i>	3	0

We asked Cohort III to share their perceptions of needs within their district to achieve an exemplary program. Collaborating across grade levels, finding funds for science materials,

helping teachers find time to teach science, and providing opportunities for all students to learn science were the most frequently identified needs (see Table 4).

Table 4
Perceptions of Needs to Achieve an Exemplary Program

Perceptions of Needs	Cohort III Number of Responses (n= 17)
Collaboration across grade levels	6
Additional funds for science materials	6
Time to consistently teach science	5
Opportunities for all students	5
Additional technology	2
Building and keeping great teachers	2
Incorporation of critical thinking skills	1
Alignment of assessment to instruction	1
Empowerment of school leads for science	1
Evaluation of what we have and what we need	1
Need a coordinator position	1
Plan for sustainability	1
Development of a strategic plan	1

We also asked Cohort III their perceptions of challenges that could impact their work in their district. A variety of challenges emerged: a focus by districts on mathematics, reading and language arts, their needs for a deeper science content background, time to do the work they believe is needed, and funds for classrooms (see Table 5).

Table 5
Variables Challenging Coordinators' Impact on Science Programs

Variables Challenging Coordinators' Impact	Cohort III Number of Responses (n=17)
Math and English/language arts focus	5
Need content expertise in science	3
Time to do the work	3
Availability of funds	3
Pressures teachers face	2
My ability to foster "buy-in"	2
Communication within district and with schools	2
Other competing focal areas for the district	1
Size of district	1

Daily Exit Slips

The impact of the daily activities on the coordinators was collected via exit slips. Analysis of the coordinators' responses follows.

Day 1 — The first day of the Academy provided participants with an introduction to VISTA, a discussion of their role as science leaders, and participation in a simulation which allowed the participants to consider the various factors within a school district impacting student learning. The simulation, "Building Systems for Science Literacy" from WestEd, examines the various factors within a district that can impact student achievement. The simulation addresses the following goals: 1) learning how to connect professional development designs to the specific learning needs of students and teachers; 2) learning the inputs necessary for designing effective professional development; 3) encountering the constraints and the supports for effective

professional development; 4) learning what is needed to sustain teacher professional development; and, 5) understanding the role of leaders in planning professional development.

The simulation offered a common learning experience, and framed the work for the next four days. The participants felt that the simulation was a very beneficial part of their experience. Participants shared how they will implement new science programs, how they will handle resistance to change, and how the simulation helped them understand the process of change. Three responses stand out as exemplar responses for the group:

- “Developing a sense of community goes a long way. So does celebrating success and hearing everyone’s voice and seeing needs. The game told me to build a foundation and community before attempting change.”
- “I think one of the greatest pieces to the game was using a cohort of people to make informed decisions for the district. Putting time and energy on the front end is extremely important. I will gradually move those that are resistant along through professional development tailored to their needs.”
- “I will be more aware not to offer ‘one size fits all’ professional development experiences. The simulation game helped me focus on ways to motivate reluctant teacher learners and the importance of creating or developing teacher leaders.”

These responses indicate that participants learned and/or took away the key goals and outcomes of the simulation. Themes and number of similar responses in Table 6 provide further insight into the overall benefits of the simulation for the participants. Overall, the participants felt that investing in research and planning of professional development, as well as building in opportunities for collaboration and communication, were important. Some outcomes of the simulation resonated more strongly with some cohorts than others, such as a build-in of sustainability opportunities (Cohort II) and multiple areas that must be addressed simultaneously (Cohort III). The diverse personal needs and experiences, in addition to the needs of the district, are reflected in the data.

Table 6
Implementing New Programs and Dealing with Individuals Resistant to Change

Themes	Cohort II n=15	Cohort III n=17
Invest in research and planning of professional development	4	13
Need to know staff needs	0	0
Student learning comes from teacher learning	0	0
Build in collaboration and communication	2	6
Build in rewards and incentives	1	0
Requires time to change practice	0	11
Create buy-in	8	8
Engage teachers in professional development	6	8
Build community/relationships	2	1
Evaluate and monitor progress	1	0
Build in sustainability opportunities	1	0
Must address multiple areas simultaneously	0	6
Work toward a critical mass	0	3

Day 2 — The focus of this day was on recognizing and assessing quality teaching, using available data for planning, and introducing strategic planning. The exit slip focused on recognizing quality teaching and the use of data for planning. To determine participant

understanding of the sessions focused on recognizing and assessing quality teaching time, the participants were asked to select one of the introduced terms—Hands-on, Inquiry, or Problem-Based Learning—from the day’s discussion and elaborate upon it (see Tables 7-9). The participants indicated their reasons for selecting their term, and how they envisioned improving their efforts to assist teachers in their practice. Their reasons for selecting terms to define ranged from their personal and their districts’ needs to fostering twenty-first century skills. Their strategies for assisting teachers in their practice ranged from professional development to embedding in curriculum. The different participant backgrounds are again reflected in the reasons for selecting specific definitions over others. In Cohort II, six of the 15 chose Hands-on, five chose Inquiry, and six chose Problem-Based Learning. In Cohort III, six of the 17 chose Hands-on, eight chose Inquiry, and three chose Problem-Based Learning.

Table 7
Use of the Term “Hands-on”

Reason	Responses for Cohort II/ Cohort III	Use in Practice	Responses for Cohort II/ Cohort III
Identified need at site	2/5	“Teaching teachers”	2/0
Most familiar of the three	2/0	Professional development	1/3
Least familiar of the three	1/1	Increase student involvement	1/1
Desires to become an expert	1/0	Budget to provide materials to teachers	0/1
Science should be taught this way	0/1	No answer provided	0/2

Table 8
Use of the Term "Inquiry"

Reason	Responses for Cohort II/ Cohort III		Use in Practice	Responses for Cohort II/ Cohort III
Identified area of weakness at site	3/3		Assist teachers in skills development	1/2
Feel comfortable, already use this	1/0		Use as a tool for evaluation and feedback	1/0
Previous encounter with idea	1/0		Professional development	1/3
Driving force for the other two	0/2		Meetings with teachers	1/0
Students are the focus here	0/2		Incorporate into district philosophy (mission)	1/0
			Inclusion of science fair	0/1

Table 9
Use of the Term "Problem-Based Learning"

Reason	Responses for Cohort II/ Cohort III		Use in Practice	Responses for Cohort II/ Cohort III
Actively trying to build this skill currently	1/1		Develop curriculum (lessons and units)	2/1
STEM focus	1/0		Need to develop professional development	0/1
Potential for student motivation	1/0		No answer	2/1

Fosters 21 st century skills	1/0		
Relevance is important	1/1		
Part of division strategic plan	0/1		
No reason	1/0		

The second focal area for Day 2 was on the use of data by teachers to understand student thinking and to plan their science instruction. Participants responded to this question by considering their role, the needs of their districts, and the needs of their teachers (see Table 10). Not all participants responded to both parts of the question. Responses for Cohort II reflect consideration of district and teacher needs. The participants in Cohort III focused their thoughts on the needs of their teachers. Interestingly, most of the Cohort III responses fell under the theme of identifying trends, weaknesses, and areas of challenge. One participant's response summarizes all of the responses: "The data can unveil gaps in the curriculum, the instructional practices, and lesson plans that must be improved in order to improve/increase student achievement. The data should drive all instructional aspects."

Table 10
Use of Data in Understanding Student Thinking and Planning Instruction

Themes for Use of Data by District Administrators	Responses for Cohort II/ Cohort III	Themes for Use of Data by Teachers	Responses for Cohort II/ Cohort III
Provide teachers with appropriate strategies for use	1/0	Drive instruction	2/0
Broader view, specific insight	1/0	World rankings	4/1
Big picture for decision-making	2/0	Access, review, and discuss	1/0
Planning and Budgeting	1/0	Understand achievement gaps	2/0

Plans for improvement	1/0	Reflecting and improving/raise rigor and expectations	1/0
Don't know	1/0	Identify trends and weaknesses/areas of challenge	1/13
		Develop best practices	1/0
		Identify curricular weaknesses	1/0
		Needed changes in science programs	0/2
		Reinforce the need to make connections in our instruction	0/2
		Areas of student misconceptions	0/3
		Guide instructional planning	0/2

Day 3 — During Day 3, participants focused on developing an action and strategic plan. Both Cohorts II and III identified at least one major priority for their plan once they had an understanding of strategic planning. The participants had a wide range of priorities within each cohort and between the two cohorts, based on their needs and those of their districts. These priorities focused on planning professional development, working on specific areas (such as Nature of Science) building teacher buy-in, and gaining buy-in from district leadership (see Table 11). With the responses being different with little overlap among districts, it points to the unique needs of each district.

Table 11
Action and Strategic Plans: Priorities

Major Priority	Responses for Cohort II/ Cohort III
Include plans for professional development	2/1
Include training in Nature of Science	2/0

Include building buy-in among leadership	1/4
Plan to address threats to student achievement	1/1
Engage teachers in building science literacy and help for working with English Language Learners	1/0
Include building buy-in among teachers	1/0
Include science in division plans	1/0
Build a vision for science with teachers	1/0
Build a common vision and mission	1/0
Include the needs of new secondary science teachers	1/0
Vertical alignment of curriculum, communication, and collaboration	0/2
Professional Learning Communities and curriculum	0/2
Collect baseline data via observations and talking with others	0/1
Materials part of strategic plan and budget	0/1
Curriculum and Pacing Guides	0/1
Improve elementary scores, especially sub-groups	0/1
Instructional materials adoption	0/1
Authentic assessment	0/1

For Cohort II, a panel of experienced science coordinators from around Virginia shared their experiences and answered questions posed by these new district science leaders. The participants reflected on the discussion to identify insights gained from the coordinators about their work and to identify questions they still had for them and other coordinators. Several insights indicate the range and depth of the participants' learning:

- “.... some of the issues shared were very interesting and also seen in other districts.”

- “I learned that large districts operate a lot differently than smaller districts and would like to learn more about their curricula K-12.”
- “It’s interesting how we are all so different, yet [have] many of the same challenges.”

This last quote exemplifies the feeling of over half of the participants as they were surprised by the similarity in obstacles and challenges. This served as a unifying point for all of the participants.

Cohort III had the opportunity to interact with the Virginia state department science director. This session provided the participants with information about state initiatives and how the Virginia Department of Education could help them. Their reflection question asked them to consider how this session and working with VISTA staff and other participants impacted their experience. Some participants did not share responses to this question. Again, Cohort III has a wide range of insights into their role based on their conversations with the different groups (see Table 12).

Table 12
Themes on Insights into Their Roles

We wear many hats and many different responsibilities and roles (district office to classroom). (4)
Leadership in science requires knowledge of pedagogy, curriculum, and content. (3)
Not all school divisions have the same stance on science instruction and also have varying contributing factors. (2)
Networking is single most important. (2)
Need to take small steps with teachers, get their buy-in. (2)
Need to communicate more with principals and teachers.
Funding is major obstacle.

Day 4 and 5 — At the beginning of Day 4 in the spring, participants were asked to think back to their first three days in the fall and to share what ideas they had taken back to use in their districts, as well as what new insights they had gained since then about the program. The most common component of the program that participants continued to have insights into and to use was their learning and work with the VISTA definitions for Hands-on Science, Inquiry, and the Nature of Science (NOS) (see Table 13). Other insights focused on science education in the United States, the need for focused, data-driven professional development, and the implementation of inquiry and NOS in the classroom. The participants also had strategic planning as a focus and used activities from the program, such as the “apple activity” which focuses on the definition of Hands-on Science. A number of other ideas and program components were of value to other participants (see Table 13). Again, we are finding a range of insights that reflect the coordinators’ needs and the needs of their districts.

Table 13
Reflecting on Insights from Day 1-3 and on “What Have I Used?”

Themes for New Insights	Responses for Cohort II/ Cohort III	Themes for “What Have I Used?”	Responses for Cohort II/ Cohort III
Notable definitions: Hands-on, NOS, Inquiry	7/2	Conducted professional development on definitions (NOS, Inquiry, Hands-on)	8/5
Professional development-needs, planning, conducting	2/4	Used the “apple activity”— sharing the activity with new teachers	3
Strategic planning for science and within the district	2/2	Using strategic planning as a district focus	3/2
District work and coordination takes time and is hard	1/3	Creating a vision for incorporating inquiry	1/1

Role of myself as a science coordinator	1/1		Baseline data collection	2/0
Data analysis and student assessment	3/0		Network and planning	0/1

(Cohort II = 14; Cohort III = 13)

Day 4 and 5 focused upon strategic planning, the examination of several instructional strategies/approaches, and the analysis of student work. The instructional strategies that were focused on were classroom discourse, the use of student misconceptions, the Nature of Science (NOS), and the “E” in STEM. They were asked to reflect on the sessions, select up to two they envisioned using with their teachers, and to explain why they selected those (see Tables 14 and 15). Participants selected discourse and misconceptions most frequently. Several participants indicated that these two areas “merge at a point if our goal is to create a science-literate community.” The NOS session introduced new strategies, but had been discussed previously, so its impact may have been lessened.

Table 14
Strategy Sessions That Resonated with Participants

Discourse	Responses for Cohort II/ Cohort III	Misconceptions	Responses for Cohort II/ Cohort III	STEM	Responses for Cohort II/ Cohort III
Ease of integration	3/0	Importance to learning	2/4	Relevance to district needs	2/0
Value in classroom	2/4	Ease of integration	1/0	Identified need by teachers	1/0
Familiar with this strategy	1/0	Similar to what they know	1/0	Direct impact on teaching	1/0
Current district	0/1	I grew the most	0/1	Planning and	0/2

initiative			here			conducting professional development on this	
I grew here	0/2		Workshops planned to embed this	0/3		Need to link to curriculum guides	0/1
Other	1/3		Everyone has them	0/2		Goes hand-in-hand with differentiation	0/1

(Cohort II = 14 participants; Cohort III = 17)

Table 15
Day 5: Strategy Sessions

Analyzing Student Work	Responses for Cohort II/ Cohort III		Curriculum	Responses for Cohort II/ Cohort III
Value of activity to meeting objectives	1/0		Identified need by teachers	4/0
Identified need for improving student learning outcomes	1/3		Process would help teachers teach beyond the <i>SOL</i>	1/0
Direct impact on teaching	1/1		Relevance to district needs	1/1
			Need to expand our guides based on this	0/2

(Cohort II = 11 participant responses; Cohort III = 17)

The participants also shared how they planned to use these with teachers. They felt the discourse session would help promote a literate community, and the question prompts provided a framework for the introduction and support of student talk. The participants envisioned “going over” and “helping out teachers” with the different aspects of the Nature of Science. The participants planned to share how both the web resources and the American Association for the Advancement of Science assessment items correlated to the misconceptions of middle and high school students [37]. Some participants were comfortable with inquiry so they focused on student work and curriculum. They shared that all sessions filled a need in their district and were relevant to their work in their districts.

The participants reflected on the strategic planning process over the entire Academy. They were asked to describe how they envisioned their plan helping them with their district work. The two themes identified more than once were that the plan would provide focus and future direction, and the plan would help to “overhaul the curriculum in the district” (see Table 16). The coordinators’ responsibilities vary in their districts which is reflected in their responses.

Table 16
Themes for Envisioning How the Strategic Plan Will Help Their Work

Themes	Responses for Cohort II/Cohort III
Focus and direction, framework for work	7/12
Need to revisit, revise, improve the plan	2/1
Need to rethink evaluation of PD	0/2
Possibly establish plan next year	1/0
District shot down plan so now I will work at my school	0/1

(Cohort II = 10 participants responding; Cohort III = 16)

Activity Logs

To earn a stipend, participants had to document at least forty hours of work across the year related to their job and the Academy, but outside of the Institute. To document their work, the participants provided a log of their activities outside of the five days in the Academy that indicated their use of ideas from the Academy. The participants reported from 40-73 hours of

work outside of the Academy and their normal work. On average, participants reported fifty-three hours of work related to the Academy. The coordinators impacted from 1-250 teachers and from 20-12,000 students, partially indicating the varying size of their school districts. While these hours and the impact on teachers and students were reported in order to receive a stipend, they provide insight into the components of the Academy that the participants valued or felt they needed to support their work. The participants reported reading from the resources provided, such as *Designing Professional Development for Teachers of Science and Mathematics*, incorporating activities used in the Academy into their professional development, and developing other types of professional development (see Table 17) [29].

Table 17
Summary of Log of Application of Learning

Daily Themes	Resource	Responses for Cohort II/ Cohort III
Leadership – Leading School-Based PD: Building Capacity for Science Learning Simulation (Day 1)	Reading of:	NA/10
	Articles	3/7
	PD Design Framework	2/0
	<i>Ready, Set, Science!</i>	
Leadership – Recognizing and Assessing Quality Teaching (Day 2, 4, 5)	Hands-on Science	5/2
	Inquiry-Based Science	7/8
	Problem-Based Learning	2/5
	Nature of Science	9/2
Leadership Planning – Your School Division- Data (Day 2, 3, 5)	Data Analysis	1/2
	Use of Data Websites	4/0
Strategic Plan for Science (Day 3, 4, 5)	Development of plan continued	9/10
Professional Development Planning	Development of	11/17

and Sharing (Day 3, 4, 5)	professional development sessions and delivery to district teachers	
Other	Benchmark development and analysis	NA/7
	Textbook Adoption	NA/2
	Science Fair	NA/4
	Curriculum Alignment	NA/2

(Cohort II = 11 responses; Cohort III = 17)

Professional Development Impact on Participants

As shared earlier, the NSCA has six goals for participants. This section will describe the impact on participants of the various NSCA program components aligned to each goal. Each goal was correlated to the sessions conducted each day and to the exit slip questions (see Appendix B). Examining the themes identified from the daily exit slip questions allowed us to assess whether the NSCA achieved each goal.

Each day of the NSCA had a component that helped participants deepen their understanding of the ideas in Goal 1, “improvements in leadership, teacher learning, quality teaching, and student learning.” Table 18 identifies the activity each day matching the goal. Weaving this goal into each day provided participants with time to learn, reflect, and grow in their understanding and skill.

Table 18
Goal 1 Correlated to Daily Sessions

Day 1: “Building Systems for Science Literacy” simulation from WestEd
Day 2: Update from State, Recognizing and Assessing Quality Teaching (State and District Data), and Strategic Planning
Day 3: Teacher Professional Development Planning and Sharing of Plans and Expert

Panel/VA State Science Director

Day 4: Strategic Planning I and Update from State; Discourse, Misconceptions, Nature of Science

Day 5: Strategic Planning II and Curriculum; Analyzing Student Work, Inquiry, Curriculum

Goal 1 is that participants learned and/or took away the key goals and outcomes of the simulation. They gained new insights into teacher and student learning from participating in the activities designed to share the VISTA definitions for Hands-on Science, Inquiry, and Problem-Based Learning, as well as participating in the sessions on discourse, misconceptions, curriculum, and analyzing student work. Reflecting on the emerging themes shared in the daily analysis allowed us to assess whether this goal was achieved. Goal 1 was achieved based on the following overarching themes identified:

- Teacher buy-in and professional development are essential for the definitions to be adopted by teachers. (Cohorts II and III)
- Collaboration and building community support improvements. (Cohorts II and III)
- VISTA definitions for Inquiry, Hands-on Science, and Problem-Based Learning support these improvements. Needs are different at each district and personally for the science coordinators. They envision using these ideas in professional development, as a feedback tool for classroom observations, and to develop curriculum. The definitions provide the coordinators with a support structure for working with teachers. (Cohorts II and III)
- Classroom discourse strategies, identification and use of student misconceptions are important components for making improvements. (Cohorts II and III)
- Analyzing student work and the development of curriculum by teachers are important strategies for helping districts improve. (Cohorts II and III)

Goal 2 was “developing a common understanding of hands-on science, inquiry, problem-based learning, and the nature of science.” Reflecting on the emerging themes shared in the daily analysis allowed us to assess whether this goal was achieved. Goal 2 was achieved based on the following overarching themes identified:

- As indicated for Goal 1, the sessions focused on the VISTA definitions for Inquiry, Hands-on Science, and Problem-Based Learning and supported their development of a common understanding. (Cohorts II and III)
- Some of the participants were less familiar with these terms than others, so the sessions helped to develop understanding. (Cohorts II and III)
- The definitions support their district work and provide a support structure for working with teachers. (Cohorts II and III)

Goal 3 was “identifying aspects of effective science teaching and learning.” As with Goals 1 and 2, reflecting on the emerging themes shared in the daily analysis allowed us to assess whether this goal was achieved. Goal 3 was achieved based on the following overarching themes identified:

- Professional development and collaboration are important for a common vision to develop. (Cohorts II and III)
- The VISTA definitions provide support for teachers and themselves. (Cohorts II and III)
- Professional development focused on these definitions is planned or has occurred. (Cohorts II and III)
- Baseline data for “hands-on” is being collected to better understand the supports needed by teachers. (Cohort II)
- Classroom discourse is easy to integrate and decreases teacher talk. (Cohorts II and III)

Goal 4, “comparing district models of creating standards-based science curricula,” was achieved based on the following overarching themes identified:

- It is an identified need by district. (Cohorts II and III)
- Good curriculum helps teachers go beyond Virginia’s *Standards of Learning (SOL)*. (Cohorts II and III)
- The strategy for analysis of curriculum shared by the facilitators from their former districts will be used in professional development. (Cohorts II and III)

Goal 5, “investigating data sources available to use to provide a focus to improve district science programs,” was achieved based on the following overarching themes identified:

- Data help to identify gaps in instruction and assist with decision-making. (Cohorts II and III)
- Data will help determine which strategies are most effective. (Cohorts II and III)
- There is a need for focused, data-driven professional development. (Cohorts II and III)

Goal 6, “developing a science program strategic plan,” was achieved based on the following overarching themes identified:

- Participants were comfortable with identifying district strengths and weaknesses.
- Strategic plan priorities varied based on the needs of each participant and their district. Some of the priorities included the following: planning for professional development in general, planning for Nature of Science professional development, providing science literacy for all students, addressing threats to student achievement, building a common science vision among teachers, and several others.

An examination of the themes identified from the participant responses allowed for answers to the research questions guiding this study. We used each question as the lens for reviewing and selecting themes. Guiding the study of the impact of the New Science Coordinators Academy are the following questions:

- 1) To what extent do the science coordinators gain knowledge about each of the NSCA goals during the five-day Academy?
- 2) Which goals of the NSCA were viewed as most beneficial to the science coordinators?
- 3) What needs do the science coordinators express to facilitators that are not met by the NSCA?
- 4) To what extent do the science coordinators use the new knowledge in their district work?

For question 1, the extent to which the coordinators gained new knowledge about each of the goals, it is important to remember that the coordinators came to the Academy with a wide range of prior experiences. Their reflections (see Tables 3-17) indicate that they learned from the activities designed to match each goal of the NSCA. The insights took many forms, from learning new information to considering new perspectives. Overall, the science coordinators gained new knowledge from the NSCA.

For question 2, which goals were most beneficial, it is difficult to determine from this data whether one component was more beneficial than another. The various backgrounds of the coordinators resulted in different components resonating more strongly with some than others. All activities were highly regarded by some of the participants and no activities were disavowed by all. All of the goals in some way improved participants' understanding or reminded them of the importance of considering all of the ideas or components presented as they build their programs.

For question 3, needs not addressed by the facilitators, the science coordinators were very honest about areas in which they need help. They made the following requests:

- “Additional research to support goals”;
- “Needing data protocols for working with data and teachers”;
- “If I don't see results, what next?”;
- “More on developing curriculum”; and,
- “More information on how other districts work.”

The answer to question 4, the extent of participant learning used by them in their own districts, is informed by the data logs the participants submitted at the end of the spring (see Table

17). These logs indicate that the participants read and used the publications shared with them. They incorporated some of the activities into their own professional development with teachers, incorporated the VISTA definitions in professional development, and continued working to analyze data and develop their strategic plans. In conversations with the coordinators at the various meetings, the coordinators have reiterated that the NSCA was beneficial to their work. In addition, they have asked for opportunities to work together again with the VISTA team to further develop and improve their strategic plans.

Discussion and Limitations

Research on the learning of science coordinators, and their impact on the teaching and learning of science in their districts, is very limited. This is unfortunate, as they can play a critical role in how their districts view the teaching of science and how science instructional materials are developed, selected, and implemented. In addition, their role can extend to the instructional practices teachers learn about, are encouraged to use, and feel supported in their efforts to implement. These areas all support the outcomes of effective science leaders as outlined in the NSTA “Position Statement: Leadership in Science Education” [28]. Successful implementation of reform is dependent upon science leaders working in five areas: science teaching and learning, professional development, science curriculum, and assessment.

Each NSCA provides participants with an opportunity to build a network with other science leaders across Virginia, build a common vision for science instruction, and obtain tools to support their work in their own districts. Participant reflections indicate that they learned from their experiences and intend to use this knowledge. Overall, the reflections indicate that the NSCA successfully addressed its goals and met the needs of the participants. The reflections also indicate that all participants believed the tools and support of the group to be important to their work.

The participants came to the Academy with diverse prior experiences and diverse roles and responsibilities as science leaders. The components of the Academy were important to all participants; it is no surprise that different components of the program resonated more strongly with some participants than with others. The program allowed participants to enter successfully from different places, and to develop new understandings and skills for use in their positions. The simulation, “Building Systems for Science Literacy,” provided an important common

experience allowing participants to consider their current understanding, to learn other participant strengths, and to begin building collegial networks. The model Problem-Based Learning and Inquiry activities (on Day 2 and 5) provided a common experience for the participants to discuss best instructional practices, and to consider their roles in working with teachers to improve hands-on, inquiry-based science instruction. They indicated that these activities and definitions would be very helpful in their district work. The development of individual strategic plans allowed participants to meet their needs and the needs of their districts. These different components support the needs of these learners as they provide multiple entry points and opportunities to grow [22, 38, 39]. The skills and opportunities provided in the NSCA align with the dimensions and components identified and shared in the literature review [3, 9]. The activities of the NSCA can help the participants take on a role within their district that impacts teacher practice and student learning. According to participants, the NSCA empowered them to take a leadership role, because they had a well-developed plan and activities to carry it out.

This study's strong linkage among the agenda, goals, activities, and daily evaluation suggests that the New Science Coordinators Academy is a well-planned professional development. Eight of 11 (73%) Cohort II participants and 17 of 19 (89%) Cohort III participants thought that all components of the program were applicable. The effectiveness of the professional development for the coordinators is evidenced by the responses of the participants regarding their comfort with the program, their use of various aspects of the program, and their confidence (i.e., not needing further help).

An innovative aspect of the program was to provide further planning, in addition to the planning during the Academy, by providing a stipend for the participants to create and implement professional development. This aspect of the program seems to be an effective method of having the participants carry through with the intent of the Academy to increase effective professional development for teachers.

This study faces several limitations. First, the sample size is small ($n=32$), but it is growing. The data continues to reflect the participants' learning and specific needs. The data available for analysis (Participant Reflections and Logs) is limited, but does provide insight into participant perceptions. In the future, responses from the final two cohorts will allow for more reliability as to perceptions and use in the short term in participant work. Second, additional study of how the

participants continue to use their learning is needed. The ability to track these individuals is essential, as it will provide science educators insight into the impact of the Academy on their role as district leaders and the impact they have on student learning.

The overall purpose of this Academy, as identified in the grant proposal, is to support the development of the state infrastructure necessary to bring improvement to classroom instruction and student achievement. Developing statewide definitions for important common science terms furthers building a cohesive infrastructure. The data shared in this article support this purpose as the Academy provided learning opportunities for new science coordinators, and they left with new insights matching their needs. Future studies need to consider their impact on classroom instruction and student achievement.

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Appendix A
Agenda for Each Day

Day 1	Day 2	Day 3
<p>UVA Data Collection</p> <p>Introduction of Staff</p> <p>Program Overview and Goals</p> <p>Brief Introduction of VISTA</p> <p>Introduction to the Science Landscape in VA</p> <p>Introduction to VA Science Organizations and Their Role as a Science Leader</p> <p>Leadership- Leading School-Based PD: Building Capacity for Science Learning through the “Building Systems for Science Literacy” Simulation (WestEd)</p> <p>The Building Systems Simulation Debrief</p> <p>Wrap-up and Homework</p> <p>Exit Slip</p>	<p>Goals for the Day</p> <p>Leadership- Recognizing and Assessing Quality Teaching; engaging participants in a PBL lesson</p> <p>Definitions and Instruments- Hands-on Science, Inquiry, PBL, and the Nature of Science</p> <p>Leadership Planning- Your School Division and Data (TIMSS, NAEP, AAAS, and School Division Data)</p> <p>Strategic Planning for Science</p> <p>Wrap-up and Homework</p> <p>Exit Slip</p>	<p>Goals for the Day</p> <p>Leadership Planning- Teacher Professional Development</p> <p>Interactive Roundtable</p> <p>Teacher Professional Development Planning and Consult with Experts</p> <p>Sharing Professional Development Plans</p> <p>Planning for Day 4 and 5</p> <p>Wrap-up</p> <p>Exit Slip</p>

Day 4	Day 5
<p>Welcome Back</p> <p>Strategic Planning I</p> <p>Focusing on Effective Science Instruction: Classroom Discourse</p> <p>Focusing on Effective Science Instruction: Misconceptions</p> <p>Nature of Science</p> <p>Update from the State</p> <p>Wrap-up</p> <p>Exit Slip</p>	<p>Reflections</p> <p>Focusing on Effective Science Instruction: Analyzing Student Work</p> <p>Focusing on Effective Science Instruction: The Role of Curriculum</p> <p>Focusing on Effective Science Instruction: Inquiry II</p> <p>Strategic Planning II</p> <p>Wrap-up</p> <p>UVA Evaluation</p>

Appendix B Correlation of Goals to Academy Sessions

Goal 1 — improvements in leadership, teacher learning, quality teaching, and student learning. The following sessions and exit slip questions addressed this goal:

Daily Sessions Correlated to This Goal	Exit Slip Questions Correlated to This Goal
Day 1: “Building Systems for Science Literacy” simulation from WestEd	Day 1 Question 1 and 2
Day 2: Update from State, Recognizing and Assessing Quality Teaching (State and District Data), and Strategic Planning	Day 2 Question 1
Day 3: Teacher Professional Development Planning and Sharing of Plans and Expert Panel	Day 4 Question 1 and 2
Day 4: Strategic Planning I and Update from State, Discourse, Misconceptions, Nature of Science	Day 5 Question 1
Day 5: Strategic Planning II and Curriculum, Analyzing Student Work, Inquiry, Curriculum	

Goal 2 — developing a common understanding of Hands-on Science, Inquiry, Problem-Based Learning, and Nature of Science. The following sessions and exit slip questions addressed this goal:

Daily Sessions Correlated to This Goal	Exit Slip Questions Correlated to This Goal
Day 2: VISTA Definitions and Instruments	Day 2 Question 1
Day 4: Nature of Science (NOS)	Day 4 Question 1 Day 5 Question 1
Day 5: Analyzing Student Work and Inquiry	

Goal 3 — identifying aspects of effective science teaching and learning. The following sessions and exit slip questions addressed this goal:

Daily Sessions Correlated to this Goal	Exit Slip Questions Correlated to this Goal
Day 1: <i>Building Systems for Science Literacy</i> simulation from WestEd	Day 1 Question 2
Day 2: VISTA Definitions and Instruments	Day 2 Question 1
Day 4: Discourse, Misconceptions, NOS	Day 4 Question 1 and 2
Day 5: Analyzing Student Work, Inquiry, Curriculum	Day 5 Question 1

Goal 4 — comparing district models of creating standards-based science curricula. The following sessions and exit slip questions addressed this goal:

Daily Sessions Correlated to This Goal	Exit Slip Questions Correlated to This Goal
Day 5: Curriculum	Day 5 Question 1

Goal 5 — investigating data sources available to use in order to provide a focus to improve district science programs. The following sessions and exit slip questions addressed this goal:

Daily Sessions Correlated to this Goal	Exit Slip Questions Correlated to this Goal
Day 2: Recognizing and Assessing Quality Teaching (State and District Data)	Day 2 Question 2
	Day 4 Question 1

Goal 6 — developing a science program strategic plan. The following sessions and exit slip questions addressed this goal:

Daily Sessions Correlated to This Goal	Exit Slip Questions Correlated to This Goal
<p>Day 2: Recognizing and Assessing Quality Teaching (State and District Data), Strategic Plan,</p> <p>Day 3: Teacher Professional Development Planning,</p> <p>Day 3: Sharing of Plans and Expert Panel</p> <p>Day 4: Strategic Planning I</p> <p>Day 5: Strategic Planning II</p>	<p>Day 3 Question 1 and 2</p> <p>Day 5 Question 2</p>

WOMEN OF FAITH IN SCIENCE: THE DOUBLE GLASS CEILING

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Abstract

The majority of female pre-service elementary school teachers pursuing licensure is choosing English as their cognate rather than mathematics or science. The reason females are not choosing science as their cognate may be due to the fact that science has long been considered a masculine pursuit. To complicate the issue, pre-service female teachers of deep religious faith are further challenged to navigate the dichotomy of science and religion. As a result, women, and especially women of deep religious faith, are at risk of not participating in science studies. The author suggests that there is room in the science classroom for open dialogue with students regarding the distinction between science and religion. This dialogue may help students, especially women of faith, gain a deeper understanding of the nature of science and encourage participation in science.

Introduction

During Summer 2013, science educators at the collegiate level from across Virginia participated in the VISTA Science Education Faculty Academy at George Mason University. As a group, we engaged in a weeklong series of activities that facilitated learning and discussion related to the challenges and future of science education.

During the Academy, a particular session piqued my interest. The session addressed the concept of social justice in science, and I began thinking about the very nature of science and how individuals from different cultures, religious backgrounds, and genders participate in science.

As the father of a high school daughter who has expressed an interest in pursuing a degree in chemistry, I began to reflect on the challenges females face in the field of science. I started exploring the literature regarding the history of women in science. In a historical analysis of education, gender and science, Watts points out that gender assumptions have “long kept women on the margins of science” and that “the past has long tendrils into the present” [1]. It appears that these tendrils could still be affecting female students.

For example, as a professor of education at a private evangelical Christian university, I noticed that the majority of female pre-service elementary school teachers pursuing licensure was choosing English as their cognate rather than mathematics or science. In a conversation with one of my female students who had recently graduated from a public school for gifted and talented students in science, mathematics and technology, I was intrigued by the numerous advanced placement and dual enrollment courses she had taken in science. When I asked why she was not considering becoming a science teacher, she simply said, "I don't like science." As a result, the student decided to choose English as her cognate. In discussions with colleagues from other universities, a similar phenomenon had been observed. However, my situation appeared somewhat unique in that, not only were the majority of my students female, but being from a Christian university many of my students had a deep religious faith. Watts touched on the issue of religion by pointing out that a woman's success or even willingness to try to succeed in the sciences was greatly influenced by where she came from: class, family, networks, and religion [1].

I began to wonder how female students of deep religious faith, regardless of religious affiliation, navigate science. It appeared that not only did young women of faith have to acclimate to a discipline that had long been considered a "masculine" pursuit, but they were further challenged to reconcile the dichotomy of science and religion [1]. The battle between science and religion is often played out in the media. For example, the well-known scientist and biologist Richard Dawkins in an editorial to *The Independent*, a British national morning newspaper, decried his opposition to religion by stating, "Even the bad achievements of scientists, the bombs and sonar-guided whaling vessels, work! The achievements of theologians don't do anything, don't affect anything, don't achieve anything, don't even mean anything" [2]. This type of rhetoric may cause people of faith to have a negative attitude toward science. In their case study, Roth and Alexander examined students taking physics at an all-male Christian boarding school and reported that the students made the following statements about their beliefs:

- "Religion and science do not connect."
- "Physics offends my beliefs."
- "Science completely goes against what God created."
- "In science, I feel like I am drawn away from religion" [3].

The tension between science and religion is real among students. Understanding how students negotiate their religious beliefs with science must continue to be explored; however, the deeper issues of how females navigate the religious and gender bias imposed by science may prove to be more problematic. In a sense, women of faith are faced with a double glass ceiling.

The glass ceiling is an analogy that refers to an artificial barrier placed above women and minorities who try to advance in a profession. The first glass ceiling most women in science must overcome is navigating a predominantly masculine profession. As reported by *USA Today Magazine*, women in science often experience significantly lower salaries as compared to their male counterparts, and often have limited access to upper management positions within their organizations [4]. To complicate matters, women of deep religious faith pursuing the sciences are further plagued with a tension between science and religion, and must reconcile their religious beliefs with those of the scientific community [5]. Science and religion are often in stark contradiction, creating a second glass ceiling for women of faith to overcome.

The Literature on Women of Faith in Science

Though scarce, the literature does touch on the issue regarding women of faith in science. For example, Astley and Francis conducted a quantitative study exploring the relationship between attitudes toward religion and science among 187 female students attending a series of lectures at the North of England Institute for Christian Education study day. A negative correlation was found between science and religion among female students. The study provided evidence that the more religious the female student, the less positive her attitude toward science [6].

In a similar study, Levesque and Guillaume surveyed 375 female students enrolled in teacher education courses at California State University regarding issues of religion and science. Specifically, the researchers were looking at the theory of evolution. They found that female students with a “strong belief in God, an exclusive view of salvation, and a literal reading of the Bible” were found more prone to reject the theory of evolution. The authors tried to reconcile their finding by stating that “religious faith need not be an obstacle to accepting the scientific theory of evolution” [7]. The statement is problematic in the sense that the authors’ expectation is “acceptance” of the theory rather than just understanding the theory.

In an ethnographic study, Brandt described the experience of Deborah, a Native American woman, in an undergraduate biology program at a university in the southwestern *United States*.

The study addressed the issues of language, power, and authority and how Deborah had to accept the “game rules” of scientific discourse while negotiating her Native American heritage with that of Eurocentric science [5]. In a conversation with her mother, she expressed her frustration which was grounded in her Native American spiritual beliefs:

Well, in our Navajo way of thinking, I was trying to tell my mother about the atom and molecules, and all this and she looked at me like I was crazy. And I’m like, “you know, this is what I’m learning!” You have to go through so much explaining. “Here’s our body, the organ systems, the heart. Within our heart are tissues . . . [w]ithin that are cells and ... [t]here are molecules that make up the cells, and within that are the atoms.” It can’t be seen! But that’s our whole makeup! ... And she’s looking at me like I’m crazy, because our Navajo creation story is similar to Adam and Eve ... So I’m trying to explain it! [5]

These studies are not presented to debate the origin of life, but to demonstrate that there is a distinct population of females who hold deep religious views that sometimes contradict that of science. This form of double jeopardy may further discourage young women of faith from pursuing the sciences. Brandt points out that Eurocentric science may put up artificial barriers that exclude people of various cultures and religions from participating in the sciences by dismissing other ways of knowing; this may often cause confusion and anxiety within students [5].

Social Ramifications of the Issue

Socially accepted ways in how we act, think, feel, and believe play an important part in finding self-identity and how a person fits into socially meaningful groups [5]. Changing one's identity to be able to participate in deposing groups may be too much to endure for some students. Furthermore, there are particular social stigmas attached with a particular way of speaking, acting, believing, or performing among peers.

In his study of minority students and their involvement in high school science classes, Brown argues that participation in scientific discourse carries considerable social risk, especially among students in the minority who constantly have to negotiate their relationship with teachers, classmates, family, and community. This social process is marked by “assimilation and resistance” [8]. In order to survive, students must have the ability to perceive the values and

norms that govern acceptable behavior at each location or social setting [5, 9]. What is acceptable belief and discourse within a religious community may not be acceptable within the science classroom and vice versa. As a result, women, and especially women of deep religious faith, are at risk of not participating in science.

Conclusion

As a society, we cannot afford to allow any voices, regardless of culture, religious background or gender, to be silenced with respect to scientific discourse. To hear these different voices, both the formal and informal power structures must be sensitive to the past bias that still inhibits women from pursuing science. Moreover, acknowledgment of the ongoing tension “between religious and science fundamentalism” must be addressed [10].

I believe that there is room in the science classroom for open dialogue with students regarding the distinction between science and religion. Furthermore, as an educator, my experience has been that classroom discussion regarding science and religion has proven to be beneficial in helping students gain a deeper understanding of the nature of science. Simply, the nature of religion should not be taboo as a discussion topic. When handled in a respectful and professional manner, it can provoke deep thought and challenge students to see the limitations of both science and religion in how each answers a particular question. My hope is that all students, and especially women of faith, will become active participants in scientific discourse and active members of the scientific community.

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The Journal of Mathematics and Science: COLLABORATIVE EXPLORATIONS

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PART II: REGULAR JOURNAL FEATURES

Virginia Mathematics and Science Coalition

THE STABILITY OF BOATS: A SCIENCE, TECHNOLOGY, ENGINEERING, AND MATHEMATICS (STEM) EXERCISE

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Abstract

In what might be called genuine Science, Technology, Engineering, and Mathematics (STEM), an engineering construct subject to well-understood physical principles is analyzed mathematically to yield predicted behavior. In this article, we provide just such an example. The mathematics is at the high school level. Among other things, one actually sees an application of the quadratic formula. Experimental verification of the results may be realized with simple materials.

Introduction

In an extraordinary piece of geometric analysis, Archimedes studied the stability of a floating paraboloid of revolution. An account of this work may be found in Stein [1]. Heath's book contains still more material on the work of Archimedes [2]. In the context of the work in the present article, readers of either of these books will take note of the important role that the density of the boat material plays in questions of stability.

While studying Archimedes' work in a freshman seminar class, the idea of considering the stability of boats of a simpler structure arose, potentially making it easier to compare the mathematics of the problem with experimental results. The most obvious of these is a rectangular parallelepiped with a square cross section. Each of our boats will have a length substantially longer than its square edge. The use of a long boat allows us to deal only with the cross section of a partially immersed square. In the parlance of aircraft stability, our boat may roll, but is not permitted to yaw or pitch. A study of the stability of a boat in the shape of an arbitrary rectangular parallelepiped requires a deeper analysis.

In the photograph in Figure 1, we show three examples. The left-hand boat is a square cross-section plastic box with a tight fitting lid, while the central boat is solid pine. The right-

hand boat is a square cross-section boat of pine with a $3/8$ " steel spine fitted along its long axis.

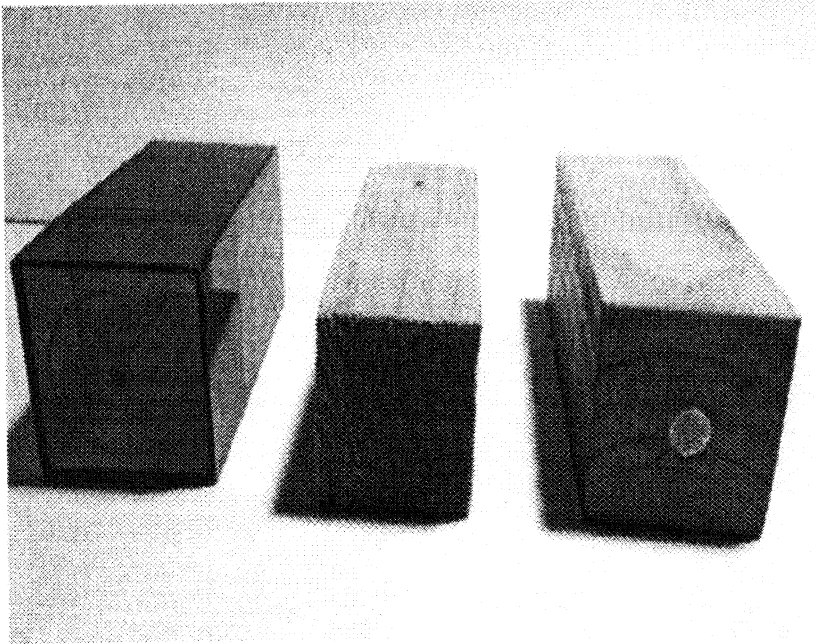


Figure 1. Three square boats: How will they float?

The elementary geometric and algebraic methods that will be employed are appropriate to good high school students interested in physical or engineering applications. Any desired experimental materials can be cheaply constructed.

As a general matter, stability investigations deal with small perturbations from an “equilibrium” position of some physical system. One asks whether or not that system, a boat in this case, will tend to return to that equilibrium once slightly disturbed. To study our problem, we need specific help from Archimedes. These principles may be proved using modern methods:

- A1. The weight of a rigid body acts at its center of mass. [Archimedes would have said “center of gravity.”]

- A2. A body floating in water displaces a quantity of water whose weight matches that of the boat.
- A3. The (upward) supporting weight of the displaced water acts at *its* center of mass, a location commonly called the “center of buoyancy.”
- A4. Two opposing forces acting on a rigid body will cause it to rotate if and only if the forces act along different lines (the lever principle).

Now, we need a disclaimer that will hold throughout the article. We will confine our investigation solely to those perturbations that leave the volume of displaced water fixed. Something like a down draft on a real boat would violate this constraint. Eventually, however, that boat would return to *some* calm water configuration in which, by Archimedes A2, the boat would displace precisely its weight in water. Our analysis could then be deemed to begin at this stage of the perturbation.

Alternatively, one may decide to examine only those configurations in which our square boat is initially floated with sufficient care that the weight of the displaced water volume does, indeed, exactly match the weight of the boat. Then, our analysis will deal with the stability of the chosen immersed configuration.

The First Stability Question

We begin with a long boat of square cross section whose center of mass falls midway along its long central axis. A simple way to accomplish this is to use a solid boat of uniform density. According to our agreement on the elongated shape of the boat, we need to work only with the plane cross section of the boat and of the water it displaces while floating.

We want to launch our boat by simply placing it in water. One possible configuration for this launch would put one of the long flat rectangular surfaces of the boat parallel to the water surface. (Passengers would then have a convenient place to walk.) Is this configuration stable if the boat encounters a very small wave?

In its strictly upright position, the boat will maintain its horizontal orientation because,

as in Figure 2, the supporting weight of the water and the weight of the boat act along the same vertical line. There is no rotation.

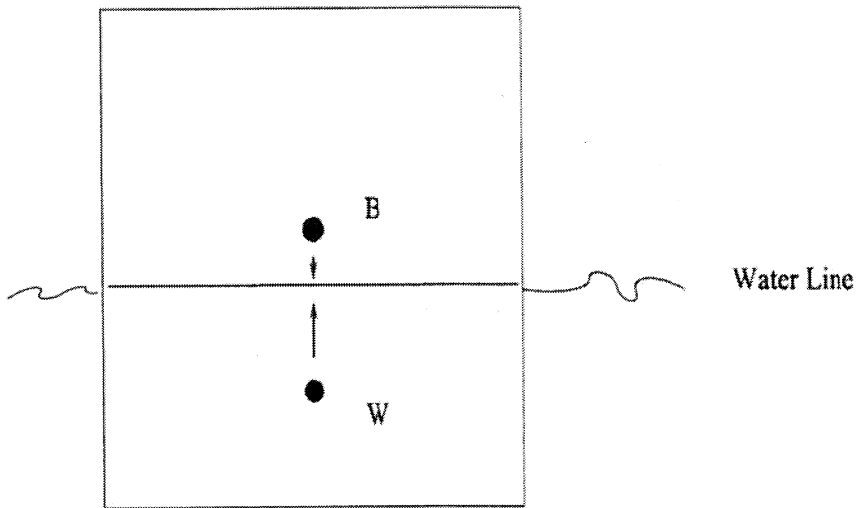


Figure 2. A boat in strict horizontal float.

If, however, under the influence of a mote of dust or a small ripple in the water, the boat lists slightly, say, to the right, we would see a configuration shown in Figure 3. For the sake of clarity, we have exaggerated the size of the list-angle, θ , in that figure.

Temporarily, we use a rectangular coordinate frame with origin at the lower left-hand corner of the boat, and with axes fixed to the edges of the boat. This is the “body-fixed” frame. In this frame, the coordinates of the center of mass of the boat are obviously the same, list or no list. They are $B = (e/2, e/2)$, where e is the edge-length of the square cross section of the boat.

The center of mass of the supporting displaced water is a different matter. Crucial to the resolution of the stability problem is the recognition that that center moves, relative to the fixed-body axes, because the *shape* of the displaced water changes when the boat lists. In particular, that shape shifts from rectangular to trapezoidal (see Figure 3). The diagram suggests the variability of the center of buoyancy of this trapezoid.

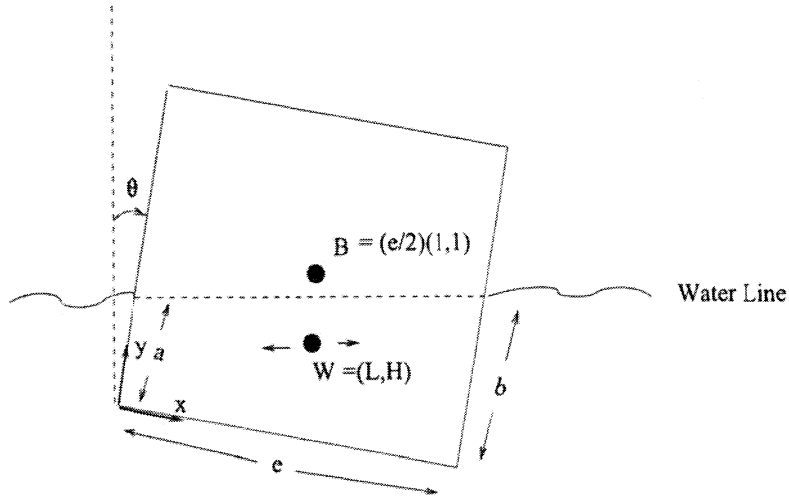


Figure 3. A boat listing from the horizontal.

We need to locate the center of buoyancy, and there are a variety of ways of managing this technical matter. One way or another, one must deal with the center of mass of a continuous body—the displaced water. Archimedes had a method that relies on the principle of the lever and fundamentally does an integration. His “summation methods” are recounted in *Archimedes: What Did He Do Besides Cry Eureka!* [1]. We omit the details and simply give the answer that can be obtained by an ordinary integration.

We let a and b be the short and long legs of the displaced trapezoid. If we denote by A the area of the trapezoid, then obviously $A = e(a + b)/2$. Using our body-fixed rectangular frame, the center of mass (L, H) of the trapezoid will satisfy

$$\begin{aligned} AL &= (e^2 / 6)(a + 2b) \\ AH &= (e / 6)(b^3 - a^3) / (b - a) \end{aligned} \tag{1}$$

Students unfamiliar with either version of integration may, instead, employ yet another Archimedean “global” lever principle to find the center of gravity of the trapezoid. A rectangle of base e and height a has area $A_1 = ea$ and center of gravity at $(e/2, a/2)$. A triangle of base e and height $b - a$ (mounted above the rectangle) has area $A_2 = e(b - a)/2$ and

center of gravity $(2e/3, a + (b - a)/3)$. Then according to the principle of the lever, $AL = A_1(e/2) + A_2(2e/3)$ and $AH = A_1a/2 + A_2(a + (b - a)/3)$. One may check that these give the same results as equation (1).

Let us write $\hat{\rho}$ for the weight density of the boat material in some chosen units. Let δ be the weight density of water in those same units and let ℓ be the length of the boat. Then according to Archimedes A2,

$$e^2 \ell \hat{\rho} = A \ell \delta,$$

so that $\hat{\rho} / \delta = A / e^2$ is a quantity whose numerical value is *independent* of the units of measurement. Throughout the remainder of this article, we write ρ for the ratio $\hat{\rho} / \delta$, the weight density of the boat material measured in units of the weight density of water. For short, we refer to ρ simply as the weight density of the boat.

As ρ is a (constant) physical characteristic of the boat material and e is a geometric constant characteristic of the boat shape, the quantity $A = \rho e^2$ is also a constant, independent of the list-angle θ . Just to remind the reader, while the *area* of immersion of the boat is constant, the *shape* of that immersion is not. In much of the sequel, our stability results will be expressed in terms of the physical constant:

$$\rho = A / e^2$$

The dependence of the edge-lengths, a and b , on the list-angle θ is determined by the geometry of the trapezoid, a figure whose area, A , is constant for our particular boat.

$$b = a + e \tan(\theta)$$

$$A = e \frac{a + b}{2}$$

so that,

$$a = A / e - (e / 2) \tan(\theta)$$

$$b = A / e + (e / 2) \tan(\theta)$$

It is, therefore, convenient to rewrite the formulas in (1) to describe the coordinates of the center of buoyancy as functions of the area and the list-angle:

$$\begin{aligned} L &= (e/2) + e^3 \tan \theta / (12A) \\ H &= (e/6)[3A/e^2 + e^2 \tan^2 \theta / (4A)]. \end{aligned} \quad (2)$$

Then in a quite natural way, the density, ρ , of the boat material, makes an appearance:

$$\begin{aligned} L &= (e/2)[1 + \tan(\theta) / 6\rho] \\ H &= (e/2)[\rho + \tan^2(\theta) / 12\rho]. \end{aligned}$$

It remains now to locate the relative positions of the points B and W in a coordinate frame whose horizontal axis is parallel to the waterline. We need only rotate the boat-fixed frame counterclockwise through the list-angle. Then in this new frame, the respective horizontal and vertical coordinates of the boat center of mass, B are $(e/2)(\cos \theta + \sin \theta, -\sin \theta + \cos \theta)$. The coordinates of the center of buoyancy are $(L \cos \theta + H \sin \theta, -L \sin \theta + H \cos \theta)$.

The forces acting on the boat are its weight and the buoyant support of the water. These are equal and opposite, and both act vertically along lines perpendicular to the waterline. However, these vertical lines can be different from one another, giving rise to a rotation as in Archimedes' principle A4. Thus, by Archimedes' A1, the vertical line of action of the boat's weight passes through the coordinate of B along the direction of the waterline, namely $(e/2)(\cos \theta + \sin \theta)$. Meanwhile, by Archimedes' A4, the vertical buoyant force passes through the horizontal component of W , $L \cos \theta + H \sin \theta$, along the direction of the waterline.

For stability of the clockwise listing boat, the center of buoyancy must fall to the right of the center of mass of the boat so as to exert a restoring rotation to the boat. Otherwise, the rotation will continue in the clockwise direction, tipping the boat even further.

$$\begin{aligned}
&\text{Stability Condition: } L \cos \theta + H \sin \theta > (e/2)(\cos \theta + \sin \theta) \\
&\text{Instability Condition: } L \cos \theta + H \sin \theta < (e/2)(\cos \theta + \sin \theta)
\end{aligned} \tag{3}$$

Using the expressions for L and H as given by (2), the stability condition (3) is

$$(e/2)[\cos \theta + \sin \theta / (6\rho) + \rho \sin \theta + \tan^2 \theta \sin \theta / (12\rho)] > (e/2)(\sin \theta + \cos \theta).$$

The $(e/2) \cos \theta$ terms cancel and we can factor out the common $\sin \theta > 0$ multiplier.

Then for stability,

$$1/(6\rho) + \rho + \tan^2 \theta / (12\rho) > 1.$$

That is,

$$6\rho^2 - 6\rho + 1 + \tan^2 \theta / 2 > 0.$$

Now, the quadratic polynomial $f(\rho) = 6\rho^2 - 6\rho + 1$ has roots at $1/2 \pm \sqrt{3}/6$. Moreover, $f(\rho)$ is non-negative except for $\rho \in (1/2 - \sqrt{3}/6, 1/2 + \sqrt{3}/6)$. This means the stability condition above is satisfied for all $\rho \in (0, 1/2 - \sqrt{3}/6] \cup [1/2 + \sqrt{3}/6, 1)$ and all non-zero values of θ . We would, of course, prohibit such large values of the perturbation angle θ that would violate the trapezoidal nature of the perturbed geometry. This is a trivial matter here.

Our result: For small perturbation list-angles, a square cross-section boat with uniform density will float stably in the horizontal position for densities that satisfy:

$$0 < \rho \leq 1/2 - \sqrt{3}/6 \quad \text{and} \quad 1/2 + \sqrt{3}/6 \leq \rho < 1.$$

We call these the *stable* ranges for the horizontal configuration. For intermediate densities, that is, $\rho \in (1/2 - \sqrt{3}/6, 1/2 + \sqrt{3}/6)$, the horizontal configuration is unstable.

The previous discussion has dealt with rightward perturbations. For stability at the horizontal equilibrium, we examined displacements in which the boat would enjoy a counterclockwise recovery from some disturbed rightward position. Formally, this meant that our list-angle, θ , was deemed to be positive if taken in the clockwise direction.

From a physical point of view, there should be no distinction in the classification of stable and unstable configurations under left and right, or right perturbation. However, it is a simple matter to employ the analysis we have used to obtain clockwise recovery from a disturbed leftward position.

The analysis may be repeated verbatim while the sign of the list-angle, θ , remains unspecified. To complete the argument so as to arrive at appropriate recovery/non-recovery inequalities, we remove a common factor, $\sin \theta$. For negative list-angles, that multiplier is negative. The directions of the resulting inequalities are, therefore, determined by the sign of the perturbing list-angle. The influence of the sign of the list-angle is now obvious. If the perturbing list-angle is positive (in the clockwise direction), recovery will be counterclockwise. If the perturbing list-angle is negative, recovery will be clockwise. We have, then, Theorem 1.

Theorem 1. Given a long boat of homogeneous material with square cross section whose density, ρ , falls in either of the two stable ranges above, there is a tolerance, $\epsilon = \epsilon(\rho) > 0$, such that the boat will remain stable in the horizontal configuration under any list perturbation with $|\theta| < \epsilon$.

The Second Stability Problem

Square boats of intermediate densities are unstable in the horizontal configuration. Easy experiments with such boats suggest that a “45 degree” orientation is stable. We examine this issue and Theorem 2 is the result.

Theorem 2. A long boat of square cross section will stably float in the 45 degree orientation against small perturbations if its density, ρ , falls in the range $9/32 \leq \rho \leq 23/32$.

Owing to different geometric shapes of the displaced water for light and heavy boats, we first consider densities less than $1/2$ and later densities greater than $1/2$. The proof of the

theorem for the singular case $\rho = 1/2$ is left to the reader.

That reader will notice a gap between this result and the range for stable horizontal float. There are two ranges of densities, $1/2 - \sqrt{3}/6 < \rho < 9/32$ and $23/32 < \rho < 1/2 + \sqrt{3}/6$ where *neither* the horizontal nor the 45 degree orientation is stable. (The author will provide a mathematical analysis in a subsequent paper.)

A. The case $\rho < 1/2$.

For a boat of density less than 1/2, the displaced water in the strict 45 degree orientation has the shape of an isosceles right triangle. If such a boat lists slightly to the right, the displaced water remains right triangular, but is no longer isosceles. Figure 4 shows such a displacement triangle with short leg a and long leg b .

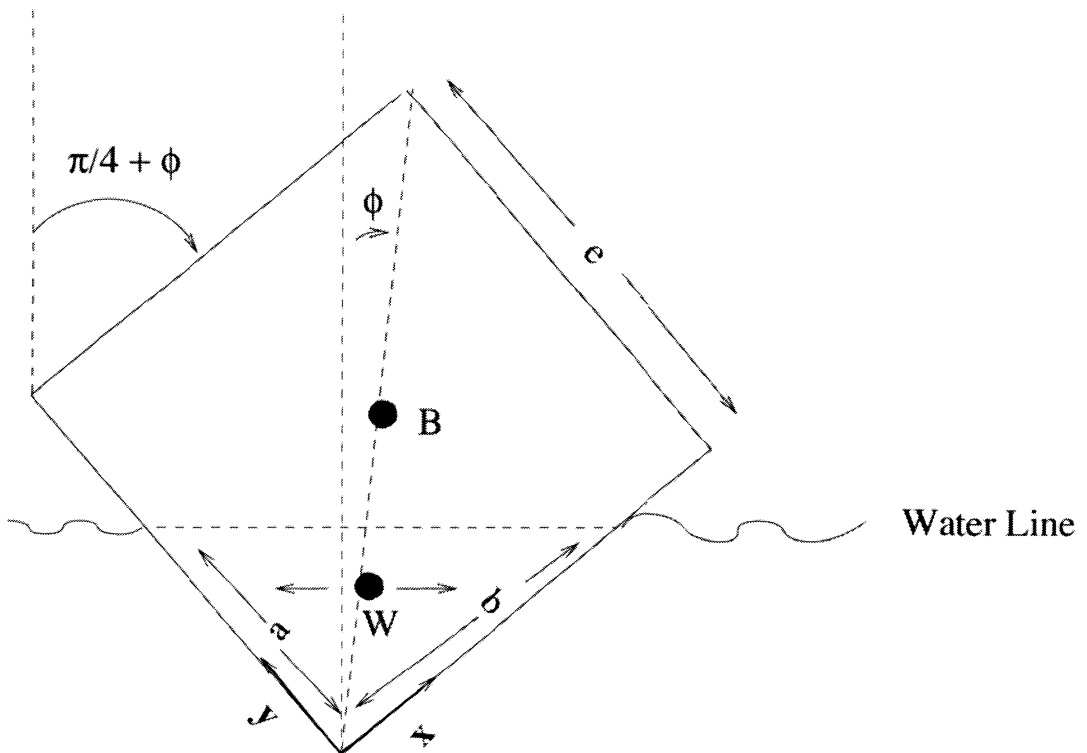


Figure 4. A low-density boat listing from the 45 degree configuration.

A natural “base line” against which to measure the list-angle is a diagonal of the square. We denote this list-angle by ϕ . The geometry of the right triangle permits one to link a and b :

$$a = b \tan(\pi/4 - \phi) = b(1 - \tan \phi)/(1 + \tan \phi). \quad (4)$$

As before, in order to locate the center of mass of the boat and center of buoyancy in the list orientation, we may use the rectangular coordinate frame fixed to the boat with origin at the deepest corner of the displaced water: “vertical” along the a side, “horizontal” along the b side. In this coordinate frame, the center of mass of the boat is, of course, $(e/2)(1, 1)$. The center of buoyancy is $(b/3, a/3)$. Before we pass to the waterline coordinates, it is useful to use an intermediate coordinate frame, also fixed to the boat. Thus, our new vertical will be the diagonal of the boat issuing from the deepest point of water displacement. The new horizontal will be a perpendicular to this diagonal, also passing through the deepest point (see Figure 5).

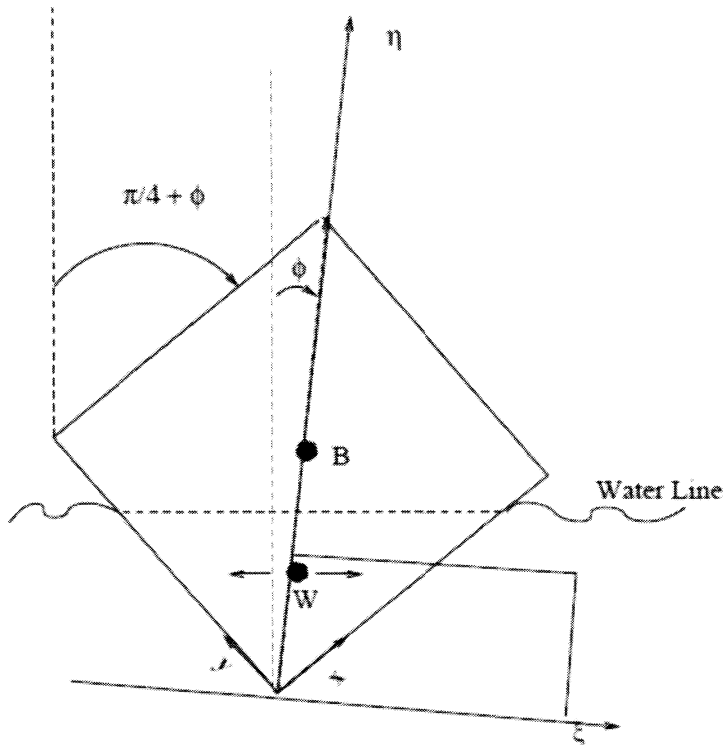


Figure 5. An interim coordinate frame for a low-density boat.

Using standard distance formulas, point to line, we can compute the coordinates of the center of mass of the boat, B , and the center of buoyancy, W , in this new frame:

$$B = e(0, \sqrt{2}/2)$$

$$W = 1/(3\sqrt{2})(b-a, b+a)$$

Rotating this intermediate frame counterclockwise through the list-angle, we come to respective horizontal coordinates along the waterline. For the center of buoyancy:

$$[(b-a)/(3\sqrt{2})]\cos(\phi) + [(b+a)/(3\sqrt{2})]\sin(\phi).$$

For the center of mass of the boat:

$$(e\sqrt{2}/2)\sin(\phi).$$

Which of these is larger? If the former, the boat is stable in the 45 degree position. If the latter, the boat is unstable.

From (3), we have $b-a = 2b \tan \phi / (1 + \tan \phi)$ and $b+a = 2b / (1 + \tan \phi)$. Hence, we can establish a criterion for stability:

$$(4/3)b / (1 + \tan(\phi)) > e$$

Or,

$$(16/9)b^2 / (1 + \tan(\phi))^2 > e^2.$$

Or

$$(16/9)ab / (1 - \tan^2(\phi)) > e^2.$$

Remembering that the area, A , of the displaced water is $A = ab/2$, we notice that the density, $\rho = A/e^2$, will appear. Thus, the stability criterion, for $\rho < 1/2$ and the boat in the 45 degree orientation, is

$$A > (9/32)(1 - \tan^2 \phi) > e^2.$$

Then for any $\rho \geq 9/32$ and *any* perturbation angle, $\phi \neq 0$, this stability criterion is satisfied. Once again, we should observe a trivial constraint on the perturbation angle: It should not be so large as to spoil the triangular shape of the perturbed configuration. Then for boats of density less than $1/2$, the density must fall in the interval $9/32 \leq \rho < 1/2$ in order that the 45 degree orientation be stable under small perturbation.

To complete the argument for the case $\rho < 1/2$, we need only mention that removal of the factor $\sin \phi$ from our inequalities will enforce the symmetry of the stability criterion for negative angular perturbations, ϕ .

B. The case $\rho > 1/2$.

Now, the perturbed cross section is a five-sided figure (see Figure 6). The (perturbed) waterline cuts off a short leg of length a and a long leg of length b . As before, the edge-length of the boat is denoted e .

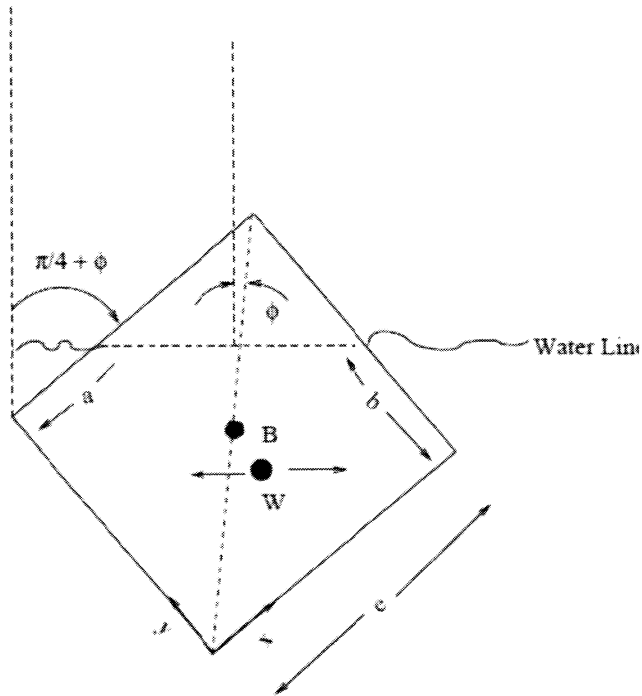


Figure 6. A high-density boat listing from the 45 degree configuration.

We may continue with a brute-force analysis employing some unpleasant algebra

and trigonometry to verify the stability of the 45 degree orientation for densities $1/2 < \rho < 23/32$. It is, however, more efficient to rely on the work already done on the low density case. We need a “dual” to that argument.

Let us review the low-density configuration, the perturbed version of which is shown in Figure 4. Use x 's generically for coordinates along the waterline. In the perturbed Figure 4, A is the area below the waterline, x_1 the coordinate of its CG. The boat of area e^2 has coordinate x_0 for its CG and the pentagonal region with area $e^2 - A$ has coordinate x_2 for its CG. By the lever principle (or an ordinary integration), $Ax_1 + (e^2 - A)x_2 = e^2x_0$.

Or better,

$$A(x_1 - x_0) + (e^2 - A)(x_2 - x_0) = 0.$$

Now, to study stability in the low density 45 degree configuration, compute the total moment about the CG of the boat after *clockwise* angular perturbation ϕ . The boat itself contributes no moment, and the water contributes a counterclockwise moment $A(x_1 - x_0)$. Let us assume that the density, ρ , satisfies $9/32 \leq \rho < 1/2$ so that the 45 degree orientation, as we have shown above, is stable. Then $A(x_1 - x_0) > 0$, so that $(e^2 - A)(x_2 - x_0) < 0$. The latter inequality tells us that if the figure were *reflected* in the waterline, the immersed area, $(e^2 - A)$ with coordinate x_2 for its CG would produce a clockwise moment about the CG of the boat. That is, a boat with density $1 - \rho$ (and immersed area $e^2 - A$) when perturbed *to the left*, would tend to be restored by the resulting moment. Hence, any density, $1/2 < \rho \leq 23/32$ would produce a stable 45 degree configuration.

Experimental Epilogue

One could look for physical verification of the stability analysis above. It is obvious that the boats we are studying are far from a practical design. The discipline of naval architecture, however, relies on the use of complex models whose stability analysis employs numerical methods, together with much more attention to the dynamics of response to perturbations. Among other things, disturbances in heavy weather entail a stability investigation of a very much more elaborate nature than the one we have presented. Nevertheless, consideration of center of buoyancy and center of mass, as in the work above, will always play a role in the design of a boat intended for a particular application.

Experimental validation of the fine details of the calculations above presents interesting challenges. For instance, for a very low density boat, the merest lateral shift of the center of gravity of the boat from its geometric center is bound to cause a list from the horizontal configuration, making it difficult for a square boat of real material (wood for example) to exhibit true horizontal stability. The same idea holds for the 45 degree orientation of square boats of intermediate density. In the end, then, one should look for “nearly horizontal” or “nearly 45 degree” stability of actual square boats.

The photograph in Figure 7 shows a flotilla of our three boats. The low-density plastic box boat is nearly horizontal as is the pine boat with the steel spine. The intermediate pine boat is clearly in the (near) 45 degree configuration. The three boats have the following respective densities: .21 for the plastic box boat, .82 for the steel spine boat, and .35 for the pine boat.

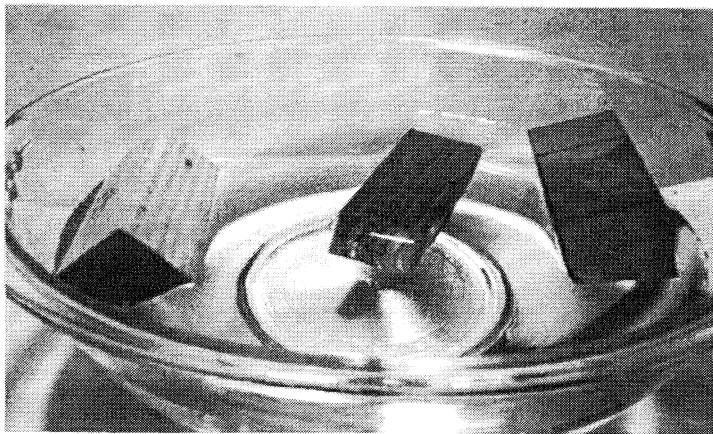


Figure 7. A flotilla of three boats of varying densities.

One may achieve a closer physical approximation to the mathematical prediction by making “adjustments.” The photograph in Figure 8 shows the plastic box boat with some small correcting patches which, presumably, move the center of gravity of the boat more in coincidence with the geometric center of the boat.

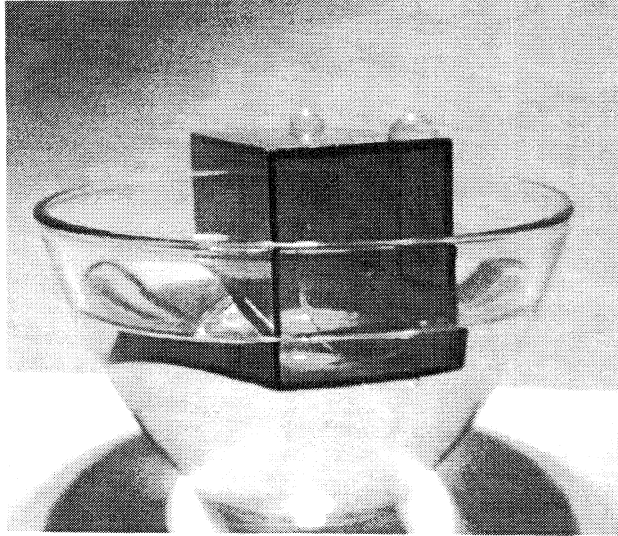


Figure 8. A low-density boat with corrected center of gravity.

Further Work

As indicated above, the stability “gaps” in the horizontal configuration can be resolved. Triangular boats should be easier to study. The role of density should play a prominent role in all of these studies. Students may construct the boats with inexpensive materials and check the mathematics against experimental results.

Acknowledgments

During the spring semester of 2012, while the author and his students in *Mathematics 150* at The College of William and Mary were studying the work of Archimedes, Charles Garland gave the author the pine boat that floats stably in the 45 degree orientation. He provoked the author to explain the phenomenon to himself and to the students. David Lutzer read and re-read the manuscript. He provided mathematical and stylistic advice that enabled the author to repair numerous lapses in the exposition. John Drew and John Bensel helped to build the high-density square boat. Patricia Rublein photographed the boats.

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VIEWS OF COACHING PRACTICE EXPRESSED BY SCHOOL-BASED COACHES

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Abstract

This study reports on the views of coaching expressed by school-based coaches and coaching experts in response to observing the practice of a novice coach featured in a video. Researchers hypothesized that a coach participant's observations about another coach's practice would be a useful tool for examining participants' beliefs about coaching. Researchers compared responses from school-based coaches to the responses of coaching experts and views expressed in leading coaching literature in order to examine the variation in school-based coaches' views. Analysis of responses from both practicing coaches and coaching experts revealed eight themes that describe components of the videotaped coaching cycle: 1) coaching relationships; 2) the use of praise by the coach; 3) discussions of student learning; 4) how coaches respond to teachers' questions; 5) how coaches prompt reflection; 6) how coaches address teacher knowledge and learning; 7) discussions of mathematics content; and, 8) facilitation of the coaching session. The analysis also revealed that these themes correspond to accepted domains of coaching knowledge reported in the coaching literature.

Introduction

Ongoing initiatives to improve mathematics teaching in the United States and the below-average performance of American students on international assessments have resulted in calls for changes in mathematics classrooms [1-3]. Some school districts have turned to mathematics coaches as one method of improving achievement [4]. The duties of a mathematics coach vary,

from conducting professional development to providing lesson demonstrations and instructional feedback to teachers [5]. Regardless of the specific duties, the coach's primary goal is to "impact teaching and student learning" [6]. Some recent research studies have demonstrated that mathematics coaches can have a positive impact on mathematics achievement [7-9]. The level of impact is related to the coach's knowledge of what constitutes effective coaching [7].

Currently in the United States, coaching practice is defined through its enactment following various models prescribed by those who train coaches and write about coaching. At present, there is little empirical basis for the effectiveness of these models. Recently, in an attempt to consolidate a knowledge base about coaching, researchers have begun to identify domains of mathematics coaching knowledge [10]. The eight domains presented within that work represent "a starting point for further analysis of mathematics coaching knowledge." Still, if these domains represent a general consensus within the field regarding what constitutes coaching knowledge, the challenge remains to understand what practicing coaches view as effective coaching. It is conceivable that the views of effective coaching held by practicing coaches might be quite different than those expressed by coaching authors or coach trainers. This is important since local school districts might desire to implement a vision of coaching consistent with that expressed in a particular coaching model, yet hire coaches who hold or develop views inconsistent with that model.

With this motivation, we designed a unique coaching assessment that uses video of a novice coach. Video has been effectively used as a means for exploring teachers' content knowledge, as well as examining teachers' ideas regarding effective pedagogy [11, 12]. We hypothesized that a coach's assessment of another coach's practice as depicted in a video would give an important "view" of what school-based coaches believe to be important, and how these views might differ from views expressed by the coaching authors and expert coaches. Through comparisons of responses from minimally trained, school-based, practicing coaches to responses from expert coaches and coaching literature, we address the following two research questions: 1) what variation can be found in the views about coaching practice expressed by practicing coaches; and, 2) how do these views compare to those expressed by experts and coaching authors?

Methodology

Research Context — The Examining Mathematics Coaching (EMC) Project is a five-year research study investigating the types and depths of knowledge needed by effective coaches in K-8 mathematics classrooms. The EMC Project defines a mathematics coach as “an on-site professional developer who enhances teacher quality through collaboration, focusing on research-based, reform-based, and standards-based instructional strategies, and mathematics content that includes the why, what, and how of teaching mathematics.” In this model, a coach works eight times in a school year with each individual teacher in a coaching cycle involving a pre-lesson conference, lesson observation, and a post-lesson conference. The EMC model focuses only on the classroom supporter role of the coach, while acknowledging that within their schools, coaches may take on additional roles [6]. For the EMC Project, coaches identify three teachers with whom they will follow this model. The EMC Project does not hire or assign coaches, so the coaches’ support of teachers beyond the identified three may vary.

Participants

Data were gathered from two groups of participants: EMC coaches, whom we will call “Project coaches,” and coaching experts. Each of these groups represented a sample of convenience and will be described separately in the paragraphs that follow.

Project Coaches — The Project coaches were school-based coaches who had been hired by local school districts to serve as mathematics coaches. At the time of the video assessment, these coaches had been enrolled in the Project for two years, serving as a control group in a crossover treatment research design while coaching in their local schools. However, they had yet to receive any professional development other than a brief, one-hour orientation to the coaching model and Project expectations sixteen months prior to taking this assessment.

Table 1 provides a description of the coaching backgrounds reported by these participants. Their experiences ranged from zero to 130 hours of training in coaching, involving multiple models of coaching. All participants had at least two years of coaching experience in the Project, except two as noted, who had no coaching experience in the Project.

Table 1
Reported Hours and Types of Coach Training

Project Coach Code	Cognitive Coaching (hours)	Instructional Coaching (hours)	Content-Focused Coaching (hours)	Other Coaching Trainings (hours)	Total Training (hours)
1			55		55
2					0
3 ^a					0
4		24			24
5	40	90			130
6			18		18
7				24	24
8			3		3
9					0
10					0
11 ^a					0
12		12			12
13			3		3
14			15	10	25
15		12			12
16					0
17				40	40
18		12	40	10	62
19	40				40
20					0
21				15	15

^a Project coach had no coaching experience at the time of this study.

Coaching Experts — Six coaching experts were purposefully selected for participation in this study. These experts were chosen to represent different coaching perspectives. Two of the experts are authors of widely used coaching books, while other experts had the following backgrounds: a Mathematics Specialist researcher with numerous publications in the area; a

Mathematics Specialist policymaker and author of numerous articles; a professional development researcher who has implemented coaching in several projects; and, a professional development provider who has provided training to coaches across the nation.

Coaching Video Assessment

In order to gain insight into participants' views of coaching practices, we used a video-based assessment that featured a coaching session held between a novice coach and two teachers. The coach had participated in approximately three hours of training aimed at providing an overview of the design and purpose of pre- and post-lesson coaching sessions. As a result, she was considered a novice coach.

The video-based assessment featured the novice coach's initial coaching experience in which she worked with a pair of middle-grades teachers whose goal was to prepare and implement a team-taught lesson on stem-and-leaf plots within a summer professional development program. The video-based assessment consisted of three components: a mathematical introduction, the pre-lesson conference (or "pre-conference"), and the post-lesson conference (or "post-conference").

Mathematical Introduction — The mathematics featured in the coaching assessment featured stem-and-leaf plots. To be sure that all participants would have some familiarity with the mathematics and the task featured in the video, one of the authors created a five-minute segment describing the featured task, an overview of stem-and-leaf plots, and possible solutions to the task.

Pre-Conference — In the pre-conference video (approximately seven minutes long), the novice coach's questions and statements focused on three general areas: the challenge level of the task; the launch of the task; and the multiple solutions of the task. The following excerpt provides a typical exchange between the coach and teachers during the pre-conference:

- Coach: Because these are eighth graders, maybe that might not be something you even need to address. And that's something that you guys might want to discuss when you're planning it: Do we need to address what a stem-and-leaf plot is? Or do we need to make sure that they—well, but when you're walking around observing ...
- Teacher 1: But I'm saying how—how would you go about introducing this activity to the students?

Coach: That's a good question. That's one of the things we might discover. I'm not sure. What kind of confusions do you anticipate during the problem? What do you think might be confusing to them? What kind of confusions? That might be the same question as what problems we might ...

Post-Conference — The post-conference video was approximately eight minutes long. In this video, the novice coach began by asking the teachers for their opinions of the lesson. After each teacher briefly shared her thoughts, thirty-four seconds in total, the coach shared her opinion, stating that the lesson went very well. In addition, the coach indicated different aspects of the lesson that she liked, including the use of the timer, facilitation of group discussion, guiding the students toward understanding, and circulating among students in the classroom during the lesson. Finally, the coach recognized that the lesson had been rushed due to time constraints, and prompted the teachers to consider what they might have done had the time constraints not been in place. The following excerpt represents a typical dialogue between the coach and teachers during the post-conference:

Coach: The twelves and the thirteens, and I also made a note that, umm, then you were walking around to that group, rather than telling them, "Oh, that's not the way," you did a great job at guiding them through understanding what they had written.

Teacher 2: Umm-hmm.

Coach: You did a great job of saying, "Now, these represent what? These represent what?" And they were able to tell you twelves, thirteens ...

Teacher 2: I couldn't think of how to get her to the point of, look, now this is the one with all of my ten. I couldn't think of how to do that.

Coach: But you didn't necessarily need to. I think the fact that you left it at making sure that she understood what she was saying was fine because the group across the table had the one and all the data points.

Teacher 2: Yeah, they did. Yeah.

Assessment Questions — After watching the video, participants responded to the following request: "Please assess this coach's practice as depicted in the video and write a brief summary (under 200 words) of your opinion."

Data Analysis

We analyzed the responses to the assessment prompt separately for the Project coaches and the coaching experts. Using an approach akin to grounded theory, we identified concepts within each data set [13]. We then compared the emergent themes from the two data sets and integrated them to form overarching themes. We then noted differences and similarities in how the Project coaches and the coaching experts viewed the coaching practice of the novice coach. The following section contains elaborations for specific applications of coaching knowledge that emerged from the analysis of the responses provided by the Project coaches and coaching experts.

We did not analyze the data in the context of the model in which the coaches were trained, and instead include the data in Table 1 to show that our sample was diverse in its coaching background. One reason for this is that several of the coaches were trained in more than one model. Another reason is because it is difficult to account for whether a coach has read about another coaching model or discussed other models with other coaches. Moreover, we do not know the extent to which a coach adheres to or agrees with a model in which s/he is trained. Finally, our purpose was to uncover variation in the views expressed by practicing coaches and how these views might differ from those expressed in texts and by experts. We do not make claims about the source(s) of the coaches' views. Attempts to align the participants' views to views expressed in the models in which they were trained would make ontological claims that we are not prepared to make.

Results and Analysis

Eight themes emerged from our analysis. Under each theme, we present concepts and representative quotes that define the theme and a summary of how the theme is discussed in leading coaching texts. We focus on the leading texts and their associated coaching models: “Cognitive Coaching,” described in *Cognitive Coaching*; “Mathematics Coaching,” described in *A Guide to Mathematics Coaching*; “Instructional Coaching,” described in *Instructional Coaching*; and, “Content-Focused Coaching,” described in *Content-Focused Coaching* [14-17]. Hereafter, we refer to the ideas encompassed in these texts by their associated model names.

Theme 1: Coaching Relationships — Five of the 21 Project coaches and three of the 6 coaching experts mentioned the coach's relationship with the teachers. Words and phrases used to define this category included: “trust,” “rapport,” “comfortable,” “uncomfortable,” “not personally engaging,” and “not intimidating.” The following quotes are representative:

- Project Coach 15: It was obvious to me that there was a rapport and trust relationship between the [coach and the two teachers].
- Coaching Expert 106: The planning process appeared stilted and uncomfortable for the coach and the teachers.

Our first level of coding identified whether or not the relationship was mentioned by the participant. The second level of coding attempted to identify whether the comments were favorable or unfavorable. By favorable and unfavorable, we mean with regard to effective coaching, not just positive or negative phrasing. A code of neutral was assigned if we could not find evidence that assigned value to the trait in terms of coaching effectiveness.

Using this coding scheme, we found that four Project coaches and one coaching expert made comments that used positive phrases, similar to Project Coach 15, but made no assertions about whether or not this trait contributed to effective coaching. These responses were coded as “neutral.” Similarly, one Project coach and one coaching expert made comments that used negative phrases, similar to Coaching Expert 106, but made no assertion about coaching ineffectiveness. These responses also were coded as neutral.

Only one coaching expert made a comment that we labeled as unfavorable, meaning ineffective coaching. Coaching Expert 105 remarked that “this level of coaching may get ‘relationships’ developed ... but it doesn’t dive deep enough into content and doesn’t challenge practice ...” We must note that the participant did not make specific comments about the relationship of the coach and teachers in the video. Instead, the participant situated comments in the larger concern about the tensions between effective coaching and relationship considerations.

Theme 1: What Do Leading Coaching Texts Say about Relationships? — All of the models in coaching texts we surveyed assert that relationships with teachers are important considerations for coaches. The literature varies, however, in how coach-teacher relationships are developed and maintained.

Instructional Coaching and Cognitive Coaching both identify the need for relationships as a starting point in bringing about teacher change. Mathematics Coaching emphasizes the importance of building rapport with teachers. As stated in *A Guide to Mathematics Coaching*, “a collaborative relationship enables a coach to help teachers develop deep mathematical content knowledge and effective research-based instructional strategies” [15].

Knight asserts that, to build relationships and get around teacher defensiveness, “[Instructional Coaches] can share stories, laugh and empathize, offer positive comments, discuss personal issues, and listen with great care during interviews” [16]. Cognitive Coaching lays out useful communication and relationship-building tools that coaches can employ to help change beliefs that lead to changes in behavior.

There is considerable tension within the coaching literature, however, over whether maintaining positive relationships is sufficient for producing an effective coaching program. Knight poses the question, “What good does it serve students if an [Instructional Coach] and teacher work together in a healthy relationship but their friendly conversation has no impact on the quality of the teacher’s teaching?” At the end of that passage, though, Knight concludes, “If we are viewed in such a way [as any other teacher], and teachers come to see us as colleagues they can trust, there is a good chance that together we can make a difference in the way teachers teach and students learn in schools” [16].

Knight’s concept of the coaching relationship, and its self-evident potential of impact, do not appear to be shared by all coaching authors. For instance, West and Staub do not view Content-Focused Coaches as “any other teacher,” asserting that the relationship between coach and teacher is collegial but that the interaction “will not be symmetrical” [17]. Another coaching author, Killian, draws clear distinctions between coaches who coach “light” and coaches who coach “heavy” [6]. Killian asserts that “coaching light results in coaches being accepted, appreciated, and even liked by their peers,” but that such actions result in “coaches who are valued, although may not be needed.” In contrast, coaching heavy occurs when coaches ask thought-provoking questions and have fierce and difficult conversations. According to Killian, “Coaching heavy causes [teachers] to feel on edge, questioning their actions and decisions” [6].

Theme 1: How Do Project Coaches’ Views about Relationships Compare to Those Expressed by Coaching Experts and the Coaching Literature? — We do not claim to have completely captured participants’ views of coaching relationships. However, it is interesting that some participants made positive comments about the coach-teacher relationships in the video, while others made negative comments. Such a diverse set of opinions suggests that a common vision for what constitutes positive and effective coaching relationships is not held among practicing coaches, and even coaching experts. The diverse ways in which the topic is discussed in coaching texts support such an observation.

Our viewpoint is that a response such as that given by Coaching Expert 105 expresses a sophisticated view of coaching relationships because it captures the tension between maintaining positive working relationships with a teacher and promoting teacher growth, which is also expressed in leading texts about coaching. No other participants expressed that level of sophistication with regard to relationships. Further research that asks participants to specifically comment on whether or not the coach-teacher relationships are likely to produce teacher growth and change might reveal whether coaches view relationships in this light. We believe the ability to discuss the tensions around maintaining relationships and promoting teacher change requires a sophisticated view of coaching.

Theme 2: Praise — During the analysis, praise emerged as a theme, as participants addressed the novice coach's use of phrases, such as "I like" in the lesson debriefing. Fifteen of the Project coaches and five of the coaching experts offered statements that were coded as praise. Coded statements from both groups represented favorable, unfavorable, or neutral views of the coach's use of praise.

The five Project coaches who viewed the novice coach's use of praise as favorable felt that it was appropriate to provide the teachers with positive feedback. Project Coach 15 stated, "She used positive feedback successfully as she complimented them on several items (such as their movement throughout the room during the lesson)." Similarly, Project Coach 8 stated, "I appreciated her positive approach in validating the teaching that had been done."

In contrast, the five Project coaches who viewed the novice coach's use of praise as unfavorable indicated that her use of praise placed her in the role of evaluator. Project Coach 2 stated, "One thing that struck me was how many times the coach used the word 'I like the way' This seemed like a little more of a judgment stance than I am comfortable with in coaching." Similarly, Project Coach 13 stated, "I noticed that she kept telling the two teachers how much she 'loved' or 'liked' what they did during the lesson. This to me is too evaluative."

The remaining five Project coaches noted the evaluative or positive nature of the novice coach's praise, but without indicating the individual's stance as favorable or unfavorable. For example, Project Coach 19 focused on the positive nature of the novice coach's feedback, stating, "During the post-conference, she had a lot of positive feedback that was specific." Alternatively, Project Coach 6 focused on the evaluative nature of the comments: "She came across as an

evaluator during the post-conference when she constantly said, ‘I liked when’” These participants have highlighted a feature of the novice coach’s practice without indicating whether they find the practice favorable or unfavorable.

Unlike the Project coaches, the coaching experts who mentioned praise noted its limitations for improving instruction, regardless of whether they offered a favorable, unfavorable, or neutral view of the novice coach’s use of praise. For example, Coaching Expert 101 stated, “During the debriefing, the coach was very complimentary. She began with opportunities for praising the teachers (good), but never advanced to supporting their growth.” Here, a favorable view of praise was offered along with an acknowledgement of its failure to support the teachers’ professional growth. Similarly, Coaching Expert 105, who offered a neutral view, stated, “Lots of praise was given, with little challenge.” In summary, the coaching experts differed in opinions regarding the appropriate use of praise in the debriefing session. Regardless of their individual stances, however, collectively the coaching experts reacted to the use of praise in a critical way, acknowledging the need for a coach to move beyond praise in an effort to challenge and support teachers in their professional growth.

Theme 2: What Do Leading Coaching Texts Say about Praise? — Establishing the relationship between the coach and the teacher is acknowledged as a key consideration in the coaching process. A coach’s practice of offering praise impacts the development of the relationship, as it can define the coach as an evaluator or a mentor [16]. According to Knight, the coach should begin the relationship by listening to and respecting the teacher. In general, the models that address praise agree that coaches should push beyond praise and challenge teachers in order to support instructional change and improve student achievement [14, 16].

Theme 2: How Do Project Coaches’ Views about Praise Compare to Those Expressed by Coaching Experts and the Coaching Literature? — There was considerable variation in the views about praise expressed by the Project coaches. Project coaches who viewed the use of praise as appropriate believed in the importance of validating the teachers’ practices. In contrast, Project coaches who viewed the use of praise as inappropriate felt that this resulted in the coach serving in the role of evaluator. Coaching experts noted that the use of praise holds limited potential for impacting instruction and/or student achievement, a view that is expressed to some extent in the coaching literature. To what extent praise benefits or detracts from the practice of a coach is an open question, and there is considerable variation in the views expressed by practicing coaches about the use of praise and its purposes.

Theme 3: Attending to Student Learning — All six coaching experts and five Project coaches mentioned some aspect of attending to student learning in the coaching session. Coaching experts included the following observations : a focus on classroom management; a failure to explore how students learned; and, little evidence presented of student understanding. For example, Coaching Expert 105 asked, “Where was the student work at post-conference? In my view, there was a missed opportunity to look deeply on what students did or didn’t do to consider next steps. At no point did they think aloud about evidence of student learning.” Further, Coaching Expert 106 noted, “I saw no evidence of curriculum documents that would help clarify what students should learn.”

Some Project coaches noticed the lack of attention given to student learning as well. Project Coach 9 noted, “I would like to see more probing into the reasoning behind student outcomes.” Similarly, Project Coach 17 commented, “I didn’t see deep reflection on the part of the teachers about the mathematics and their students’ success or struggles.” In these instances, Project coaches’ responses were similar to those of the coaching experts. Not all Project coaches who mentioned student learning, however, focused on this lack of evidence. For example, Project Coach 14 said, “Their lesson was carefully crafted through joint discussion on what the main objective was, how it would be taught, expected student learning.” This response addressed expected student learning, but offered no commentary on how that was handled in the post-conference.

Theme 3: What Do Leading Coaching Texts Say about Student Learning? — Instructional Coaching encourages the coach to address four items with teachers: student behavior, content, instruction, and formative assessment. Student learning is attended to in Instructional Coaching’s expectations for what coaches should address with teachers in instruction—specifically, that teachers use practices that ensure all students master content. With the emphasis on formative assessment, Instructional Coaching asks coaches to notice if the teacher uses formative assessment effectively to gauge how well students are learning [16].

Instructional Coaching focuses much of its attention on how a coach can address the teacher’s use of assessment—particularly formative assessment. Little attention is given to how a coach assesses student learning. However, the aspects of formative assessment that a coach is expected to understand require an Instructional Coach to know a great deal about how to assess student learning and need [16].

In contrast, Cognitive Coaching focuses attention on building reflective capacity in teachers. Regarding student learning, Cognitive Coaching asserts, “knowledge about students and how they learned comes to life through the application of and reflection about teaching experiences” [14].

Content-Focused Coaching makes students’ mathematical learning the central focus of coaching sessions. Whenever possible, the coach brings evidence of student learning, such as student comments, examples of student thinking, student assessment data, and samples of student work to the coaching session. Thus, a Content-Focused Coach assesses student thinking and learning for the purpose of focusing coaching conversations and planning sessions on specific student needs and outcomes [17].

Theme 3: How Do Project Coaches’ Views about Student Learning Compare to Those Expressed by Coaching Experts and the Coaching Literature? — It is interesting to note that all six coaching experts identified the lack of attention to student learning, and only a small number of Project coaches did so. Because of the word limit identified in the prompt, we cannot argue that Project coaches did not note the lack of attention to student learning. Yet, among the topics the practicing coaches addressed in their assessment, the absence of attention to student learning seems odd, since it is discussed so richly in the coaching literature and by all of the coaching experts. Project coaches noticed praise in the coaching conversation readily, but neglected the fact that the praise was not focused on student learning. The coaching experts seemed to discuss student learning in coaching sessions in a more sophisticated way than the Project coaches.

Theme 4: Responding to Teachers’ Questions — Seven of the 21 Project coaches and one of the six coaching experts noted that the novice coach did not answer some of the teachers’ questions. Words and phrases used to describe this aspect of the novice coach’s practice included “resisted,” “avoided,” “was not willing,” and “did not answer the teachers’ questions.” The following quote is representative of the comments coded under this theme:

Project Coach 14: The coach would not give suggestions and only answered with low-level questions. The teacher seemed to want some ideas.

It is difficult to determine whether participants felt that not answering the teachers’ questions was a favorable or unfavorable coaching move. Project Coach 12 wrote, “[The novice coach] avoided answering the question ‘How would you teach this lesson?’ but rather continued

with guiding questions so that the teacher could reflect ...,” which suggests the participant found favor in this practice. In contrast, Project Coach 9 wrote, “One teacher asked, ‘How should I do this?’ without getting an answer,” which suggests this participant had concerns about the practice. A third coach qualified these concerns:

Project Coach 1: I was surprised that she didn’t seem to answer the teacher’s questions when they asked her what she would do during the pre-conference. If this is a planned part of her coaching, then I understand it; I just couldn’t tell.

Only one participant made comments that we coded as unfavorable:

Coaching Expert 105: I also don’t think the coach is specific enough or willing to give straight-out suggestions when teachers request them.

Theme 4: What Do Leading Coaching Texts Say about Responding to Teachers’ Questions? —

We found it difficult to summarize recommendations for responding to teachers’ questions. The challenge is that the four models on which we focused all rely heavily on reflective questioning. While none of the models strictly forbids the coach from answering teachers’ questions, concern over the coach’s role, the coach-teacher relationship, the teacher’s learning and self-monitoring, and the teacher’s autonomy influences how various coaching authors approach the issue. At one extreme is a coach who gives too much advice and dominates the coaching conversation. Mathematics Coaching illustrates potential consequences of such practice: “Lessons planned by coaches are not likely to be implemented and, in fact, undermine true collaboration” [15]. Cognitive Coaching advocates that “rather than give advice to or solve problems for another person, a mediator helps the colleague to analyze problems and develop her own problem solving strategies” [14].

An overarching issue is that a coach’s role is unique from that of a mentor because it is not assumed that the coach is the only expert in the room. Instructional Coaching emphasizes that the teachers and coaches are equals and that coaches are learning as much from the experience as the teachers. According to Knight, when coaches give the impression that they are the expert and offer too much advice, they run the risk of taking on the role of supervisor. Instructional Coaches “don’t tell teachers what to believe; respecting partners’ professionalism, they provide them with enough information to make their own decisions” [16]. While the last

part of this statement suggests that Instructional Coaches do impart information, earlier passages emphasize that coaches sometimes “find that they have to help teachers find their voice[s]” and that “coaches who temporarily set aside their own opinions for the sole purpose of really hearing what their colleagues have to say are powerfully demonstrating that they truly value their colleagues’ perspective” [16].

Cognitive Coaching gives similar cautions about roles and relationships, making clear distinctions between coaches and mentors. Since a coach has a leadership role in improving teacher practice, there are obvious challenges in avoiding direct, expert advice and eliciting teacher change. Cognitive Coaches navigate this issue by eliciting teacher talk through reflective conversations using conversation tools, such as pausing, paraphrasing, probing, and listening. These coaching moves underscore a basic premise of Cognitive Coaching: Teacher change comes from teacher reflection, and teacher talk is an avenue for teachers to redefine their cognitive structures [14].

In contrast, Content-Focused Coaching features a coach directly addressing a teacher’s question and offering straightforward advice [17]. Yet, despite Content-Focused Coaching’s advocacy of giving receptive teachers direct feedback and assistance, West and Staub are concerned about relationship and role aspects as well. In the reflection on an exchange with a teacher in a different case study, West notes that she is doing most of the talking and worries that she might be acting as a “sage on the stage” [17]. The distinction between the more direct practice of Content-Focused Coaching and the practice recommended by other authors may come from the assumption about the coach’s role and relationship with the teacher. While Content-Focused Coaching promotes a collegial relationship between teacher and coach, it also advances the perspective that Content-Focused Coaches are expected to have more teaching experience than the teachers they coach and that the interaction “will not be symmetrical” [17].

Theme 4: How Do Project Coaches’ Views about Answering Teachers’ Questions Compare to Those Expressed by Coaching Experts and the Coaching Literature? — The analysis of participant responses and the review of a selection of coaching texts indicated that the topic of responding to teacher questions invokes a variety of responses. Tension between concerns over the coach-teacher relationships, teacher self-directed learning, and the coach’s responsibility for improving teacher practice makes responding to teachers’ questions difficult terrain to navigate. While we found an example in the literature of a coach who answers teachers’ questions directly, much of the literature emphasizes a more reflective approach. A propensity toward helping

teachers develop their own solutions to instructional issues can be at odds with a coach's asserting his or her own viewpoint.

Within our data, a relatively small number of coaches mentioned the issue of responding to teacher questions. We do not know what the lack of comment on this issue means, but within the responses that note the issue, there is considerable variation in how responding to teacher questions is discussed among the participants. Only one coaching expert (Coaching Expert 105) explicitly asserted that the lack of direct assistance is ineffective practice. Among the Project coaches, two simply noted it, two seemed slightly uncomfortable with the coach's approach, and one seemed to find favor in the approach. Another Project coach qualified her comments by wondering if it was a planned move. This variation and lack of specificity makes us wonder: If this type of question were asked directly of participants, would views about the tension between reflective questioning and direct assistance be revealed? We hypothesize that those who have read a variety of coaching authors will take a stance on the issue or discuss the tensions among approaches, as the one coaching expert in our sample did.

Theme 5: Reflection — Through the coding process, the theme of reflection emerged as seven participants mentioned the novice coach's skill in either supporting or not supporting the teachers in the reflection process. The majority of the twenty participants did not mention reflection in their responses, despite the novice coach's opening question of "How do you think it went?"

Two of the Project coaches indicated that the novice coach successfully engaged the teachers in reflection. Project Coach 12 wrote, "This coach was skillful in getting these teachers to be reflective on their practice." Similarly, Project Coach 8 stated, "During the post-conference, she ... guided the teachers into evaluating their own teaching. ... She offered suggestions where necessary, but like the teachers she was watching, she guided the teachers to reflect." Both participants offered statements regarding the occurrence of reflection without offering a critique.

In contrast, three Project coaches and two coaching experts suggested that the novice coach failed to engage the teachers in reflection. Project Coach 20 said, "I was wondering about the post-conference a bit. I did not really hear the coach question anything that happened during the lesson; lots of praise, but not a lot of reflective 'what could you have improved' conversation." Similarly, Coaching Expert 102 wrote, "Instead of responding so quickly each time that the teachers said something, she maybe could have led them through more of a reflecting conversation that focused on student performance." Based on their responses, it appears that

participants expected the novice coach to support teachers in reflecting on areas of improvement. Specifically, the participants emphasized reflecting on either improving practice or student achievement.

Theme 5: What Do Leading Coaching Texts Say about Reflection? — Across the different coaching models, reflection is recognized as a key component of the coaching process. Although there is agreement that the coach is expected to engage the teacher in reflection, the purpose of that reflection differs across models, including gaining skill in self-directed learning, making decisions regarding effective teaching actions, yielding appropriate interventions, and focusing on students' content-specific learning [14-17]. These different foci of reflection align with the models' perspectives. In some instances, the focus is on improving practice (Cognitive Coaching and Instructional Coaching), while in other instances the focus is on student achievement (Mathematics Coaching and Content-Focused Coaching).

Theme 5: How Do Project Coaches' Views about Reflection Compare to Those Expressed by Coaching Experts and the Coaching Literature? — In the majority of responses, Project coaches did not speak to the role of reflection in the coaching process when assessing the practice of the novice coach. Without follow-up interviews, it is impossible to infer why these participants opted not to address the role of reflection in the novice coach's practice. For those who chose to write about reflection, however, there was variation regarding the effectiveness of the novice coach. While only two expert coaches mentioned reflection, those who did expressed views that aligned with coaching literature. It would appear that acknowledging the level of reflection and its purpose is key toward gauging its effectiveness, yet not all participants saw this.

Theme 6: Teacher Knowledge and Learning — Two of the 21 Project coaches and two of six coaching experts made comments related to teacher knowledge and teacher learning. The two Project coaches' comments were directed toward the coach and teachers' discussion of the task, and the fact that the coach did not seize this learning opportunity. The following is representative:

Project Coach 7: It didn't seem like the teachers were that clear about their own understanding of the problem, but the coach didn't dwell on this—she just kept going back to her questions. The teachers seemed to debate, but the coach didn't address their misconceptions in my opinion.

Coaching Expert 101 noted, “The coach did not draw out or advance the mathematical or pedagogical understandings of the teachers.” This comment’s tone seems to express an unfavorable view of the coach’s actions; however, the expert’s comments fell short of judgment.

Coaching Expert 105 was more explicit:

It seems like [the coach] is going through a process she doesn’t fully understand and isn’t clear about the specific goals For example, though the teachers did the problem prior to the lesson, they didn’t discuss it in any depth or challenge each other’s answers or analyze each other’s thinking. So they didn’t seem to learn much from having done the problem I also don’t think the coach is specific enough or willing to give straight-out suggestions even when teachers request them. This level of coaching may get “relationships” developed between and among teachers, but it doesn’t dive deep enough into content and doesn’t challenge practice specifically enough to really improve it in substantive ways. ... I wonder: Is this coach willing to ask hard questions that might stretch a teacher’s thinking? ... The coach made an attempt at “challenging” students in the pre-conference, but it went nowhere. It seems to me these teachers were not particularly knowledgeable about the math they teach, and the coach did not add much to their knowledge base or even expose the fact that their knowledge was not as robust as it may need to be.

This response was the most thorough of any of the responses that addressed teacher knowledge and learning, and it contained several key points: that teachers and coach can learn mathematics during the session, that there is a tension between maintaining relationships and stretching teachers’ thinking, and that coaches can expose teacher misconceptions and add to teachers’ knowledge bases.

Theme 6: What Do Leading Coaching Texts Say about Teacher Knowledge and Learning? —

The issue of teacher knowledge and learning is addressed in the leading coaching models, but the texts and models are not consistent in the way they suggest addressing it. Cognitive Coaching relies heavily on reflective questions to encourage teachers to refine knowledge bases. Instructional Coaching suggests structured co-planning intended to help the teacher make connections among concepts. Content-Focused Coaching features a coach who takes a more direct approach, pointing out important pedagogical and content knowledge to the teacher. Mathematics Coaching discusses a scenario in which a teacher who had not acquired an adequate background was coached on effective use of manipulatives with a focus that “not only improved

the teacher's knowledge of instructional strategies, but also increased her content knowledge" [15].

Some of the differences in how coaching texts recommend addressing teachers' understandings of content result from assumptions about the knowledge base of the coach. The distinct models of Instructional Coaching and Cognitive Coaching make no assumptions that the coach is more knowledgeable about the subject matter content than the teacher being coached. In contrast, the Content-Focused Coaching model and the Mathematics Coaching model assume that the coach has a high level of content knowledge and is more experienced than the teacher being coached.

In terms of pedagogical knowledge, Instructional Coaching is more direct. This is partly due to the fact that the Instructional Coaching program is not content-specific. It is also due, in part, to the fact that Instructional Coaching has roots in programs that build on professional development sessions focusing on strategies for teaching reading. Coaches who work in conjunction with professional development are likely to be more transparent about teacher learning concerns because professional development programs tend to possess explicit learning outcomes.

How a coach approaches teachers' understandings of content is also influenced by the various models' assumptions about relationships. The distinctions among the models described there can be repeated here: Instructional Coaching and Cognitive Coaching are particularly sensitive to avoiding perceptions that the coach's job is evaluation or supervision, while Content-Focused Coaching does not shy away from the coach's role as an expert. Mathematics Coaching also assumes that the coach is an individual with expertise in both mathematics content and pedagogy.

Theme 6: How Do Project Coaches' Views about Teacher Knowledge and Learning Compare to Those Expressed by Coaching Experts and the Coaching Literature? — We did not find a great deal of variation in the Project coaches' discussion of teacher knowledge and learning, possibly because so few of the participants mentioned the theme. We include the theme, however, because it could be important to future studies. The issue of whether or not certain types of coaching improve teacher knowledge is at the heart of Killion's comparison of a "coaching light" and a "coaching heavy" approach. Killion describes coaching light as focusing on relationships to the point of not challenging the teacher's thinking, and argues that coaching light is unlikely to improve teacher knowledge and practice [6].

This point of view is expressed in Coaching Expert 105's comments. This expert expresses a concern about the level of coaching and the lack of challenge, and discerns a difference between superficial coaching discussions and those likely to challenge a teacher's knowledge and practice.

Theme 7: Lesson Content — Beyond student learning of content and teacher knowledge of content, participants offered additional commentary regarding the mathematics content contained within the lesson. One Project coach indicated that the novice coach supported the teacher reflection on the mathematics content of the lesson:

Project Coach 8: She prompted the teachers to think about what and why they were teaching the lesson, as well as the prior knowledge.

In contrast, four Project coaches alluded to the novice coach's lack of attention to the lesson's mathematics content. The following quote is representative:

Project Coach 13: During the pre- and post-conference, not a lot was mentioned about math content and connections.

Two coaching experts provided comments related to the lesson's content. The following statement is representative:

Coaching Expert 105: She does not hone in on the ideas that are embedded in the lesson. She allows the teachers to name the activity as ideas—in other words, they say the goal is for students to recognize and use stem-and-leaf plots or something like that, which is not really a Mathematical Big Idea. A Mathematical Big Idea might be something along the lines of, understanding that stem-and-leaf plots are one way of representing data. No matter how the data is represented, the mean, median, and mode—central tendencies—of the data can be determined and do not change. What are the possible answers to this question? What strategies could be used for finding the 20 data points that would ensure the given median and mode? The math is embedded in those strategies. In other words, why does the problem offer the constraints it does?

Both coaching experts who commented on the lesson's mathematical content provided insight regarding the lack of attention given to the mathematics during the pre-conference. This attention to the role of mathematics content during the planning process distinguished the responses of the coaching experts from those of the Project coaches, who focused more on the failure of the novice coach to mention the mathematics within the post-conference.

Theme 7: What Do Leading Coaching Texts Say about Content? — Of the leading coaching models, Content-Focused Coaching and Mathematics Coaching are the two models that are content-specific. Both give explicit guidance about how coaches should approach the lesson's mathematics content in their coaching sessions. Content-Focused Coaching provides three case studies to illustrate a coach working very precisely through mathematics content in the planning phase of the coaching cycle. Mathematics Coaching asserts that during co-planning, coaches should spend time listening to teachers in order to ascertain what they know about mathematics.

Theme 7: How Do Project Coaches' Views about Content and Coaching Compare to Those Expressed by Coaching Experts and the Coaching Literature? — Among Project coaches, we found variation in their views about whether or not the lesson content conversation was present. Also, the manner in which Project coaches discussed content differed from the way the coaching experts discussed content. The experts who mentioned content gave detailed descriptions of content's role in the planning conversation. Project coaches who mentioned content tended to simply note its absence, or in one case comment favorably on the coach's way of prompting the teachers to think about the lesson content.

We acknowledge that a deep understanding of the mathematics content that is discussed in lessons is likely necessary for a participant to comment on the mathematics content. If a participant watches the videotaped coaching session and is unfamiliar with or uncomfortable with the topic of stem-and-leaf plots as a tool to understand data, that participant may not be able to make meaningful comments about the content discussions. Yet even without a deep knowledge of a specific mathematical topic, a coach who views content as central to the coaching discourse could comment on the presence or absence of mathematics content discussions within coaching sessions.

Theme 8: Facilitation — Four coaching experts and eighteen Project coaches noticed aspects of the novice coach's ability to facilitate the coaching session. We define facilitation broadly as

how the coach manages, leads, guides, and directs the coaching conversation. Concepts categorized in this theme included references to the coach's role in the design and management of the session, and references to the coach's role in encouraging teacher growth. The following key words and phrases were used to describe this theme: "leading," "engaging," "pushing," "pressuring," and "influencing" the teachers; "creating the right atmosphere"; and, the "management of the discourse" (e.g., moving through a list of questions and sticking to a script). The following comments are representative:

Project Coach 13: The coach really tried to lead the discussion without dominating. ... she had specific questions and [an] outline that guided the pre-conference.

Coaching Expert 101: The coach did not draw out or advance the mathematical or pedagogical understandings of the teachers. ... the coach did not seem focused on intent the coach did not engage the teacher in a discussion of the mathematical potential in this problem and whether/how to engage the students in that mathematics.

Some Project coaches expressed a favorable view of the coach's facilitations of the discussion. For example, Project Coach 5 wrote, "The coach did a good job of facilitating the discussion," and asserted that the coach "pressed" the teachers to address goals. Project Coach 2 did not share this view: "I am not sure that the coach pushed their thinking enough. ... The coach was pretty passive once they veered away from her specific questions."

Some Project coaches expressed an unfavorable view of the coach's efforts to draw both teachers into the conversation. Project Coach 11 wrote, "Two teachers were present, yet only one teacher seemed to be vested in the lesson. ... I would've expected the coach to direct questions to this teacher to foster more engagement." Similarly, Project Coach 12 wrote, "She could have drawn the teacher in the middle into the conversation more during the pre-conference."

While the Project coaches' responses varied from favorable to unfavorable to neutral views of the coach's facilitation of the session, the coaching experts who mentioned facilitation tended to lean toward an unfavorable view. Coaching Expert 106 wrote that "the coach was not a facilitator, but [a] director." Coaching Expert 102 wrote that the coach placed herself in an "expert role," and felt that the coach could have led the teachers through "a more reflecting conversation."

Not all of the coaching experts' comments were unfavorable. Coaching Expert 102 felt that the "coach did a nice job of staying on track." Similar observations were also expressed by Project coaches, several of whom noted that the coach followed a list of questions. Project Coach 20 noted, "[She] followed the sequence of questions and a script."

Theme 8: What Do Leading Coaching Texts Say about Facilitation? — Mathematics Coaching does not address specific aspects of facilitating coaching sessions. Instead, it provides overall guidelines about the types of reflection in which coaches should engage teachers and the types of tasks on which coaches should focus, such as curriculum, implementation, and planning.

Cognitive Coaching emphasizes a mediation role of the coach. According to Costa and Garmston, a mediator "facilitates mental processes for others as they solve their own problems, make their own decisions, and generate their own creative capacities" [14]. This is not to say, however, that Cognitive Coaches are not responsible for structuring the coaching environment. Costa and Garmston provide specific structures for coaches to use in their interaction with teachers, which they call mental maps. Highlighted are structures for the planning conversation, the reflecting conversation, and the problem resolving conversation. Costa and Garmston also provide structure for coach questioning, emphasizing pausing, paraphrasing, and probing with the intent of supporting a coach's facilitation of the session [14].

Content-Focused Coaching provides its view of the coach directing the flow of the pre- and post-conferences through its three case studies. Instructional Coaching emphasizes a partnership role, where the coach facilitates sessions by helping teachers identify their needs and developing co-constructed checklists for improvement. Instructional Coaching uses the word "guide" frequently when describing the work of a coach. A coach guides teachers to make sense of observation data collected by the coach, and guides teachers to reflect on classroom behavior, types of instruction, and ways of formatively assessing learning.

Theme 8: How Do Project Coaches' Views about Facilitation Compare to Those Expressed by Coaching Experts and the Coaching Literature? — We find a great deal of variation in how Project coaches discussed facilitation and, in general, it is hard to know whether they have a favorable or unfavorable view of this novice coach's facilitation of the session. Nevertheless, facilitation is indeed an aspect of the coaching session that participants first noticed and then made comments. We find variation in how participants discussed the novice coach's actions and

the novice coach's role as facilitator. Comparison of the Project coaches' views to those expressed in the literature and by experts was difficult, since these views vary as well.

Discussion

From this data analysis, eight themes emerged: 1) coaching relationships; 2) the use of praise by the coach; 3) discussions of student learning; 4) how coaches respond to teachers' questions; 5) how coaches prompt reflection; 6) how coaches address teacher knowledge and learning; 7) discussions of mathematics content; and, 8) facilitation of the coaching session. Many of these themes are not distinct. For example, a participant who pays close attention to the nature and purpose of the coaching relationship will likely notice the use of praise in a coaching session. If that participant is focused on coaching models that highlight that the purpose of coaching relationships is to improve student learning, then that observer is likely to note the presence or absence of discussions about student learning within the coaching session.

Likewise, the issues of responding to teachers' questions and prompting reflection overlap. What observers believe about the way to promote reflection will likely influence their characterizations of a coach's technique for responding to teacher questions. Coaches' views on reflection are also tied to how they view the means to address a teacher's knowledge base, or lack thereof, and whether to view a coaching session as an opportunity to actively give instruction to a teacher or to encourage a teacher's learning by promoting reflective practice.

Our identification of the variation in how our sample of school-based, practicing coaches discuss these eight themes is a first step in understanding what types of views of coaching practice exist among practicing coaches. Knowing the variation in views expressed among practicing coaches gives researchers and professional development providers insight when developing measurement tools and interventions. Views and beliefs about coaching can influence coaching practice. Because several of our practicing coaches were trained in more than one model, simply noting the model in which a coach is trained, or to which the coach claims to adhere, might not provide a true indication of the coach's view of coaching practice in the field. We suggest that further research is needed to establish to what extent practicing coaches' beliefs in these eight themes is related to coaching effectiveness, as measured by improvements in teacher knowledge, teacher practice, or teacher beliefs.

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STEMteach: PREPARING THE NEXT GENERATION OF MATHEMATICS AND SCIENCE TEACHERS

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Abstract

With an increasing demand for individuals prepared in Science, Technology, Engineering, and Mathematics (STEM), one university responded to this call by changing its teacher preparation program. Better-prepared mathematics and science teachers have the opportunity to engage and excite students, thereby preparing and promoting more of them to enter the STEM professions. The described program is a replication of the national UTeach model that recruits content majors in mathematics and science to explore the teaching profession during a first-semester course that includes an early field experience in the elementary grades. This field experience is designed to be engaging for both the teacher education candidates and the elementary students in an effort to demonstrate the joy of teaching and to retain the candidates in the program. The ultimate goal of the program is to increase the production of quality secondary mathematics and science teachers who can transfer their own deep understanding of their content to students so that these students will be career and college ready in the STEM disciplines.

In a small college freshman classroom at the University of Central Arkansas (UCA), fourteen young men and women are grouped at tables and asked to pretend that they are third-grade students. Laid out before them are various black canisters filled with cotton swabs doused with household scents. Students are instructed to classify the unknown scents (cinnamon and lemon) by smell. A University clinical instructor facilitates the lesson by asking students to contemplate and classify the unknown scents on a T-chart while she models effective teacher pedagogy through inquiry-based instruction. Students further explore different ways to classify and sub-classify various types of seashells. Student groups explain that their classifications are based on various characteristics of the seashells, including size, color, type, and shape. The instructor clarifies that these characteristics are called physical properties, and that this system is a common way to classify matter. At the conclusion of the lesson, the freshmen are asked to compare and contrast open versus guided instruction using the 5E Learning Cycle (Engage, Explore, Explain, Extend, and Evaluate); then, to consider the type of instruction that spurs

independence, problem-solving, and initiative. The instructor goes on to state, “We are striving for open confidence. The real world is not a worksheet!”

At first glance, the college class would appear to be a typical pre-service teacher education class; however, students in this classroom are mathematics and science content majors who are participating in an innovative college program, STEMteach, housed at the University of Central Arkansas. With the hopes of promoting teaching as a career choice among STEM majors, STEMteach students will graduate with a content degree in mathematics or science, as well as a teaching license. They are taught by a seasoned Master Teacher whose expertise is in K-12 mathematics. During their tenure as college freshmen, these students will participate in the typical track of science and mathematics courses found in universities around the country as well as complete teacher education classes that require them to conduct classroom observations and teach students beginning in their first semester of coursework.

University of Central Arkansas STEMteach is a mathematics and science teacher preparation program that models the innovative UTeach program, which began at the University of Texas in 1997. The strength of the UTeach model lies within its unique collaboration between Colleges of Natural Science and Mathematics, and Colleges of Education. The program is distinctive in its early, intensive field experiences for teacher candidates, the use of Master Teachers as instructors, and the development of teacher candidates’ content knowledge and effective teaching strategies. The program has the following goals: 1) to attract and retain more and better students to secondary mathematics and science career paths; 2) to establish an enriching curriculum that integrates modern technological teaching tools with opportunities to experience the joy of scientific discovery and problem solving, and a mastery of the content; and, 3) to prepare outstanding mathematics and science teachers who are leaders of their discipline, integrate technology to enhance the classroom, and involve students in inquiry-based learning. As an added benefit, students can earn a Bachelor of Science in Mathematics or Science and a teaching license within four years. This unique opportunity provides students additional career options after graduation with no additional time or expense, while still allowing them the opportunity to pursue graduate or professional schools if they wish.

The Increasing Demand for a STEM-Prepared Workforce

The STEMteach initiative was created to respond to the national, state, and local need to increase mathematics and science teachers. Specifically, the national call for an increased and a better-prepared workforce in Science, Technology, Engineering, and Mathematics (STEM) is

widely documented. The Brookings Institute, an organization that conducts research on a broad range of issues, suggested, “Workers in STEM fields play a direct role in driving economic growth,” and revealed that one in five of all United States jobs needs a significant background in at least one of the STEM disciplines [1]. To put this in perspective, in 2011 alone, 26 million jobs in the United States were reliant upon workers trained in a STEM discipline. Data from the United States Bureau of Labor Statistics supported these findings, classifying ninety-seven jobs as “STEM occupations,” such as jobs and careers in mathematical and computer sciences, engineering, architecture, medicine, management, education, manufacturing, and sales [2]. The Bureau found that this high demand for workers skilled in STEM disciplines translated to higher salaries for these employees who earned an average salary of \$77,800. This exceeds the average annual salary for all occupations in the United States by nearly \$35,000 [2].

Regrettably, our education system appears to be falling short when preparing students for STEM-related careers. “Change the Equation” is an alliance of leaders representing the business communities who have an interest and a stake in the increased availability of a highly trained STEM workforce, and who are devoted to improving STEM teaching and learning. In 2012, the group released “Vital Signs,” a report that described the status of STEM education in the United States, which revealed, “Across the STEM fields, job postings outnumbered unemployed people by almost two to one” [3]. For occupations in healthcare that required STEM preparation, the gap was even wider with over three job postings for every unemployed person. In comparison, the number of unemployed people for all occupations outnumbered the available jobs by nearly four to one.

Motivating and Nurturing STEM-Talented Learners in the K-12 Classrooms

With the documented shortfall of STEM talent in the United States, the need to motivate and support STEM talent rests squarely on the capacity of our education system to identify and nurture ability [4]. To facilitate the development of STEM innovators, the National Science Board (NSB) recommended that K-12 students have investigative, real-world experiences in STEM learning. In particular, they recommended students be engrossed in inquiry-based learning that is centered on real-world problems. In response to this need, the NSB encouraged STEM teachers to participate in programs that utilized inquiry-based learning and that emphasized the importance of both content knowledge and pedagogy in their practices. The U.S. National Commission on Mathematics and Science Teaching for the 21st Century and the recently released “Vital Signs” also maintained that, to better prepare students for the STEM workforce, teachers must have a deep knowledge of their subject matter, and it was recommended that preparation

programs focus on providing candidates with a clear understanding of content knowledge and the most effective instructional methods [3, 5].

Current Status of STEM-Prepared Teachers

As indicated by recent reports, many K-12 STEM teachers have not had the educational experience necessary to develop their content knowledge or pedagogy. For example, in elementary grades, Fulp found that less than 5% of elementary teachers received undergraduate degrees in science and 40% took four or fewer undergraduate courses in the subject [6]. In addition, the National Research Council reported that many teacher preparation programs only required two courses in mathematics for future elementary teachers [7].

Secondary teachers are typically more prepared in their specific discipline; however, many are teaching out of their content area. For example, Augustine reported that 69% of students in grades 5-8 were taught by mathematics teachers who were either not certified or did not have a mathematics degree [8]. In addition, an alarming 93% of middle school physical science students did not have a teacher who was certified or who possessed a degree in physical science. The trend continued in high school (31% mathematics; 61% chemistry; 67% physics) with teachers not being certified or having a degree in their subject area. Change the Equation reported similar results [3]. They found that only 31% of eighth graders were taught by teachers with undergraduate degrees in mathematics and only 48% of their science teachers had degrees in science.

When teachers lack content knowledge in their assigned teaching discipline, the effects resonate throughout the classroom. For example, in a review of literature, Tairab found that science teachers exhibited hesitancy, and struggled to deliver effective instruction when their knowledge of content was limited [9]. In particular, Tairab reported that teachers often neglected effective teaching methods, such as inquiry-based learning and open discussion, and utilized textbook learning and independent seatwork instead. In further support of strong content preparation, Rosenberg, Heck, and Banilower found a positive relationship between teachers' establishment of an investigative classroom environment and the number of content courses they took in college [10]. As indicated by these studies, teacher subject-matter knowledge is a necessary ingredient in effective teaching.

To address issues with content knowledge, Tairab recommended teacher education programs emphasize a deep level of content attainment among prospective teachers [9]. Tairab

suggested subject-matter specialists and education specialists devise plans to ensure that prospective teachers gain the content knowledge and pedagogical skills needed to be effective teachers, an approach that is a hallmark of the UTeach teacher preparation program. The UTeach students graduate with undergraduate degrees in STEM disciplines as well as with teaching licenses, acquiring a deep level of subject-matter knowledge in their undergraduate fields and developing their pedagogical skills through their education courses [11]. Throughout their four years of college, these students put their content knowledge and pedagogical skills to practice during multiple opportunities of observing and teaching in classrooms. These experiences are integrated into their pedagogy courses, not isolated events, and allow them the chance to hone their teaching craft in authentic environments. Currently, thirty-four universities replicate the UTeach program, producing more than 1,600 teachers. At the University of Texas at Austin, 90% of UTeach graduates enter the teaching profession and nearly 80% of those are still teaching five years later—both of these rates exceed the national average [12].

Responding to the Call

In August 2011, Arkansas Governor Mike Beebe announced the creation of “STEM Works,” an initiative whose primary purpose was to increase the number of well-prepared STEM students within the state. The focus on STEM resulted from the Governor’s Workforce Cabinet’s determination that developing students in these areas has the greatest potential for promoting economic growth in the state [13]. The initiative identified three programs for students in grades K-12 and one program for higher education. The K-12 programs were “Project Lead the Way,” “New Tech High Schools,” and “EAST Core.” The program for higher education was a replication of the UTeach model. All of these programs employ an inquiry-based, investigative approach to learning, an approach that has proven to increase student achievement and engagement [14, 15].

To fully realize the potential of the three K-12 programs and to ensure that all students in the state were receiving a quality education in the STEM disciplines, the group recognized the need for well-prepared mathematics and science teachers in every classroom and for a pipeline of highly qualified teachers to continue to support these initiatives. Supporting the National Science Board’s call for “rigorous, research-based STEM preparation for teachers” through the combination of research, theory and practice, the UTeach model specifically targets those students seeking a Bachelor of Science in Mathematics or Science who may not have previously considered the teaching profession [4]. Universities in the state competed for grant funding and approval to replicate the program, and three universities were approved and began

implementation in Fall 2012. This article specifically focuses on program implementation at one of the three universities chosen to replicate the model.

Implementation of STEMteach

All universities who are approved to replicate the model commit to the publication, *UTeach: Elements of Success*, which includes the use of dedicated master teachers, collaboration between colleges, and early and intensive field experiences [11]. Programs also agree to establish a distinctive program identity. At the University of Central Arkansas, the program was branded as “STEMteach” to coincide with other programs at the University, such as the “STEM Residential College” and the “STEM Institute.” The program identity aids in the marketing and recruitment of candidates who have typically not considered teacher licensure as an option. Often, candidates who pursue a Bachelor of Science in Mathematics or Science do not consider teaching as a career path. As an example, in 2012-2013, the University of Central Arkansas had over 1,000 STEM majors, but only seventeen sought a teacher’s license. To attract these students to STEMteach, program identity and recruitment are critical to the success of the program.

To recruit candidates into the program, candidates begin with a one-hour, 1-credit course entitled, *Step 1: Inquiry Approaches to Teaching* which introduces them to inquiry-based learning and offers candidates an opportunity to explore teaching without a commitment. Mathematics and science majors are accustomed to experimenting and investigating so the methods of the course are appealing to most. In the first semester of the program, candidates observe and teach three lessons in a third or fourth grade classroom rather than in grades 7-12 classrooms. Although candidates are completing requirements for secondary licensure, working with students in earlier grades allows candidates to experience teaching in a low-risk environment while focusing primarily on the practice of teaching. These first teaching opportunities are designed to ensure successful experiences for the candidates, understanding that their first impressions of the profession are likely to shape their long-term opinions.

In the second semester, candidates continue to explore teaching in the course *Inquiry-Based Lesson Design*, known to students as “Step 2.” Following a similar approach as Step 1, this class gives candidates the opportunity to develop and perfect lessons in the University classroom and then teach those lessons to students in area schools, this time to middle school students. All lessons, from both Step 1 and Step 2, are designed to be age-appropriate and to be highly engaging for the students. Again, the goal is to create successful experiences for the candidates and to deliver beneficial lessons for the local school students. Early success is

important. As candidates experience the joys of teaching, the motivation to join the profession increases which, in turn, improves the chances that candidates will continue with the program. UTeach Institute data indicate that, on average, 60% of those who take Step 1 will enroll in the Step 2 class [16]. To further remove obstacles and to encourage them to continue in the program, students who successfully complete these first two introductory courses receive tuition rebates so that there is no expense for exploring these classes.

Unlike most traditional teacher education programs, the UTeach model gives candidates the chance to experience teaching from the first day in the program while continuing to pursue their academic goals of a baccalaureate degree in mathematics or science. Convincing mathematics and science majors to *try out* the program is the most prevalent challenge to date. Focusing introductory classes on the practical rather than on the theoretical is appealing to students, and leads many to take what is perceived to be a “fun class” merely for the experience. Once enrolled, program faculty can demonstrate the importance and rewards of teaching to candidates who likely would never have encountered them, thus promoting the opportunity to recruit candidates to the program. Based on national trends, 43% of candidates who enroll in the first course will complete the program, a rate that represents a significantly higher potential production of mathematics and science teachers than the institution’s current program.

In the 2012-2013 academic year, the University had thirteen candidates complete the mathematics education program for teacher licensure, which was considerably higher than the previous three-year average of eight candidates. The production of science teachers was fewer, with only two completing the program in life science and two in physical science. While the life science numbers for the last year were on par with previous years, the two candidates in physical science were the first to complete that program in the past three years. This level of production of mathematics and science teachers is inadequate and insufficient to meet the demands of the state’s school system.

Since its inception at the University of Central Arkansas (UCA) in 2012, eighty candidates have participated in the STEMteach program. Beginning with the Fall 2012 group of nineteen, the incoming class of Fall 2013 has increased to fifty-one students enrolled in the first course (Step 1), and seventy-one students are currently enrolled in at least one class in the program. While the growth is encouraging, there is room for even greater growth. Table 1 represents the numbers of STEM majors enrolled at the University during the past four years. Assuming the UTeach Institute projection of 43% of those who take the first class will progress to

program completion, recruiting just 10% of the STEM majors at the University to take the first course would increase production of mathematics and science teachers from the 2013 total of seventeen to nearly fifty candidates over the course of four years [16].

Table 1
Total Number of STEM Majors

Content Area	2009	2010	2011	2012
Biology	655	649	640	645
Chemistry	120	130	126	126
Computer Science	126	121	160	194
Mathematics	142	147	130	130
Physics and Astronomy	51	69	58	68
Total	1,094	1,116	1,144	1,163

The UCA STEMteach is positioned to help provide mathematics and science teachers for our state, teachers who will be equipped to respond to the increased need for content knowledge of the Common Core State Standards and the Next General Science Standards. The Common Core State Standards (CCSS) in mathematics shift our approach for educating students about the subject [17]. Two of those shifts, coherence and rigor, require a deeper understanding of content knowledge, the depth of knowledge that content majors will likely have. The new standards call for mathematics students to think across grades and to link topics within the grades. The CCSS are more rigorous, going more deeply into fewer topics, requiring conceptual knowledge, procedural fluency, and application. Teachers with degrees in the content will have the necessary background to make both of these shifts, as well as sufficiently address the eight mathematical practices of the standards.

In addition, the Next Generation Science Standards (NGSS) requires similar shifts. Students will explore content in greater depth and complexity while engaged in the practices of science and engineering. To further deepen student understanding of science content, crosscutting concepts will be used to link core ideas within and across grade levels—thereby creating a coherent progression of knowledge as students advance through school [18]. As with the CCSS, the NGSS requires a more rigorous study of science content, further evidence of the

need for teachers to have a greater depth of knowledge along with the pedagogical strategies to deliver this content.

Conclusion

Recall the classroom described in the introduction of this article. The students are in their first semester of STEMteach, and soon they will be observing and teaching a lesson in an elementary classroom. By the time they finish their undergraduate degrees, they will be prepared to enter the classroom, armed with content knowledge and pedagogical skills. Equally important are the valuable experiences each student has gained from observing and teaching classes in elementary, middle, and high schools. These students are offered experiences not typically found in pre-service teacher education, including the chance to graduate with a content degree and the opportunities for student teaching beginning in their freshman year.

The implementation of STEMteach and other innovations like it are not only important, but necessary. Adoptions of such innovations are cause for teacher education as a field to reflect on its role in supporting and increasing the number of STEM teachers. The field of teacher education has not always been so open-minded. With traditional teacher preparation programs no longer meeting the demand to produce mathematics and science teachers, and the adoption of the new CCSS and NGSS and their national focus, it becomes critical for the field to be creative and embrace such innovations.

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ANALYZING THE GENDER GAP ON AN ENTRANCE EXAM FOR MATHEMATICALLY TALENTED STUDENTS

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Abstract

We investigate the qualifying entrance exam for the University of Minnesota Talented Youth Mathematics Program (UMTYMP), a five-year accelerated program covering high school- and undergraduate-level mathematics. The exam is used to assess the computational, numerical reasoning, and geometric skills of hundreds of fifth-, sixth-, and seventh-grade students annually. It has accurately identified qualified students in past years, but female participants consistently have had lower overall scores. Based on our belief that they are equally well qualified, in 2011 we began an extensive investigation into the structure and content of the exam to determine the possible sources for these differences. After gathering and analyzing data, we made relatively modest changes in 2012 which essentially eliminated the gender bias on one version of the entrance exam, increasing the percentage of females who qualified. The other unmodified versions in 2012 exhibited the typical gender difference from previous years. We continue to analyze the possible reasons for the gender differences while monitoring the overall student performance upon entering the Program.

Introduction

The University of Minnesota Talented Youth Mathematics Program (UMTYMP, pronounced “um-tee-ump”) is a highly accelerated program for middle school and high school students who are talented in mathematics. Each year, approximately 500 participants take their mathematics courses through UMTYMP, instead of their regular schools, meeting once per week for two hours. In the first two years of the Program, students cover honors-level algebra, geometry, and precalculus at an accelerated pace; during the following three years, students earn University of Minnesota credits for a sequence of courses covering calculus, linear algebra, multivariable calculus, and vector analysis. Students regularly finish UMTYMP as tenth graders and take upper-division mathematics courses at the University for the remainder of their high school careers [1].

Like many other accelerated mathematics programs, UMTYMP has historically had more male participants than female. In the mid-1990s, a multifaceted intervention funded by the Bush

Foundation resulted in incoming classes with female enrollment of over 30% [2]. Once the funding ended for these costly initiatives, the percentage decreased to between 25% and 30%. Beginning in 2010, this percentage has been rising, and in the 2012-13 academic year 35% of the admitted UMTYMP algebra class was female. These increases are particularly exciting because we do not currently have an intervention program targeting female enrollment. Rather, the results seem to be in large part due to an analysis of our qualifying exam, and subtle changes in the problem content and difficulty levels to make it more gender neutral in identifying the best candidates for the Program. This article discusses our initial efforts and describes which adjustments had an effect on the results.

The Entrance Exam—Testing Process

Students in grades 5-7 who wish to enter UMTYMP must achieve a satisfactory score on an entrance exam developed by our academic staff. The exam covers a variety of concepts in arithmetic, numerical reasoning, mathematical modeling, geometry, and spatial reasoning. In each question, students are given two quantities and must decide if one is always larger than the other, if they are always equal, or if there is not enough information to decide (see Figure 1). The format is based on the Quantitative Scholastic and College Ability Test (SCAT) used by the Center for Talented Youth at Johns Hopkins. In the early 1980s, the actual SCAT was used to identify potential UMTYMP students. The exam has traditionally been comprised of fifty questions to be answered in twenty minutes, giving students an average of 24 seconds to work on each problem. The purpose of this exam design was for higher scores to indicate the ability to quickly process and understand mathematical concepts that are necessary to be successful in algebra.

- (1) x and y are positive numbers and $x < \frac{x+y}{3}$.
- (a) x
 - (b) y
- (2) The sum of the remainders when each of these numbers is divided by 3:
- (a) 3, 10, 12, 19
 - (b) 6, 11, 25, 27

Figure 1. Practice questions for the UMTYMP Algebra Entrance Exam—Students must determine the size relationship between the two quantities in each question.

Historically, the passing score has hovered around 40/50, although it has changed at times due to test item analysis or other factors. As part of their registration form, students answer essay questions about their interest in mathematics and UMTYMP; these responses are used as part of the evaluation process, especially for students close to the passing line. In some years, for example, we have admitted all students scoring at least 41, and then a subset of the students with a score of 40 based on their essay answers.

Two entrance exams are given each year: the “Early Exam” is generally held in February, and the “Regular Exam” is given in late March or early April. The Early Exam is part of a larger optional program called UMTYMP Opportunities, which gives students a chance to learn more about the testing process. One week before the Early Exam, students come to campus to work through a series of sample problems with our instructors, culminating in a short practice test. The value of this opportunity is not the mathematical content; rather, we find that exposing students to the testing environment a week before the entrance exam makes them much more comfortable during the actual test. Furthermore, students who do not qualify based on their Early Exam score can register for the Regular Exam later that spring, giving them an extra chance to pass an entrance exam.

The distinction between the Early and Regular Exam pools is very important when evaluating results. The Early testers know more about the exam, and by the very act of enrolling for that exam they have maximized their chances of qualifying. Most Regular Exam testers see the exam format for the first time at the exam sitting. Not surprisingly, both the overall results and the gender breakdown of the scores on the Early Exam are often different than those on the Regular Exam.

Year-to-year comparisons can be tricky even when focusing exclusively on one of these exam pools. We have decades’ worth of scores on UMTYMP entrance exams, along with the corresponding transcripts of students who enrolled in the Program, and it is tempting to use this data to make sweeping statements about longitudinal performance. However, experience has taught us that the entrance exam data is highly variable over time due to many factors. In the past, it was common for over 1,000 or even 1,500 students to take the exam. In recent years, our recruiting has become more targeted and we now annually test 600-800 students who score higher, on average, than the students in the past. On a related note, the mathematical climate in Minnesota has changed in the last few years with the introduction of a state mandate that all students take algebra by eighth grade. This has pushed more pre-algebra curriculum into earlier

grades, which means our current testing pools are likely better prepared for an algebra course than our pools from even five years ago. Long-term comparisons of entrance exam data are therefore difficult. On a shorter time scale, we have surmised that the testing pool from one year to the next would be relatively stable, but even this assumption may be tenuous.

The Entrance Exam—Effectiveness

It is reasonable to ask whether this process is the best way to identify potential UMTYMP students. For example, although the pace of our course requires students to be able to process mathematics quickly, there is no particular data-driven reason that students should have twenty-four seconds to answer each entrance exam question as opposed to twenty seconds, or thirty-five. The main reason we have continued to use this entrance exam is that for decades it has proven to be highly effective in identifying students who are capable of succeeding in the Program.

In 2011-12, for example, 142 students enrolled in our algebra course after passing the exam, and all but one of them did well enough to continue on to the second year of the Program. Overall, of the approximately 500-600 students registered in the entire Program each year, the number of students whose grades are too low to continue is generally ten or fewer. This group includes students who are capable of succeeding in UMTYMP, but self-report that they are giving a higher priority to other courses or extracurricular activities. In other words, the entrance exam has very few false positives. Furthermore, among the students who have enrolled in the Program, we have observed a positive correlation between higher scores (above 45) and success in UMTYMP, both in terms of number of semesters completed and grades earned. Hence, the exam not only identifies a pool of capable students, but provides a good indication of who the particularly strong and committed students are.

However, these empirical observations do not preclude the possibility that the exam has a number of false negatives—students who could succeed in UMTYMP but do not achieve a predetermined passing score. We are particularly concerned that the false negatives may be concentrated among the female applicants to the Program because of three observations:

- 1) Historically, on any given entrance exam the average score of the female students has been lower than that of the males.

- 2) In the (very) few instances when females have been admitted with scores below 40 based on their essay responses, their performance in UMTYMP (in terms of grades and longevity in the Program) has equaled or exceeded that of males who scored 41 or 42 on the same exam.
- 3) Conversely, the male students who are admitted with scores at or just above the passing line have lower retention rates and grades than other students in the Program.

In other words, the entrance exam appears to adequately identify and rank appropriate male students; males who score higher on the exam are more likely to succeed in UMTYMP, and their overall performance roughly correlates with their entrance exam scores. However, female students with scores near the passing line tend to perform at a higher level than males with similar scores. Their success may be due as much to work ethic, study habits, and overall maturity as mathematical ability, but this suggests that a fixed passing line might fail to identify qualified females with scores that are one or two points below the line.

These observations caused us to wonder whether the exam could be improved so that students with similar scores would have similar success rates within UMTYMP, regardless of gender. This led to a large-scale analysis of our exam results and the admitted students' performance in UMTYMP, with a specific focus on the differences between genders. To give the reader a better context, we begin with a case study of a typical entrance exam.

A Case Study: The Regular 2009 Exam

We evaluate the gender gap on an exam in multiple ways. First, we examine the rough descriptive statistics, comparing median and mean scores. Depending on the context, we might compare the averages for all males and females, or we may analyze a specific subgroup: e.g., fifth-grade males and females; or, sixth-grade males and females who have taken a previous version of our entrance exam. Second, and perhaps more importantly, we scrutinize the students at the top of the pool to determine whether a certain passing line would result in an entering class whose ratio of males to females more closely reflects the proportion in the testing pool. This is similar to the frequently used method of comparing 90th percentile scores among the male and female pools, but allows us to focus on the demographics of a potential entering class. Finally, once students are in the Program, we track their progress to determine whether students whose exam scores were comparable performed at a comparable level in the Program, both in terms of grades and continued enrollment.

Table 2(A)
Gender Comparisons for Regular 2009 Exam

	Males	Females
Number	329	164
Mean Score	33.47	29.94
Median Score	34	30

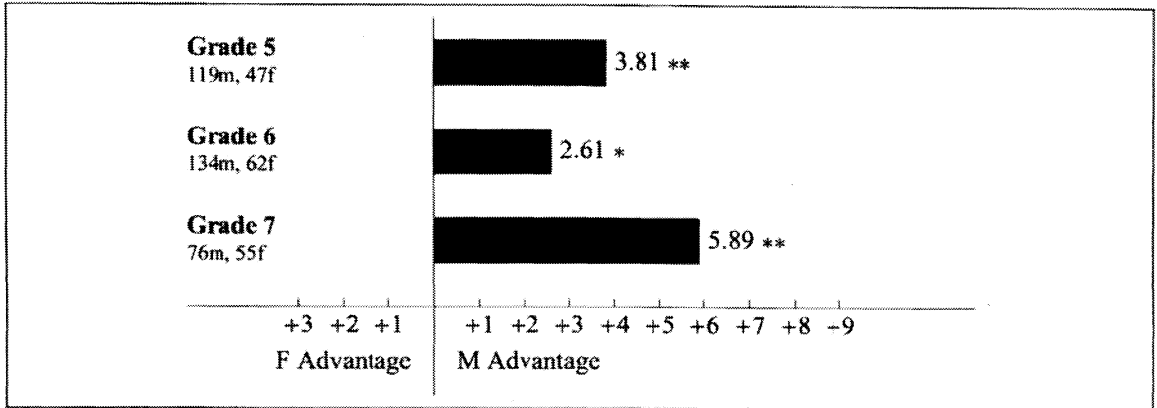
Note: Overall statistics by gender for Regular 2009 Exam. The difference in means is statistically significant ($p < 0.0001$).

Table 2(B)
Gender Comparisons for Regular 2009 Exam

Score	# Males	# Females	F% of Potential Entering Class
50	0	0	
≥49	0	1	100%
≥48	2	1	33%
≥47	7	3	30%
≥46	13	5	28%
≥45	23	7	23%
≥44	37	8	18%
≥43	49	11	18%
≥42	58	16	22%
≥41	69	19	22%
≥40	86	28	25%

Note: Scores achieved by male and female students. For each potential passing line, the last column shows the percentage of the admitted students who would be female. The overall testing pool was 33.27% female.

The results of the Regular 2009 Exam are typical and illustrate the types of disparities we have observed between males and females. Table 2(A) shows the overall statistics according to gender. The statistically significant difference in mean scores is persistent across all grade levels (see Figure 3).



* indicates a gap which is statistically significant at the $p < 0.05$ level.

** indicates $p < 0.01$.

Figure 3. Difference between average male and female scores on Regular 2009 Exam by grade level.

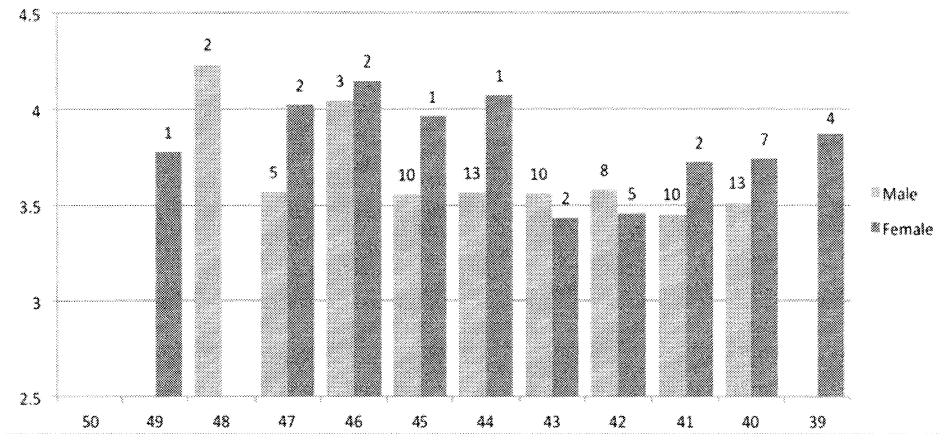
The gap was not simply due to a number of low-scoring outliers, but existed among the top performers as well. Over 33% of the testing pool was female, but Table 2(B) shows the qualifying students were disproportionately male. On this particular exam, the passing line was 40/50, although a handful of female students who scored 39/50 were admitted after evaluating the essay responses on their applications.

A consistent observation in our analysis is that female students generally omit problems at a much higher rate than males, especially toward the end of the exam. Table 4 shows the omission rates by gender for the last twenty problems on the Regular 2009 Exam. There is no penalty for wrong answers on the exam and students are encouraged to guess, so omitted problems generally indicate a student ran out of time to finish the exam. Given the omission rates in Table 4, the gap in average scores is less surprising because female students are completing less of the exam. However, this cannot entirely explain the gap. Even if we compute the percentage of correct responses among questions answered, the male students still outperformed the females by 4.5% (or 2.25 on a 50-point scale, $p < 0.001$).

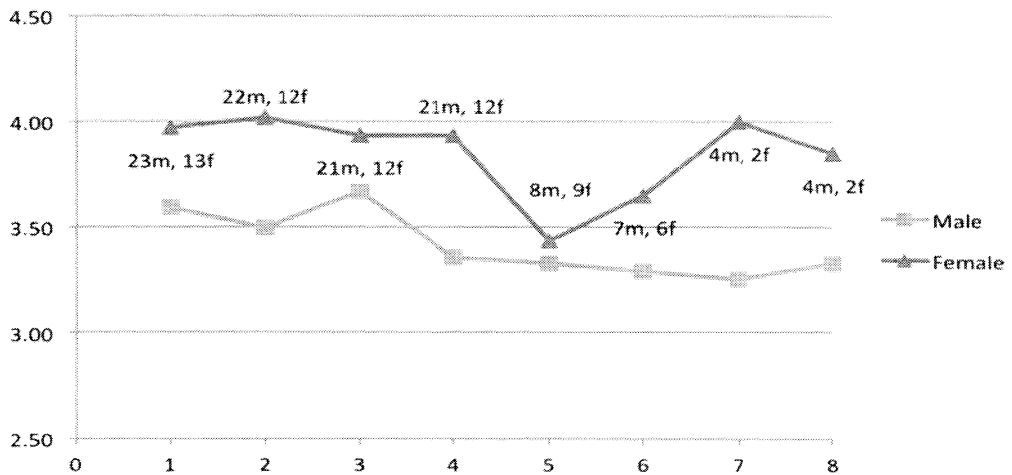
Table 4
Omission Rates by Gender on the Last Twenty Questions of the Regular 2009 Exam

Question	M	F	Question	M	F
31	5.2%	12.0%	41	17.4%	24.0%
32	4.3%	10.8%	42	20.4%	26.3%
33	6.1%	14.4%	43	22.0%	29.9%
34	5.5%	12.0%	44	22.6%	29.9%
35	6.1%	13.2%	45	24.7%	33.5%
36	7.3%	16.2%	46	27.1%	34.1%
37	11.6%	18.6%	47	32.0%	43.7%
38	13.1%	21.0%	48	35.7%	46.7%
39	19.2%	25.1%	49	35.1%	46.7%
40	19.5%	29.9%	50	37.5%	47.9%

Students who were admitted in 2009 have now completed up to four years of UMTYMP, which allows us to analyze their performance and longevity in the Program. As mentioned earlier, we have observed that female testers admitted with scores at the lower end of the historical passing range tend to be more successful in the Program than male testers with similar scores. Figure 5(A) illustrates this phenomenon for the Regular 2009 Exam testers; recall that the passing line was 40/50, with a few females admitted with scores of 39. Females admitted with a score below 42 had a higher cumulative GPA in the Program than males admitted with a score below 42 (in fact, they outperform males with scores up to 45). Figure 5(B) shows more detail for students admitted by the Regular 2009 Exam with a score below 42, tracking their average grades for each semester of the Program. Although both groups suffered significant attrition, the female students consistently outperformed their male counterparts. This suggests that, at least within this range of scores, the exam results should be interpreted differently for male and female students.



A) Average UMTYMP GPA versus entrance exam score for students admitted by the Regular 2009 Exam. The GPA is cumulative for students, measured over the course of their enrollment in the Program; a GPA of 4.3 corresponds to an A+ average. The numbers above each bar show the number of male or female students with each score who enrolled in the Program.



B) Average UMTYMP grade versus semester in the Program for students admitted with a score below 42 on the Regular 2009 Exam. The numbers at each data point show the number of male and female students enrolled that semester.

Figure 5. Comparison of Regular 2009 Exam scores versus performance in UMTYMP.

We can also measure success in the Program by retention rates. Students leave UMTYMP for many reasons: some are unable to continue due to grades (they must earn a B– or better in the first four semesters and at least a B in the remainder of the Program to proceed); some decide that the format is not appropriate for their learning style; and, some have difficulty with the commute or schedule. As one might expect, students admitted with comparatively low entrance exam scores have a much lower retention rate. However, among this high-risk population, a significantly greater proportion of female students remain enrolled which again indicates that our exam might have incorrectly identified them as marginal (see Table 6). In the remainder of this article, we will refer to the combination of course grades and continued enrollment in the Program under the blanket term “Program Performance.”

Table 6
Enrollment Rates of Students Admitted by the Regular 2009 Exam by Score Range and Gender

	Algebra	Geo/MA	Calc 1	Calc 2	Still Enrolled	Retention Rate
45-50						
Male	26	24	20	15	17	65%
Female	6	5	5	5	5	83%
42-44						
Male	31	23	16	11	12	39%
Female	8	7	7	3	4	50%
39-41						
Male	23	21	8	4	4	17%
Female	13	12	9	2	4	31%

Note: Due to deferral, leaves of absence, and other special cases, not all currently enrolled students have completed all four years. Hence, the retention rate may include students who were admitted with this exam, but have only completed *Calculus I*.

Potential Issues

Based on our statistical analysis, literature review, and anecdotal evidence, we initially identified the following possible reasons why female students persistently have lower scores than the males—and why, among those students who are admitted and enroll in the Program, female students have lower scores than would be suggested by their eventual Program Performance.

The Content Balance Hypothesis — We cycle through a number of different versions of the entrance exam; in particular, we never use the same exam for the Early and Regular testing pools in a given year. All of the versions have arithmetic, algebraic or spatial reasoning problems, but some versions might have disproportionately many problems of one type. If males and females were to perform differently on certain types of problems, this content imbalance could generate a gap in performance.

For example, studies such as those in Casey, et al. have indicated that the gender gap among middle school students on an assessment based on TIMSS problems could be traced to a difference in spatial-mechanical reasoning skills [3]. Our entrance exams typically include ten to fifteen problems that incorporate geometric or spatial reasoning, and are taken by students in grades 5-7, creating a potential for a performance gap among our testers. It should be noted that the more recent study described in “New Trends in Gender and Mathematics Performance: A Meta-Analysis” found no significant difference between male and female students’ mathematical performance regardless of the problem content [4].

The Bubble Hypothesis — Students record their answers on a bubble sheet, and the exam proctors report that the female students often seem to take much more time carefully filling in the bubbles. Although this distinction may seem trivial, on a fast-paced exam like ours it can be crucial. For example, a student who spends an extra six seconds per problem filling in each bubble would run out of time after forty questions, never getting a chance to answer the remaining problems. If females tend to spend more time than males filling in their answer sheets, it could account for some of the difference in omission rates illustrated in Table 4.

The Guessing Hypothesis — It is difficult to look at an answer sheet and identify which responses were guesses, but anecdotally our proctors have reported conversations with students after the exam in which females have been more reluctant than males to guess on the exam. This is another potential cause for the data in Table 4.

The Arrangement Hypothesis — Related to both the Content Balance Hypothesis and the fact that females are less likely to finish (or perhaps even read) the last ten questions on the exam, the placement of certain questions could affect male versus female performance. If easier problems are heavily concentrated toward the end of the exam, females may never read or answer them, whereas males are more likely to finish the entire exam.

Although some of these potential causes have some basis in the literature, most are anecdotal and may not be valid for our exam and testing pool. However, each of them allows at least a limited opportunity for testing via modest changes to the exam or by adjusting the amount of time per problem. These hypotheses all assume that females and males who take the exam are equally well qualified for UMTYMP, but the following possibility must also be mentioned.

The Testing Pool Hypothesis — On average, the female students in our testing pool may be less mathematically qualified for UMTYMP than the male students.

Recent literature indicates that at the relevant grade levels, there is no longer a significant gender gap in mathematical ability among Minnesota students [5]. However, even if the female and male students in the Twin Cities metropolitan area were equally qualified for UMTYMP, it is possible that parents, teachers, and other educators who recommend UMTYMP to students are not doing so in a gender neutral way. This issue requires investigation, but for the remainder of this article we will focus on the first four hypotheses which deal with modifications to the entrance exam.

Methods

We use multiple versions of the entrance exam, which are rotated between the Early and Regular Exam pools from year to year; for the purposes of this article, we will refer to two specific versions as Form A and Form B. In 2011, when we began our large-scale analysis, we were scheduled to use Form B for the Early Exam, and Form A as the Regular Exam; this happened to match what was used in 2009. This section describes the changes made to these exams in 2011 and 2012. The modifications are important to describe, but they are fairly detailed so the reader may wish to skim the comprehensive description and refer to the following summary and Table 7 as needed. In all, we implemented three different modifications to the exam and testing process:

- 1) In 2011, we created Forms A2 and B2 by *rearranging* the problems on Forms A and B, respectively. This allowed us to evenly distribute the difficult problems.
- 2) In 2012, we gave the Early testers a shorter, 40-question version of Form A2. These forty questions represented a better balance of topics than the full 50-question exam. This modification will be referred to as “rebalancing.”

- 3) In 2012, as a consequence of the shorter exam, the Early testers had more time per problem.

Table 7
Description of Each Exam from 2009 and 2011-2012

Exam	Form Name	Questions	Time per Question	Rearranged	Test Pool
Early 2009	B	50	24s	No	137m, 66f
Regular 2009	A	50	24s	No	329m, 165f
Early 2011	B	50	24s	No	69m, 34f
Early 2011	B2	50	24s	Yes	85m, 45f
Regular 2011	A	50	24s	No	126m, 83f
Regular 2011	A2	50	24s	Yes	163m, 88f
Early 2012	A2(40)	40	30s	Yes	176m, 82f
Regular 2012	A2	50	24s	Yes	304m, 161f
Regular 2012	B2	50	24s	Yes	89m, 41f

Modifications in 2011

We began in 2011 by attempting to address the Content Balance and Arrangement Hypotheses previously described. This required the classification of each problem according to difficulty and content. Based on student performance on Forms A and B in previous years, each question was given a difficulty rating: “Easy,” answered correctly by over 80% of all students; “Medium,” answered correctly by 55-80%; and “Hard,” answered correctly by fewer than 55% of the students. In addition, each question was categorized according to its content type, chiefly arithmetic, numerical reasoning, and geometric reasoning, with a small number of questions in modeling and statistical reasoning.

It was immediately clear that Form A had an issue with the distribution of its difficult problems, with a concentration of Hard problems in the last ten questions. Form A also had far more geometric reasoning problems than other versions of the entrance exam: eighteen questions compared to just seven comparable problems on Form B. Moreover, the geometric reasoning problems on Form A were exceptionally difficult compared to other versions, with twelve of them in the “Hard” category.

The paucity of geometric reasoning problems on Form B led to a surplus in other areas, especially arithmetic, which comprised twenty-three of the fifty problems on Form B. This version of the exam had fewer Hard problems overall, but they were concentrated at the end of the exam: thirteen Hard problems overall, but twelve of the last eighteen.

With these discrepancies, it was clear that we would eventually want to replace problems on each form to make them more similar, but during our initial analysis we wished to keep the same problems in order to preserve as much comparability as possible to the 2009 test results. We therefore focused on rearranging the problems on each form with two goals in mind: 1) making the first forty questions from each form more balanced in terms of difficulty and content; and, 2) making the first forty questions of Forms A and B more comparable to each other.

Because of its excess of Hard geometric problems, rebalancing the questions on Form A forced us to make the final ten questions very imbalanced. In this article, the modified Form A will be referred to as Form A2. The first forty questions of Form A2 had nine spatial reasoning questions and thirteen each of arithmetic and numerical reasoning, as well as eight Hard problems, with three each from numerical and spatial reasoning. The last ten questions included nine spatial reasoning problems, eight of which were Hard problems. Hence, the 40-question sub-exam on Form A2 had a very different profile than the 50-question Form A2.

The modifications on Form B were quite different. The most pressing issue was the heavy imbalance of Hard problems at the end (twelve of the last eighteen). Hence with Form B, the major change in the modified version was to make sure eleven of the Hard problems appeared in the first forty questions, including eight from arithmetic and numerical reasoning. In this article, the modified Form B will be referred to as Form B2. The first forty questions of Form B2 also smoothed out the content type distribution, with seventeen arithmetic reasoning, eleven numerical reasoning, and all seven spatial reasoning questions. Thus, the 40-question sub-exam of Form B2 was at least equal to the entire 50-question Form B and, in some ways, slightly more difficult. These two modified exams, Forms A2 and B2, were used in the following situations :

- Forms B and B2 were used for the Early Exam in 2011. The 233 students who signed up for the Early Exam were separated into a control group of 103 who took the original Form B and a group of 130 who took Form B2. (Due to the logistics of scheduling and testing rooms, splitting the pool exactly in half was not feasible.)
- Similarly, a control group of 209 students took Form A as the Regular 2011 Exam, while the remaining 251 students in the Regular pool took Form A2.

Modifications in 2012

The results of the 2011 exams were promising enough that we continued our experiment in 2012. In addition to using a rebalanced exam, our primary goal in 2012 was to address the Bubble and Guessing Hypotheses. We therefore used the first forty questions of Form A2 for the Early Exam, but kept the same time limit. This gave students thirty seconds per question instead of twenty-four, hopefully ensuring that all students (particularly the females) would have time to finish the entire exam. This version of the exam will be referred to as Form A2(40), emphasizing that only the first forty questions were used.

The results of the Early 2012 Exam were more gender neutral than other recent exams. As a control group for these results, we used the full 50-question Form A2 as the Regular Exam, with the standard twenty-four seconds per question, and all of the discrepancies from previous years immediately returned. Also note that 130 students took Form A2(40) as the Early Exam, did not qualify, and decided to re-test at the Regular 2012 Exam. Rather than giving them Form A2, a longer version of the exam they had just taken, these re-testers were given the full Form B2.

Overall Results

Tables 8(A) and 8(B) summarize the performance by gender for each of the exams in 2011 and 2012, with 2009 included for comparison. Both mean and median scores are supplied to give a more nearly complete picture. With our large sample sizes, the median is often too coarse a measure, but it can be very useful in those instances where the mean score is affected by a large number of outlying scores. Consider Form A2 in 2011, which was given to 163 males and 88 females: the median male and female scores were equal, but the difference in mean scores was a statistically significant 2.26, due to a few female students who scored 15 and below. Without those students, the gap in average scores would have been less than 1.5 (with $p = 0.156$).

Table 8
Performance by Gender on All Exams in 2009, 2011, and 2012

Exam	Form Name	Mean Male Score	Mean Female Score	Difference	<i>p</i> -value
Early 2009	B	34.87	31.97	2.90	0.018

Regular 2009	A	33.47	29.94	3.53	<0.001
Early 2011	B	36.00	33.32	2.85	0.028
Early 2011	B2	36.86	34.07	2.79	0.042
Regular 2011	A	35.56	32.59	2.97	0.007
Regular 2011	A2	34.84	32.58	2.26	0.035
Early 2012	A2(40)	33.74	32.48	1.27	0.058
Regular 2012	A2	35.31	31.65	3.66	<0.001
Regular 2012	B2	38.65	36.59	2.07	0.087

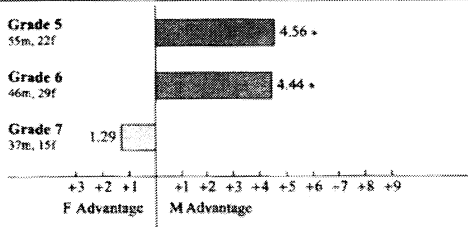
A) Mean scores by gender.

Exam	Form Name	Mean Male Score	Mean Female Score	Difference
Early 2009	B	36	33.5	2.5
Regular 2009	A	34	30	4
Early 2011	B	36	33.5	2.5
Early 2011	B2	38	35	3
Regular 2011	A	37.5	34	3.5
Regular 2011	A2	35	35	0
Early 2012	A2(40)	35	34	1
Regular 2012	A2	35	33	2
Regular 2012	B2	39	38	1

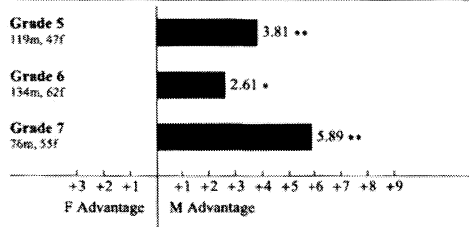
B) Median scores by gender.

The mean scores are broken down further by grade level in Figure 9, which mirrors Figure 3. Recall that the shading of each bar corresponds to the size of the sub-pool, and statistically significant differences are marked. Hence, the large gaps among seventh graders on the Early 2011 Exams, while significant, represent variation in small numbers of students. Other pools, such as the seventh graders on the Regular 2011 Exams, have far more students, but fail to have a statistically significant gap. (For seventh graders in 2011, $p = 0.08$ for the gap on Form A, and $p = 0.068$ on Form A2.) The cumulative frequency graphs in Figure 10 give a further visual representation of the performance on each exam, broken down by gender.

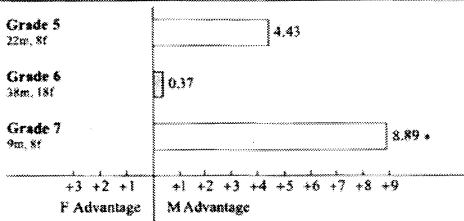
Early 2009: Form B



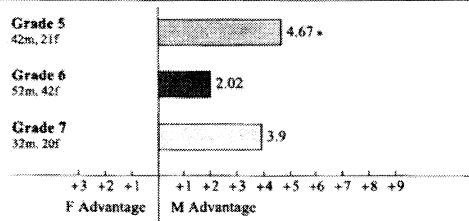
Regular 2009: Form A



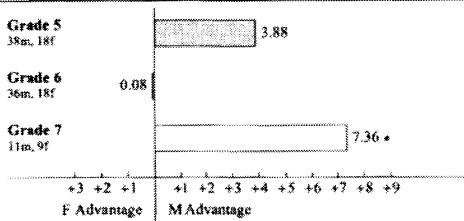
Early 2011: Form B



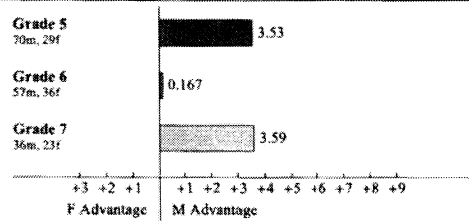
Regular 2011: Form A



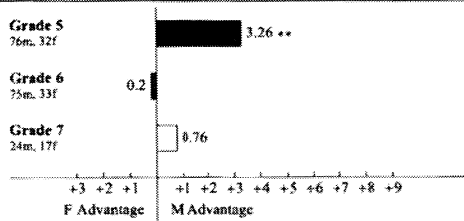
Early 2011: Form B2



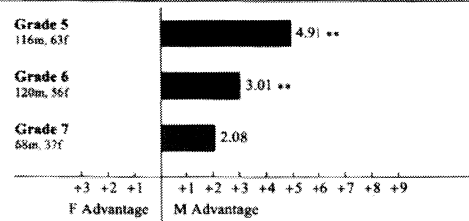
Regular 2011: Form A2



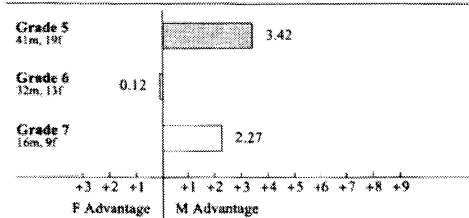
Early 2012: Form A2(40)



Regular 2012: Form A2



Regular 2012 (Retesters): Form B2

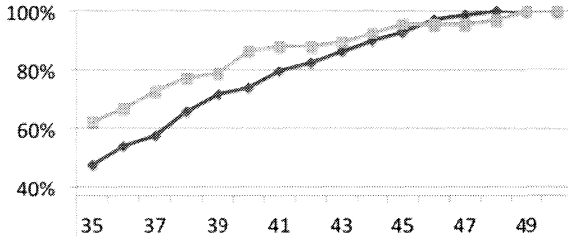


* indicates a gap which is statistically significant at the $p < 0.05$ level.

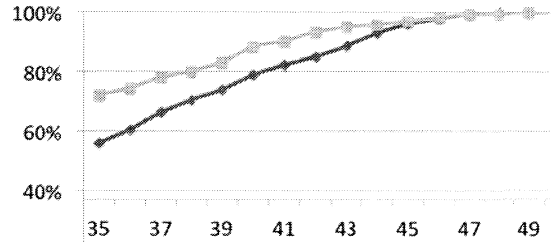
** indicates $p < 0.01$. NOTE: The bars are shaded according to the size of the pools, with darker bars corresponding to more students.

Figure 9. Difference between average male and female scores on all exams in 2009, 2011, and 2012.

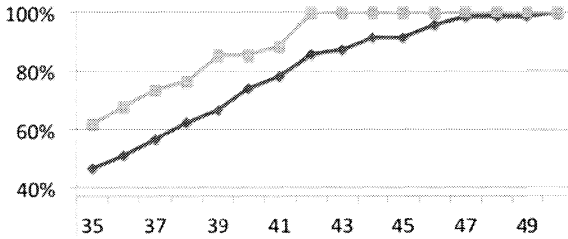
Early 2009: Form B



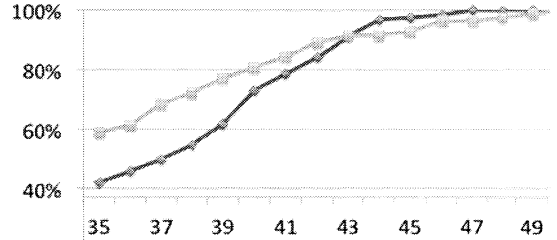
Regular 2009: Form A



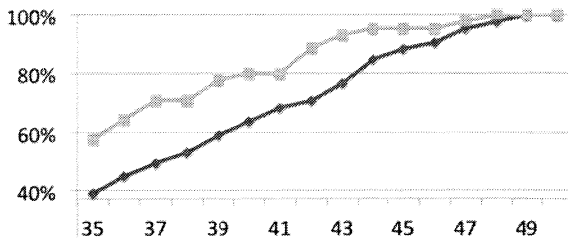
Early 2011: Form B



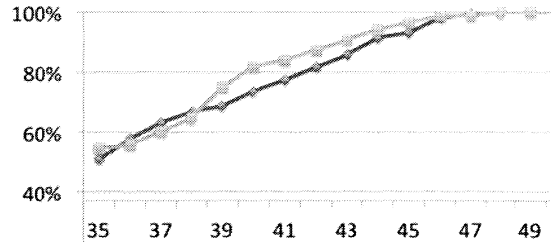
Regular 2011: Form A



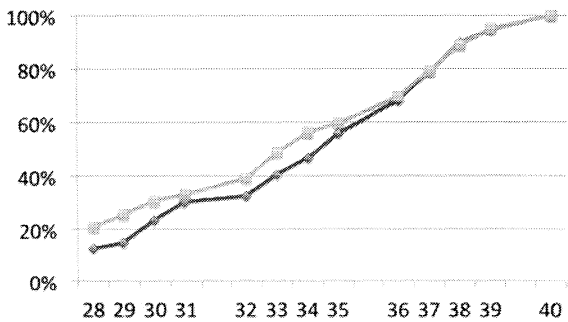
Early 2011: Form B2



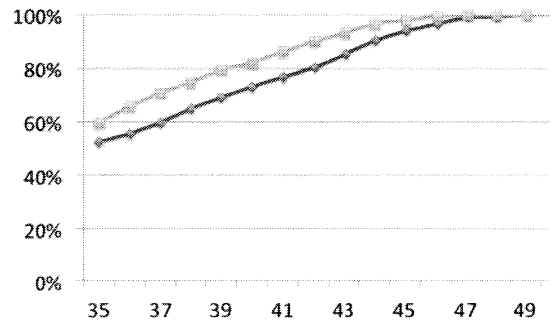
Regular 2011: Form A2



Early 2012: Form A2(40)



Regular 2012: Form A2



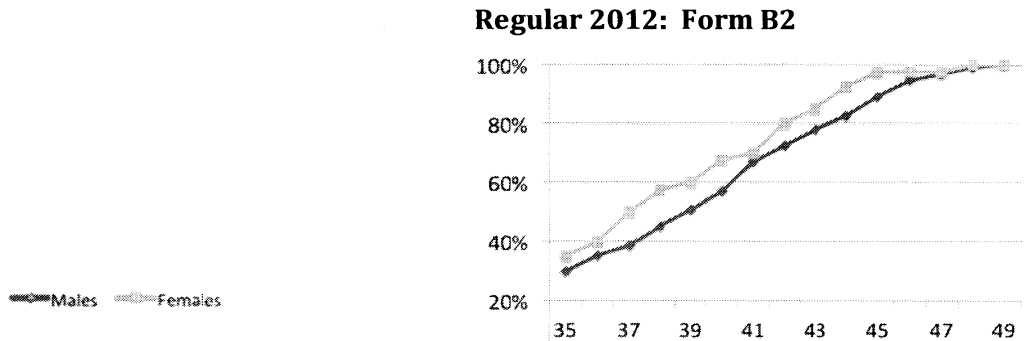


Figure 10. Cumulative frequency of scores by gender on exams.

A few striking patterns are immediately noticeable in these figures:

- With few exceptions (Early 2009 Exam and Regular 2012 Exam), the gender gap is considerably smaller among sixth graders.
- In 2011, the mean values on the rearranged versions of the tests, Forms A2 and B2, had smaller gender gaps than the original Forms A and B. The median values on Forms A2 and B2 had either smaller gaps or were very similar. On Form A2, the median male and female scores were equal; this fact alone was encouraging enough for us to continue the project through 2012.
- In particular, the cumulative frequency graphs in Figure 10 show that, for scores of 35 and up, females and males performed very comparably on the Regular 2011 Exam, Form A2. At first glance, the graph for Form A in 2011 looks very promising, with females outperforming males in the upper range of scores, but there were very few students in this pool overall, and there was a large gap in performance in the 35-40 range. This is the reason we chose to use Form A2 as the basis for the 2012 experiments.
- The Early 2012 Exam had the most gender neutral results of those whose scores are presented here. Although there was a significant gap among the fifth graders, we happen to know there was a group of four female students who scored below 20 (out of 40) and had a large effect on these statistics; if we toss out all scores below 20, the gap between males and females in fifth grade shrinks to 1.64, and

is no longer statistically significant. There were no such outliers among the male testers.

Not all of our exams have outlying students with low scores, but we have noticed that when such students exist, they tend to be disproportionately female. We currently have no definitive explanation for this phenomenon, or for why sixth grade females do better relative to their male counterparts than fifth or seventh grade females.

Omission Rates

As previously mentioned, females have historically omitted more questions than their male counterparts. This continued to be the case in 2011, but changed considerably in 2012 (see Table 11). Recall that the Early Exam used Form A2(40), with thirty seconds per question instead of twenty-four. This enabled nearly every student to finish the exam. Omission rates plummeted to near zero, with only small differences between the males and females (compare to Table 4).

Table 11
Omission Rates by Gender on the Last Ten Questions of Each 2012 Exam

Question	M	F	Question	M	F	Question	M	F
31	0.0%	2.4%	41	13.1%	26.4%	41	3.3%	2.5%
32	0.0%	1.2%	42	8.8%	22.0%	42	5.5%	5.0%
33	0.6%	1.2%	43	12.7%	30.2%	43	5.5%	5.0%
34	0.0%	1.2%	44	11.4%	27.0%	44	5.5%	5.0%
35	0.0%	1.2%	45	11.4%	26.4%	45	6.6%	5.0%
36	0.0%	1.2%	46	12.1%	25.8%	46	7.7%	5.0%
37	0.0%	1.2%	47	19.3%	32.1%	47	9.9%	7.5%
38	0.0%	1.2%	48	15.0%	29.6%	48	11.0%	7.5%
39	1.7%	4.9%	49	19.9%	33.3%	49	9.9%	7.5%
40	1.7%	3.7%	50	25.5%	38.4%	50	12.1%	10.0%

(A) Early: Form A2(40) (B) Regular: Form A2 (C) Regular (Re-Testers): Form B2

Students who took the Regular Exam were given Form A2 or B2, depending on whether they were re-testers who had already taken Form A2(40). Both Regular Exam pools had the

traditional twenty-four seconds per problem. The results for Form A2 reverted to the typical outcome, with much higher omission rates among the female students toward the end of the exam. Interestingly, the re-testers had much lower omission rates overall, and the females actually omitted fewer questions than the males.

Overall, this indicates that familiarity with the exam process may be as important a predictor of omission rates as gender, but there is insufficient data to make any definitive conclusions. Although the gender gap was reversed among the 2012 re-testers, we have examined the data and found that this has not been the case in previous years. Furthermore, although it is tempting to conclude from Table 11 that familiarity with the exam helps reduce omission rates, especially among females, it may simply represent a selection bias. Among the students eligible to re-test in 2012, perhaps more of the strong female students returned than the strong male students. In short, although there was a correlation between re-testing and lower omission rates in 2012, we cannot yet conclude causation.

Effects of Rearranging

In 2011, students took Forms B and B2 for the Early Exam, and Forms A and A2 for the Regular Exam. In both cases, the rearranged versions (A2 and B2) had smaller gender gaps in average scores, as noted earlier. Tables 12 and 13 give further details about the distribution of scores on these exams, and the percentage of female students in each grade range. These are essentially tabular versions of the cumulative frequency graphs in Figure 10. The results of Forms A2 and B2 both seem to suggest that rearranging the problems was helpful for the female testers, but this was evident in different ways.

Table 12
Scores Achieved by Male and Female Students on Early 2011 Exam,
Forms B and B2

Score	# Males Form B	# Females Form B	F% of Potential Entering Class	# Males Form B2	# Females Form B2	F% of Potential Entering Class
50	1	0	0%	0	0	-
≥49	1	0	0%	2	0	0%
≥48	1	0	0%	4	1	20%
≥47	3	0	0%	8	2	20%
≥46	6	0	0%	10	2	17%
≥45	6	0	0%	13	2	13%
≥44	9	0	0%	20	3	13%
≥43	10	0	0%	25	5	17%
≥42	15	4	21%	27	9	25%
≥41	18	5	22%	31	9	23%
≥40	23	5	18%	35	10	22%
≥39	26	8	24%	40	13	25%
≥38	30	9	23%	43	13	23%
≥37	34	11	24%	47	16	25%
≥36	37	13	26%	52	19	27%
≥35	44	15	25%	55	25	31%

Note: Testing pool was 33% female for Form B and 35% for Form B2.

Table 13
Scores Achieved by Male and Female Students on Regular 2011 Exam,
Forms A and A2

Score	# Males A	# Females A	F% of Potential Entering Class	# Males A2	# Females A2	F% of Potential Entering Class
50	0	1	100%	0	0	-
≥49	0	2	100%	0	0	-
≥48	0	3	100%	1	1	50%
≥47	2	3	60%	3	1	25%
≥46	3	6	67%	11	3	21%
≥45	4	7	64%	14	5	26%
≥44	11	7	39%	23	8	26%
≥43	20	9	31%	30	11	28%
≥42	27	13	33%	37	14	27%
≥41	34	16	32%	43	16	27%
≥40	48	19	28%	51	22	30%
≥39	57	23	29%	54	31	36%
≥38	63	26	29%	60	35	37%
≥37	68	26	28%	69	39	36%
≥36	70	34	33%	80	40	33%
≥35	75	39	34%	88	45	34%

Note: Testing pool was 40% female for Form A and 35% for Form A2.

On the Early Exam, there was a significant gender gap on Form B, which was given to 103 students. In particular, no female scored above 42, compared to ten males who scored 43 or higher. On Form B2, which was taken by 130 students, the gap was still evident (see Figure 10), but there were a small number of females with high scores. In other words, both exams were difficult for students, but the score distribution shifted higher from B to B2 for the female students, more so than for the males.

The differences on the Regular Exam were more noticeable. Females performed significantly better on Form A2 relative to the overall pool than on Form A. In Table 13, for example, we see that 28% of the students who earned scores of 40 or higher on Form A were

female; recall that the overall pool for Form A was 40% female. For comparison, a full 30% of the students who scored 40 or higher on Form A2 were female, although they only comprised 35% of the overall pool. The decreased gender gap is visibly apparent in Figure 10, where the data points for males and females are closely aligned.

The improved results on Form A2 are particularly interesting, given that the last ten questions on that version are nearly all difficult geometry problems, a type of problem with which female students have sometimes struggled. One possible explanation is that putting all of these problems at the end of the exam helped ensure that females were more likely to answer questions 1–40, which they found easier, and then answer some portion of the remaining questions.

Effects of Rebalancing

Recall that Form A2 was highly imbalanced with respect to content, but the first 40-question sub-exam, Form A2(40), was extremely well balanced. To illustrate the result of a balanced exam, Table 14 compares the results of these two forms on the Early and Regular Exams in 2012. The blank lines in the left half of the table are an attempt to arrange comparable scores next to each other; for example, a score of 36/40 on the Early Exam corresponds to a score of 45/50 on the Regular Exam.

Table 14
Scores Achieved by Male and Female Students on Early 2012 Exam, Form A2(40), and Regular 2012 Exam, Form A2

Score	# Males A2(40)	# Females A2(40)	F% of Potential Entering Class	Score	# Males A2	# Females A2	F% of Potential Entering Class
40	9	4	31%	50	0	0	-
≥39	18	9	33%	≥49	2	0	0%
≥38	37	17	31%	≥48	2	0	0%
≥37	56	25	31%	≥47	10	1	9%
≥36	78	33	30%	≥46	18	3	14%
				≥45	29	5	15%
				≥44	45	11	20%
≥35	94	36	28%	≥43	60	16	21%
≥34	105	42	29%	≥42	71	22	24%

≥33	119	50	31%	≥41	82	29	26%
≥32	123	55	31%	≥40	94	33	26%
≥31	135	57	30%	≥39	107	41	28%
≥30	150	61	30%	≥38	123	47	28%
≥29	154	65	30%	≥37	135	47	26%
≥28	158	68	30%	≥36	145	65	31%
				≥35	166	70	30%

Note: Testing pool was 32% female for Form A2(40) and 35% for Form A2.

It is risky to draw definite conclusions by comparing these two exams, because students had more time per problem on Form A2(40), and also because the Early and Regular Exams have different populations of testers. However, a gender gap is clearly evident on Form A2, yet nearly nonexistent at all levels on Form A2(40). It remains to be seen whether Form A2(40) has accurately predicted students' Program Performance, regardless of gender; however, initial data from those students' first year in the Program is very promising.

Discussion

Students who were admitted based on the 2011 and 2012 exams have not yet accumulated enough retention data and course grades for us to assess their Program Performance; hence, any study of the effectiveness of these exams in predicting future success within UMTYMP must wait for a future longitudinal study. For now, we can analyze the exam scores to see whether our modifications resulted in a testing process in which male and female students pass the exam in proportion commensurate with their proportions of the overall testing population. The answer appears to be a cautious "yes," and the appropriate testing process seems to be a blend of having well-balanced exams with respect to both difficulty and type of problem, as well as giving students slightly more time to complete the exam. Again, definitive answers must wait until we verify that the admitted students' Program Performance is consistent with their scores.

The number of parameters involved in a large entrance exam administered to a large and changing pool makes it very difficult to point to a specific exam modification and definitely conclude that it had a specific, permanent effect. Some parameters that are certainly relevant to our study include the following factors: 1) differences between Early and Regular testers; 2) which students have chosen to take the test each year and why; and, 3) which students decide to re-test within the same year. However, it is highly suggestive that the most gender-neutral results on any exam were on Form A2(4)—the only exam which was rearranged, rebalanced, and on

which students had thirty seconds per question instead of twenty-four. For the 2013 exams, we attempted to replicate this pattern. Results were encouraging and will be described in a future paper, once we have more data from 2014 and beyond to allow us to draw stronger conclusions.

Although the Content Balance and Rearrangement Hypotheses may turn out to be valid, it is harder to make any definitive conclusions about the Guessing and Bubble Hypotheses, which gave possible explanations for why females tended to have higher omission rates. Any definite conclusions about these possible causes would be beyond the scope of our current work, requiring extensive observations with stopwatches and post-test interviews to determine which answers were or were not guesses. However, an exact determination of how much each of these hypotheses might explain the high omission rates may not be necessary because, whatever the cause, the omission rates for both genders decreased to near zero once we gave students thirty seconds per question on Form A2(40) (see Tables 11 and 4). Regardless of whether females were taking too long to fill in bubbles, or were unlikely to guess, the omission rate problem has largely been solved.

However, as already mentioned, we now need to explore whether having previously taken an UMTYMP entrance exam is a better predictor of omission rates than gender. If re-testing is more beneficial for female students, we could improve our female passing rates by encouraging more females to take the test a second time. It is worth noting that, although re-testers tend to improve their response rate, they do not necessarily improve their score. Hence, familiarity with the exam process might make students work faster, but not necessarily more accurately.

An interesting byproduct of this project was the in-depth analysis of students' longitudinal success in UMTYMP compared to their entrance exam scores; this was described for students admitted on the Regular 2009 Exam, but results from other years have been very similar. Recall that females admitted by the Regular 2009 Exam with a score below 42 consistently had higher GPAs than males admitted with a score below 45, or even with a score below 42; this was the case despite the fact that some female students were admitted with a score of 39 and no male students were. Anecdotally, it was always suggested that females with lower scores were in fact comparable to males with higher scores, but this has now been verified. As an important consequence, this could justify setting separate, lower passing lines for females in an effort to increase female enrollment in UMTYMP. However, this would not be an entirely satisfactory solution from a public relations point of view. We will therefore continue to explore whether we

can create an exam on which students with similar scores have similar Program Performance, regardless of gender.

Finally, while compiling data for this study we analyzed our testing pool more closely than had been done before. This year-to-year analysis showed that our testing pool is much more variable than we had realized, and highlights a recruitment problem. Our first priority is certainly to ensure that our measuring instrument is as fair as possible, as well as capable of correctly identifying qualified students. However, in order to improve the gender balance among enrolled students (which is already high for such a program) we need to encourage more qualified female students to take the entrance exam in the first place. Studies suggest that elementary school girls are aware of the stereotype that men are considered to be better at math than women, but do not personally believe the stereotype [6]. However, studies also indicate that susceptibility to stereotype threat becomes a problem at around twelve years of age, which means that some but not all of our testing pool is likely to be affected [7]. Achieving gender balance in our enrollment could therefore require a combination of both modifications to our exam and targeted intervention programs like those described in “Can Equity Thrive in a Culture of Mathematical Excellence?” which had very positive results on female enrollment in the University of Minnesota Talented Youth Mathematics Program twenty years ago [2].

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A NOTE ON KNIGHTS, KNAVES, AND TRUTH TABLES

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Abstract.

Student and teacher (in the order above) have taken on a project of trying to understand something about Boolean algebra, logic circuits, and applications with the aid of *Mathematica*. We quickly recognized that the logical puzzles popularized by Raymond Smullyan that involve Knights (truth tellers) and Knaves (liars) are ideally suited for analysis by Boolean methods and truth tables. with a big boost from *Mathematica*. Not only is there a lot of mathematics to be learned, there is a great deal of fun to be had. The topic seems to us to be an ideal vehicle for exposing young high school and undergraduate college students to wonderful mathematics outside of the standard Advanced Placement Calculus stream.

Introduction

Most people who learn, teach, or do mathematics are familiar with Raymond Smullyan's mind-bending puzzles and, in particular, with the logical problems inherent in the conversations of knights and knaves. A knight tells the truth under all circumstances while a knave always lies. Now suppose that every inhabitant of a certain island is either a knight or a knave. To be precise, as one needs to be in Smullyan's world, the preceding "or" is used in the exclusive sense. An ordinary visitor to the island from the mainland would be unable to judge whether an islander is a knight or a knave just from his appearance or from what he says.

Suppose that our visitor meets islanders A, B, and C and that

A says that either B or C is a knight;
B says that A is a knave; and,
C says that A says that B is a knave.

The visitor's problem and our problem, too is to determine whether or not there exists any combination of A, B, and C as knights or knaves, such that their linked comments become logically consistent. In the note to follow, we use a little binary Boolean algebra and construct

truth tables to discover which (if any) combinations of knights and knaves will lead to logical consistency when all of their comments are taken together. We have intentionally avoided writing "A's, B's and C's statements" since the statements that we shall test through the construction of truth tables are not the comments actually made by the islanders, but statements derived from their comments.

The Statements

First, we observe that it might seem that the pairings "logically consistent or not consistent" and "valid or not valid" make more sense than "true or false" in the context of knights and knaves. However, since "true or false" is firmly embedded in the vocabulary of Boolean algebra, we shall ask for combinations of knights and knaves that make their linked statements true.

Let us denote A's comment by CA. Then, the associated statement to be tested is

$$SA = (CA) \text{ exclusive or } (\text{not } A) \quad (1)$$

where the statement A is that A is a knight and not A is the statement that A is a knave. The use of the Boolean exor function in deriving the statements from the comments of A, B, and C makes great sense since Xor[P, Q] is true if and only if the truth values of P and Q are different. When we use *Mathematica* to construct our truth tables, we must rewrite equation 1 as

$$SA = \text{Xor}[CA, \neg A].$$

Then the three statements derived from the listing of comments by A, B, and C as given above are

$$SA = \text{Xor}[B \vee C, \neg A], SB = \text{Xor}[\neg A, \neg B], \text{ and } SC = \text{Xor}[\text{Xor}[\neg B, \neg A], \neg C]. \quad (2)$$

The three statements taken together as a single statement will be true if and only if all three individual statements are true. Thus, we are led to the logical conjunction to be implemented with *Mathematica* and its "And" function. Thus, our test for the truth of the islanders' three statements will be determined by evaluating the Boolean function

$$F[A, B, C] = \text{And}[SA, SB, SC] = SA \wedge SB \wedge SC. \quad (3)$$

If and only if F[A, B, C] takes the value "true" do we say that the information put out by A, B, and C together is true or consistent.

Truth Tables

We have found great value in constructing the knights' and knaves' tables by hand. Just as students in high school who have refrained from using their calculators too soon but who have practiced long multiplications and divisions by hand will know their number facts better and understand polynomials more quickly than those who have not, so those who have filled in their own truth tables and not turned straight to *Mathematica* will have gained a real feeling for how truth tables work. However, the purpose of our note is to explain how one can solve a class of difficult logical problems by method rather than by resort to ingenuity. So for convenience, we turn quickly to *Mathematica* to display the truth table that will test the statements for A, B, and C as given above. The column headings for the table are those defined by equations 1, 2, and 3.

Table 1.
Truth Values for the Introductory Problem.

$$SA = \text{Xor}[(B \vee C), \neg A];$$

$$SB = \text{Xor}[\neg A, \neg B];$$

$$SC = \text{Xor}[\text{Xor}[\neg B, \neg A], \neg C];$$

TableForm[BooleanTable[{{A, B, C, SA, SB, SC, SA \wedge SB \wedge SC}},

TableHeadings \rightarrow {None, {"A", "B", "C", "SA", "SB", "SC", "SA \wedge SB \wedge SC"}}}]

"A"	"B"	"C"	"SA"	"SB"	"SC"	"SA \wedge SB \wedge SC"
True	True	True	True	False	False	False
True	True	False	True	False	True	False
True	False	True	True	True	True	True
True	False	False	False	True	False	False
False	True	True	False	True	True	False
False	True	False	False	True	False	False
False	False	True	False	False	False	False
False	False	False	True	False	True	False

We see that if and only if A and C are knights and B is a knave, their statements are consistent.

After an aside concerning the liar's paradox, the remainder of our note is devoted to the stating and solution of four more problems. Our intention is to emphasize that method may win the prize even when ingenuity and deep insight may fail.

The Liar's Paradox

Since we are concerned with knights who always tell the truth and knaves who always lie, it would seem instructive to consider the liar's paradox. We may take the statement

A says that A is a knave

as the paradox. The Boolean representation of the paradox is $\text{Xor}[\neg A, \neg A]$ and here is its truth table.

Table 2.
The Liar's Paradox.

$SA = \text{Xor}[\neg A, \neg A];$

$\text{TableForm}[\text{BooleanTable}[\{A, \neg A, SA\}], \text{TableHeadings} \rightarrow \{\text{None}, \{ "A", "Not A", "SA" \} \}]$

"A"	"Not A"	"SA"
True	False	False
False	True	False

We see that our solution scheme quickly disposes of a logical conundrum. Next, we present our four problems which feature in succession two, three, four, and five islanders having their say. We hope that our readers will agree that, with the help of a little Boolean algebra, we can solve puzzles too complicated for one to solve by conversational methods alone.

Problem 1. Our characters are islanders A and B.

A says B says A is a knave, and

B says A is a knight.

We note that since A says that B says . . . , we must construct SA with a composition of Xor's.

The statements to be tested are $SA = \text{Xor}[\text{Xor}[\neg A, \neg B], \neg A]$ and $SB = \text{Xor}[A, \neg B]$. Again, we turn to *Mathematica* and obtain the results shown in Table 3.

Table 3.
Truth Values for Problem 1

```
SA = Xor[Xor[¬A, ¬B], ¬A];
SB = Xor[A, ¬B];
tbl = BooleanTable[{A, B, ¬A, ¬B, SA, SB, SA ∧ SB}];
TableForm[tbl, TableHeadings → {None, {"A", "B", "¬A", "¬B", "SA", "SB", "SA ∧ SB"}}]
```

"A"	"B"	"¬A"	"¬B"	"SA"	"SB"	"SA ∧ SB"
True	True	False	False	False	True	False
True	False	False	True	True	False	False
False	True	True	False	False	False	False
False	False	True	True	True	True	True

We see that the two statements SA and SB are consistent if and only if both A and B are knaves.

Problem 2.

A says C is a knight;

B says A is a knight; and,

C says B is a knight or A is a knave.

Our statements are $SA = \text{Xor}[C, \neg A]$, $SB = \text{Xor}[A, \neg B]$, and $\text{Xor}[(B \vee \neg A), \neg C]$. Here is our truth table.

Table 4.
Truth Values for Problem 2.

$SA = \text{Xor}[C, \neg A];$

$SB = \text{Xor}[A, \neg B];$

$SC = \text{Xor}[(B \vee \neg A), \neg C];$

$\text{tbl} = \text{BooleanTable}[\{A, B, C, SA, SB, SC, SA \wedge SB \wedge SC\}];$

$\text{TableForm}[\text{tbl}, \text{TableHeadings} \rightarrow \{\text{None}, \{"A", "B", "C", "SA", "SB", "SC", "SA \wedge SB \wedge SC"\}\}]$

"A"	"B"	"C"	"SA"	"SB"	"SC"	"SA \wedge SB \wedge SC"
True	True	True	True	True	True	True
True	True	False	False	True	False	False
True	False	True	True	False	False	False
True	False	False	False	False	True	False
False	True	True	False	False	True	False
False	True	False	True	False	False	False
False	False	True	False	True	True	False
False	False	False	True	True	False	False

We see that the three statements SA, SB, and SC are consistent if and only if all three islanders are knights.

We also observe that the single change of switching A's comment to "C is a knave " drives the solution to the new state in which A and B are knaves and C is a knight. This new result is displayed in Table 5 below.

Table 5.
Truth Values for the Changed Problem 2

$SA = \text{Xor}[\neg C, \neg A];$

$SB = \text{Xor}[A, \neg B];$

$SC = \text{Xor}[(B \vee \neg A), \neg C];$

$\text{tbl} = \text{BooleanTable}[\{A, B, C, SA, SB, SC, SA \wedge SB \wedge SC\}];$

$\text{TableForm}[\text{tbl}, \text{TableHeadings} \rightarrow \{\text{None}, \{"A", "B", "C", "SA", "SB", "SC", "SA \wedge SB \wedge SC"\}\}]$

A	B	C	SA	SB	SC	SA \wedge SB \wedge SC
True	True	True	False	True	True	False
True	True	False	True	True	False	False
True	False	True	False	False	False	False
True	False	False	True	False	True	False
False	True	True	True	False	True	False
False	True	False	False	False	False	False
False	False	True	True	True	True	True
False	False	False	False	True	False	False

We suspect that interesting results might follow from recording the effects of successive small changes in the statements SA, SB, and SC.

Problem 3.

A says B says C is a knave;

B says A is a knave or C is a knight;

C says both B and D are knights; and,

D says B is a knight.

Our statements are $SA = \text{Xor}[\text{Xor}[\neg C, \neg B], \neg A]$, $SB = \text{Xor}[(\neg A \vee C), \neg B]$, $SC = \text{Xor}[(B \wedge D), \neg C]$, and $SD = \text{Xor}[B, \neg D]$. Since our table contains sixteen rows, we save space by printing only the row (or rows) in which $SA \wedge SB \wedge SC \wedge SD = \text{true}$.

Table 6.

The Solution for Problem 3.

$SA = \text{Xor}[\text{Xor}[\neg C, \neg B], \neg A];$

$SB = \text{Xor}[(\neg A \vee C), \neg B];$

$SC = \text{Xor}[(B \wedge D), \neg C];$

$SD = \text{Xor}[B, \neg D];$

$\text{tbl} = \text{BooleanTable}\{A, B, C, D, SA, SB, SC, SD, SA \wedge SB \wedge SC \wedge SD\};$

$\text{TableForm}[\text{tbl},$

$\text{TableHeadings} \rightarrow$

$\{\text{None}, \{A, B, C, D, SA, SB, SC, SD, SA \wedge SB \wedge SC \wedge SD\}\};$

```
Do[If[tbl[[k, 9]] == True, Print["Row #", k, ":", tbl[[k]]], {k, 1, 16}]
Row #9: {False, True, True, True, True, True, True, True, True}
```

We see that consistency is achieved when A is a knave and B, C, and D are all knights. The full truth table can be viewed by removing the semicolon at the end of the next-to-the-last line of the program above.

Problem 4.

A says B says both C and D are knights;

B says only one of A and E are knaves;

C says A says E is a knight;

D says C says B is a knight; and,

E says D says C is a knave.

Our statements are $SA = \text{Xor}[\text{Xor}[(C \vee D), \neg B], \neg A]$, $SB = \text{Xor}[\text{Xor}[\neg A, \neg E], \neg B]$, $SC = \text{Xor}[\text{Xor}[E, \neg A], \neg C]$, $SD = \text{Xor}[\text{Xor}[B, \neg C], \neg D]$, and $SE = \text{Xor}[\text{Xor}[\neg C, \neg D], \neg E]$. Since our large table contains thirty-two rows, we save space by printing only the row (or rows) in which

$SA \wedge SB \wedge SC \wedge SD \wedge SE = \text{true}$.

Table 7.

The Solution for Problem 4.

$SA = \text{Xor}[\text{Xor}[(C \wedge D), \neg B], \neg A]$;

$SB = \text{Xor}[\text{Xor}[\neg A, \neg E], \neg B]$;

$SC = \text{Xor}[\text{Xor}[E, \neg A], \neg C]$;

$SD = \text{Xor}[\text{Xor}[B, \neg C], \neg D]$;

```

SE = Xor[Xor[¬C, ¬D], ¬E];
tbl = BooleanTable[{A, B, C, D, E, SA, SB, SC, SD, SE, SA ∧ SB ∧ SC ∧ SD ∧ SE}];
TableForm[tbl,
  TableHeadings → {None, {"A", "B", "C", "D", "E", "SA", "SB", "SC", "SD", "SE",
    "SA ∧ SB ∧ SC ∧ SD ∧ SE"}}];

Do[If[tbl[[k, 11]] == True, Print["Row #", k, ": ", tbl[[k]]], {k, 1, 32}]
Row #11: {True, False, True, False, True, True, True, True, True, True, True}

```

We see that what the five islanders say is consistent if and only if A, C, and E are knights, and B and D are knaves. Again, the full truth table can be viewed by removing the semicolon at the end of the next-to-the-last line of the program above.

Conclusion

We hope that we have convinced our readers that using *Mathematica* to construct truth tables is both an interesting and efficient way of attacking Smullyan's problems about knights and knaves. Finally, we are indebted to Mr. Frank Kiefer for sparking our interest in knights and knaves.

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