

WRITING A SCIENTIFIC RESEARCH QUESTION FOR INDEPENDENT
INVESTIGATION IN THE HIGH SCHOOL LABORATORY

by

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July, 2014

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ABSTRACT

Although many professional science organizations and educational researchers continue to call for student engagement in authentic scientific inquiry, much of what transpires in today's high school science laboratories resemble the more traditional, step-by-step "cookbook" style investigation. In my experience I have found that even advanced science students find it difficult to generate a research question of personal interest, scientific significance and empirical feasibility. The focus of this project was on teaching and guiding a small group of 10 high school seniors in writing testable scientific questions, ultimately for their own independent research. In addition, I examined ways to improve student understanding of the nature of science (NOS) and assessed how student confidence levels in undertaking scientific research and in writing scientific questions may be impacted. Using a series of teaching modules, group discussion, online data sets and rubric-scored tasks, students practiced and refined the skills needed to become proficient in formulating quality scientific questions. A variety of data collection methods were used in order to gauge student progress and success. These included quizzes, surveys, student interviews and scored assessment tasks. An analysis of the data indicates consequential improvement in the quality of written scientific questions, improved comprehension of nature of science concepts and an overall rise in student confidence.

INTRODUCTION AND BACKGROUND

The National Science Education Standards, the American Association for the Advancement of Science, and the newly developed Next Generation Science Standards (NGSS) agree that today's students need to be challenged with authentic investigations into the nature of science (Rutherford & Ahlgren, 1990). Based upon my review of the research literature, those educators who appear to be most successful in getting students engaged in inquiry-based science use a constructivist approach (Chin & Osborne, 2008; Keys, 1999; Watts, Gould & Alsop, 1997). This approach involves getting students to ask questions rather than just answering content questions. It also evaluates the essence of student generated questions and guides them towards improving the quality of their questions.

For the last several years I have been teaching a seminar-style course for honor level science students called Independent Science Research. The students in this class are all successful science students and are interested in pursuing a science major on the university level. However, much of their success in high school science is based on their ability to follow specific, step-by-step laboratory procedures, often termed "cookbook" labs. It is much more difficult for them to generate a research question of personal interest, scientific significance and empirical feasibility. They simply have not had much experience doing this.

In my view, by the time they get to secondary school, students should have a sufficient conceptual understanding of scientific principles and be adequately skilled in scientific methodology and technique. From this point, students can be challenged with authentic investigations into the nature of science (NOS), which includes formulating

hypothesis, developing models and employing evidence-based testing. Much of what passes for scientific investigation today in the classroom may indeed be far from these core practices (Peters, 2005).

There are a variety of methodologies, such as modeling, scaffolding, online data sets and rubric scoring feedback, available to assist students in the formation of higher order questions and to collect valuable data for the educator to ensure student success. I therefore have designed teaching modules, practice sets and assessment tasks using online data sets. I propose that this varied and integrated approach will guide my students in acquiring the skills necessary to identify measurable variables, state specific parameters for an investigation, identify potential relationships between variables, and establish a testable hypothesis.

Focus Questions

In the future and before they are required to state a research problem for class, students may use these modules with established data sets as a basis for writing scientific research questions that meet specific criteria. The evaluation of these modules could indicate the need for further instruction or suggest that the student is ready to move on to an independent research project. Part of the instruction would include examples and a scaffold to assist students in writing clear and coherent scientific questions and appropriate rubrics for assessment and feedback. To this end, my action research project incorporated three focal questions:

- 1) Does practice and feedback with online data sets impact a student's ability to write a high quality and testable scientific research questions for investigation?

- 2) Is the student's understanding of the Nature of Science (NOS) impacted as they learn to write good scientific questions and engage in independent research?
- 3) Will student confidence levels in undertaking scientific research and in writing scientific questions be impacted?

CONCEPTUAL FRAMEWORK

Since the mid 1990's, there has been a national call for an increased focus on authentic science practices in the classroom. While there may be several views as to what exactly that may entail, most educational researchers agree that it must include inquiry-based endeavors. The National Science Education Standards points out that "inquiry into authentic questions generated from student experiences is the central strategy for teaching science" (NCR 1996, p. 31).

There remains a debate as to what constitutes authentic scientific inquiry versus the traditional emphasis of the scientific method. A rigid focus on the scientific method as a set of distinct and often discontinuous steps may actually distract students from engaging in the type of inquiry educators are attempting to promote. In one study that investigates the teaching and learning tensions between the scientific method and authentic inquiry, researchers investigated how the scientific method is presented in a typical high school. The focus was on how the students engage in scientific inquiry and how the teachers' identified the dynamics involved. When attempting to qualify the essential characteristics of authentic scientific inquiry in education, the authors of this study conclude that such inquiry includes mechanical reasoning, argumentation, pursuit of causal factors, formulating sensible hypotheses and supporting claims with evidence.

In conclusion, the authors suggest that “when articulated categories of scientific process are not rooted and built on what students are doing, they risk undermining reasoning, distracting students and teachers from the very activities we are trying to foster” (Tang, Coffey, Elby & Levin, 2009, p. 45).

However, much of the scientific laboratory experiences in public high schools today are of the formulaic, “cookbook” variety, where the scientific method is presented as a series of formalistic laboratory protocols. Students are provided a step-by-step recipe in which to gather data, perform calculations and answer specific questions (Herman, 2008). There is a recent and growing body of research that suggests supplementing traditional lectures and cookbook style laboratory exercises with active learning strategies and inquiry scaffolds, help to engage students in scientific processes that improve both learning and the retention of knowledge (Handelsman, Ebert, Beichner & Bruns, 2004).

One approach is to employ constructivist theories of teaching. A constructivist pedagogy focuses on how students build up, organize and ultimately construct knowledge. Constructivist teaching strategies are concerned with “encouraging pupil’s questions, exploring the understandings which give rise to these, and what meaning we can make of them” (Watts, 1997 p. 57). In this regard, authentic, inquiry-based science involves asking questions rather than just answering content questions posed by the classroom science teacher. Many science educators agree that good science begins with good questions. Carolyn Keys from the University of Georgia maintains that “constructivist oriented learning environments include inquiry activities in which students have the freedom to select their own methods of investigations and even their own investigation problems” (Keys, 1998, p. 119-120).

Mark Windschitl (2008) of the University of Washington believes that there does not have to be a line of demarcation between learning science content and doing authentic scientific inquiry. In fact he argues that inquiry experiences on the part of the student will often result in a well-integrated understanding of content and the honing of scientific reasoning skills. He suggests that the science teacher might consider a framework of four interrelated concepts that will support student understanding in both the intellectual and material work of science. These include organizing what we know and what we would like to know, generating a model, seeking evidence, and constructing an argument (Luft, Bell, and Gess-Newsome, 2008).

Marbach-Ad and Sokolove (2000) attempted to address two key issues surrounding effective questioning in the science classroom. First, can an instructor clearly define for students what is considered a “good” question and secondly, are there methods to teach and encourage students to ask better questions? The study involved undergraduate students in two different introductory biology classes (225-250 students). One class was taught using a traditional lecture format while the other class engaged in active learning that was interactive, cooperative and constructivist-based. Students could select which class they preferred to enroll in. A taxonomy was developed to evaluate the quality of written questions by students at specific points during the course. Both courses included specific interventions such as question-based homework assignments and short research papers. Through modeling and example, the instructor demonstrated the key characteristics of a scientific question and assisted the students in defining and critiquing the nature of “good” questions. By the end of the semester 76% of the questions in the active learning class fell into the higher ordered categories of the taxonomy compared

with only 50% in the traditional class. The authors of this study also noted that some of these improved questions could be transposed into valid research questions (Marbach-Ad & Sokolove, 2000).

Harper, Etkina and Lin (2002) studied 200 students in a college freshman engineering mechanics course and examined a method for fostering student questions and analyzed the resulting questions. Each week students submitted brief online reports in which they reflected on the application of knowledge in both lab-based cycles as well as lectures and recitations. Graders were assigned to read and respond to student questions in a timely manner. This method did clearly solicit questions about the course material, but questions were not required. The study found that 70% of the reports contained questions, even though they were not required. One general implication is that the incorporation of weekly reports encourages students to ask more questions than they otherwise would. However many of the student questions had were of a factual nature rather than high-level thought provoking ones such as researchable questions.

The study concluded that encouraging student questions in general does not necessarily result in learning, as indicated by correlating question types with conceptual test scores. The authors of this study suggest that questions which contain elements of synthesis, application and evaluation are related to greater conceptual understanding for some student populations. Furthermore, encouraging questions like this may aid students in learning how to phrase high-level questions better.

An investigation done with 9th grade biology students by Chin and Chia (2004) examined the sources of inspiration for student questions and how those questions guided their knowledge construction when engaged in problem-based learning (PBL). The

researchers found that the majority of questions raised (54.2%) were asked in pursuit of basic information. Just over one quarter of the questions (26.0%) sought explanations for previously observed phenomena. The remaining questions sought to verify if certain common beliefs could be validated (10.4%) or pertained to imagined scenarios (9.4%). A significant result of the study was the fact that only 13.5% of the questions were inspired by ideas from the school curriculum.

Other researchers believe that good questioning skills on the part of students have great potential to generate learning (Chin & Osborne, 2008; Osborne, Erduran & Simon, 2004). It can be argued that there is a substantial need for instruction of the formulation of questions. This connection between the cognitive skill of asking good questions and conceptual learning is most enhanced when the student has a high interest level in the science topic (Cuccio-Schirripa & Steiner, 2004). Therefore, the formation of a researchable question must be meaningful to the student in order to have the greatest potential to induce learning.

In their study, Cuccio-Schirripa and Steiner (2004) randomly assigned 181 middle school students to two treatments: instruction verses no formal instruction on researchable questioning. Each class had been stratified at the beginning of the school year for low, average, and high ability based on the mathematics and reading Stanford Achievement Test. Students were directed to formulate questions from science topics of high personal interest as well as low interest. The concluding data suggests that irrespective of instruction, students' high-interest question levels are of a higher quality than their low-interest question levels. According to the authors of this study, teachers may be underestimating student interest in a science topic as an important motivator in

the development of questioning skills. They also point out that personal interest in a topic can be both cultivated and potentiated by providing students with opportunities to choose a topic. They conclude by stating that “both instruction and the prerogative to select science topics of interest be used to enhance the development of the students’ own researchable questions” (Cuccio-Schirripa & Steiner, 2004, p. 221).

A few research and instructional articles (Patterson, 2001; Schlenker, 1994; Deiner, Newsome & Samaroo, 2012) referred to the use of scaffolds to both assist and evaluate student progress in self-inquiry tasks. A scaffold can break up a task into a series of components that permit frequent feedback and provide a guide for final integration. One successful use of scaffolding for directed self-inquiry was done in a college level General Chemistry II course at the New York City College of Technology (Deiner, Newsome & Samaroo, 2012). The authors point out that writing a clear, concise and well organized science paper requires critical thinking, conceptual understanding and careful construction. They also recognize that there are many external challenges, including time constraints and class size that make such tasks all the more difficult. The scaffold that the authors designed instructs students to associate key questions which particular sections of the scientific paper or laboratory report. The questions are intended to align with specific writing goals. With use, the students learn to ask and answer questions for themselves as they advance along the scaffold. This is a practical strategy that includes frequent feedback, web-based self-help modules and mini-conferences with the instructor held during laboratory sessions. The results of this approach, as reported by the authors, are significant. After working with the directed self-inquiry scaffold for one

semester, 77% of students were able to submit a scientific paper that was deemed “accomplished,” or even “exemplary” (Deiner, Newsome & Samaroo, 2012, p. 1513).

In addition to scaffolding as a means to encourage students to ask and answer questions for themselves as they work through a process, rubrics can help frame the important components of a scientific question or a scientific paper for a student. On the other hand, the problem with rubrics is that they can be too detailed and cumbersome for the student to follow and benefit from. In an article entitled *Using a Laboratory Conclusion Rubric*, Sandra Rutherford (2007) notes that specific rubrics for inquiry-based laboratory conclusions are scant and somewhat limited. She maintains that the integration of reading, writing and inquiry-based investigations is essential in teaching students the nature of science (Rutherford, 2007). She suggests a free Website called RubiStar (<http://rubistar.4teachers.org/index.php>) to assist teachers in creating specific rubrics for their own instructional purposes. Rutherford also offers a design that scores components of a laboratory conclusion as “emerging, developing, proficient or exemplary” (Rutherford, 2007, p. 11).

Other researchers have found that classifying student questions in order to determine what kinds of questions their students tend to ask helps in designing interventions to improve the overall quality of questioning. Researchers Gili Marbach-Ad and Phillip Sokolove (2002) designed a taxonomy specific to an introductory college biology class. The authors state that “in order to encourage desirable questions from students we first had to build a semi-hierarchical taxonomy, which in turn has allowed us to classify students’ questions” (p. 855). Their taxonomy includes eight categories of student questions. For example,

- Category 0: Questions that do make logical or grammatical sense.
- Category 1a: Questions about simple definitions or concepts.
- Category 1b: Questions about a more complex definition or concept.
- Category 2: Ethical, moral or philosophical questions.
- Category 3: Questions based on functional or evolutionary explanation.
- Category 4: Questions that require more information than is available in textbooks.
- Category 5: Questions resulting from extended thought or synthesis of prior knowledge.
- Category 6: Questions that contain some aspect of a research hypothesis.

The authors note that questions in categories 5 and 6 are considered to be the best type of questions for scientific investigation, while category 4 questions represent the type of curiosity that can ultimately drive the scientific process. This taxonomy could be modified for the secondary school level.

Finally there is the question of how a student's understanding of the nature of science influences how they appropriate new knowledge and ultimately perhaps, what questions they ask of it. Researchers Nancy Songer and Marcia Linn (1991) did a study with 153 eighth graders from a physical science course over 12 weeks, to examine the relationship between their views of science and the acquisition of integrated understanding. They define knowledge integration as the ability to organize information into broader categories and into more widely applicable ideas. The authors were able to characterize the students' views of science as being static, mixed or dynamic. Those who viewed science as being a static endeavor preferred to memorize information and follow prescribed models, while those who viewed science as being a dynamic process looked to gain an understanding of scientific principles and how they are related.

This study demonstrated that only about 15% of students viewed science as being dynamic, while 21% considered science a static study. The remaining 63% held mixed views. The authors conclude that those students who regard science from a static perspective are unlikely to examine the processes behind the information generated from it. However those with a dynamic view of science acquired a more integrated understanding of the topics in their physical science class. These students were more likely to make predictions and explain the reasoning behind them. The authors hypothesize that those students who can integrate and contextualize their understanding of scientific phenomena “may gain a more effective view of themselves as science learners and feel empowered to influence the direction science takes” (p. 766).

METHODOLOGY

My principle focus was on teaching and assisting students in writing testable scientific questions, ultimately for their own independent research. In addition, I am interested in improving student understanding about the nature of science (NOS) and observing how this framework can be used to improve the overall quality of scientific inquiry. Since my students have had limited experience in crafting their own scientific questions, I have utilized teaching modules, assessments tasks with rubric-scored feedback and online data sets to facilitate student learning. Graves and Rutherford (2012) point out the difficulty of promoting scientific inquiry without adequate time to visit sites. There is also the problem of limited materials and lack of access to specialized equipment. The authors suggest using any number of free online data sets provided by state and federally funded studies to guide students in the formulation of testable scientific questions. I found both their research and suggestion compelling, so I

formulated a series of online data sets that include a variety of scientific topics of interest to my students (see sample in Appendix I).

Since writing an exemplar testable question is challenging, students will require multiple opportunities for success. I am also interested in monitoring the confidence level of the students, not only with regard to their ability to write a high quality research question, but with their overall grasp of the scientific inquiry process and what it takes to be a successful researcher.

Participants

The participants for this study consist of 10 public high school seniors. There are 6 females and 4 males. They are age 17-18 and come from suburban middle class families. There are no minority groups represented among this group. These students comprise one section of an independent study science research class. This course is offered to select high school seniors who are currently enrolled in an honors level or an AP (advanced placement) science class. The class only meets 3 days per week for 45 minute sessions, so students must schedule additional time to work on their projects. The students in this class are all successful science students, as indicated by their cumulative grade point averages, and are interested in pursuing science study on the college level. Several of them have already been accepted into prestigious universities including Princeton, Brown, Cornell and the U.S. Air Force Academy.

Intervention

Since the independent science research course is select, I unfortunately have only 10 students to work with. As a result, there is no control group to use for comparison purposes. Instead, I am relying on progress over time as all students are involved in all

aspects of the intervention. I have taught this class for a few years however and I have many samples of work from previous students on this aspect of the course. This has provided me with a suitable baseline for comparison and for setting realistic expectations. The most desired outcome of this intervention is for the current class of students, post-intervention, to be able to write high quality, testable research questions, with fewer revisions, in a shorter period of time. To this end, I have divided my intervention into 4 phases. The research methodology for this project received an exemption by Montana State University's Institutional Review Board, and compliance for working with human subjects was maintained. My data collection instruments are summarized in Table 1.

Table 1
Triangulation Matrix

Focus Questions	Data Source 1	Data Source 2	Data Source 3
<p><i>Primary Question:</i></p> <p>Does practice and feedback with online data sets impact a students' ability to write a high quality and testable scientific research questions for investigation?</p>	<p>Responsive Task #1: Using Data Sets to Generate a Scientific Research Question</p>	<p>Rubric Scoring Assessment Task #1: Writing a Scientific Question (Topical)</p>	<p>Rubric Scoring Assessment Task #2: Writing a Scientific Question (Data Set)</p>
<p><i>Secondary Question:</i></p> <p>Is the students' understanding of the Nature of Science (NOS) impacted as they learn to write good scientific questions and engage in independent research?</p>	<p>Nature of Science Pre and Post Quiz</p>	<p>Scientific Inquiry Questionnaire</p>	<p>Student Feedback on Instruction Modules</p>
<p><i>Secondary Question:</i></p> <p>Will student confidence levels in undertaking scientific research and in writing scientific questions be impacted?</p>	<p>Student Confidence Survey Pre and Post</p>	<p>Scientific Inquiry Questionnaire Revisions</p>	<p>Student Interviews: Post Intervention</p>

Phase I: Pre-Assessments

During the last week in January 2014, each student completed a 25 question quiz on the nature of science (see Appendix A). The quiz includes basic concepts such as the difference between a scientific law versus a theory, a dependent versus an independent variable, and the use of data. The students also completed a science research confidence survey (see sample in Appendix B). This Likert-style survey is designed to assess the student's confidence levels in scientific knowledge and understanding, scientific experimentation skill, and abilities in innovative scientific thinking. Both of these instruments are scored and tallied respectively.

The students also completed a scientific inquiry questionnaire (see sample in Appendix C). The purpose of this instrument is to gauge how the students currently understand the processes of how scientific knowledge is developed, accepted and applied.

Phase II: Teaching Modules

Upon completion of phase I, the students participated in a series of short teaching modules. The instruction included PowerPoint presentations and small group discussions. Here students were able to learn about and discuss the characteristics of a good scientific question. They were also afforded opportunities to view samples of testable scientific questions and practice with short responsive tasks. The instruction centered around 3 main components:

- a) Elements of scientific investigation and the nature of science.
- b) Basic assumptions and limitations of scientific inquiry.
- c) Qualities and examples of a good scientific question.

At the end of the teaching modules, each student completed a Scientific Research Module Feedback Form (see Appendix D). Here they were able to rate the effectiveness of the teaching modules and provide examples of how the topics were helpful to them. After this each student was instructed to select one topic from a list of potential science projects provided at the beginning of the course, and complete Assessment Task #1: Scientific Research (see sample in Appendix E). The task requires the students to do the following:

- a) State a testable question
- b) Define specific variables that can be tested.
- c) State how changes within the experiment might be measured.
- d) Predict one likely outcome resulting from experimentation.
- e) Cite references used.

Each task was then scored using a rubric (see Appendix G). I briefly met with each student and reviewed the scoring with them and discussed any modifications that may be indicated. During this time, I was able informally interview the students regarding the process and how they understood and approached the task.

Phase III: Online Data Sets

Upon completion of phase II, the students were instructed in the usage of online data sets in the completion of Assessment Task #2 (see Appendix I). I compiled and modified a series of appropriate data sets using two sources. The Data and Story Library (DASL) is compiled by Cornell University and is intended solely for educational use by instructors for the preparation of teaching materials and assessment tools, or by students engaging in individual study. In addition, I made use of the Journal of Statistics

Education archives (JSE, 2013). The JSE archives contain data sets that may be freely used in teaching without contacting the author or JSE for permission.

Each student was instructed to review the selected data set and complete Assessment Task #2: Writing a Scientific Research Question (see sample in Appendix F). The task is similar to Assessment Task #1; however it requires more application and specificity. In this task, the students were instructed to do the following:

- a) Write one testable scientific question.
- b) Clearly state the variables that can be tested.
- c) Specify the parameters of the investigation.
- d) Hypothesize a cause and effect relationship between variables.
- e) Cite references used.

Each part of the task was scored using a teacher constructed rubric (see Appendix G). Upon completion, I again met with each student and reviewed the scoring and discussed any modifications that may be needed.

Phase IV: Post Assessment

The same pre-assessment instruments used in Phase I was repeated in the post-assessment of Phase IV. Each student repeated the nature of science quiz; however the questions were randomized and appeared in a different order. The students were not informed ahead of time that they would be taking the quiz. Likewise, each student repeated the confidence survey on science research without reference to the choices on the first attempt. The scientific inquiry questionnaire that the students completed in Phase I was then returned to them. Each student had the opportunity to review what they had previously written and make any additions or corrections to their earlier responses. At

that time, I selected 4 students (two male and two female) for a semi-structured interview (see Appendix H). This provided me with qualitative data on the thought processes of the students, what was most difficult for them and what aspects of the process (intervention) were most helpful to them in writing improved scientific questions.

DATA AND ANALYSIS

Upon completion of my intervention, I began the process of organizing and evaluating the collected data. Whenever possible, I chose a suitable statistical method to analyze the data according to accepted scientific practices. These methodologies of organization, evaluation and application of statistic test assisted me greatly in drawing reasonable conclusions that are both quantitative and inductive in nature. Likewise I carefully considered how to present the results in ways that are concise, clear and that accurately convey their import. For ease of reading, I discuss the data in the same order presented in the methodology section.

Nature of Science (NOS) Assessment

In most of their previous science courses, my students had not been given implicit instruction on the nature of science. Instead these principles and ideas were interspersed throughout the high school science curriculum. Before I began my intervention, I wanted to gain some insight into how the students understood science as a discipline, process and enterprise and how that understanding might evolve. Since they are all honor science students, I suspected that they would have an overall higher comprehension on the nature of science than those of their peers enrolled in standard or college preparatory science classes. With that in mind, I gave them an unannounced pre-quiz that included 25 multiple choice questions on various aspects of the nature of science. At about the same

time, I gathered 10 random volunteers who also took the quiz. All of these volunteers were seniors in a college preparatory science class and none had taken an honors level science course. Their scores served as a type of baseline for comparison.

Table 2 shows the comparative matched scores (high to low) between random students in a senior non-honors class (group Z) and those students in my honors class (group X). It is therefore apparent from the onset that my students are starting at a higher level in their knowledge of the nature of science.

Table 2
Comparison of Pre-Quiz Scores on the Nature of Science (N=10)

Student #	1	2	3	4	5	6	7	8	9	10
Pre-Quiz Scores % (Z)	84	76	72	72	68	68	60	64	64	54
Pre-Quiz Scores % (X)	96	92	88	84	84	80	80	76	72	72

When I ran a Wilcoxin Rank Sum Test on the matched scores for the two groups, it returned a p-value of 0.002995, which is significantly below the generally accepted alpha level of 0.5. If the H_0 is that there is no difference between these two sets of students, then this null hypothesis can be rejected. This affirms the notion that these scores likely represent two distinct distributions.

Upon completion of phase III, my students were again given the nature of science quiz and all students showed improvement in their scores. A summary of these scores are shown in Table 3.

Table 3
Comparison of Pre-Quiz and Post-Quiz Scores on NOS (N=10)

Student #	PreQuiz Score (Raw)	PreQuiz Score (%)	PostQuiz Score (Raw)	PostQuiz Score (%)	Net Gain (%)	Normalized Gain (%)
1	24	96	25	100	4	1.3
2	23	92	25	100	8	2.6
3	22	88	25	100	12	3.8
4	21	84	25	100	16	5.1
5	21	84	24	96	12	3.8
6	20	80	24	96	16	6.2
7	20	80	23	92	12	3.8
8	19	76	24	96	20	6.2
9	18	72	23	88	16	6.1
10	18	72	25	100	28	8.5
Average:	20.6	82.4	23.3	96.8	14.4	4.7
Standard Deviation:	2.011	8.044	0.8232	4.131	-	-

Although the average percent increase between the pre and post quiz scores was 14.4%, the normalized gain was 4.7%. Considering the relatively high level that my students started from, this increase is quite satisfactory. The standard deviation among the pre and post scores was just about cut in half. This indicates a tightening of scores in relation to the mean of the distribution. This can be more easily viewed in Figure 1.

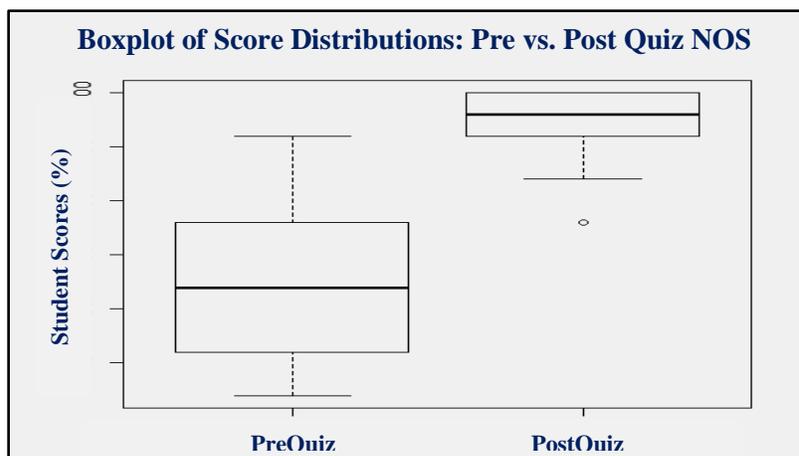


Figure 1. Score Distributions of Nature of Science Quiz, (N=10).

Finally when all of the scores are viewed together, including the non-honors baseline scores along with the pre and post quiz scores of my target honors group, the gains that my students made are given a better and clearer context.

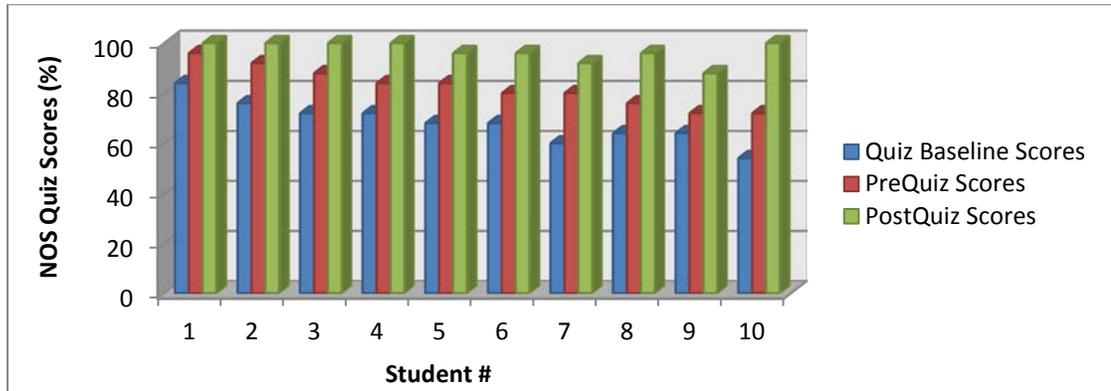


Figure 2. Comparison of NOS Baseline Scores with Pre and Post Quiz Results, ($N=10$).

Student Confidence Assessment

Also as part of the pre-assessment, each student completed a Likert-style survey to gauge their confidence in three areas of scientific research. These areas included confidence in science knowledge and application, confidence in scientific skill and confidence in scientific thinking and innovation. Each of the 10 students responded to 23 positive statements for a total of 230 responses. I anticipated that due to their positive and successful experiences with science, the final tallies would be skewed towards agreement or strong agreement with regard to the statements. This indeed was the case. While there were some who indicated a “not sure” or “disagree” response, no student selected “strongly disagree” for any of the statements. This was true for the pre and post intervention use of this instrument. Therefore I left this choice out of the final scoring.

It was interesting to note the differences between the pre and post survey tallies. Overall there was a shift away from “not sure” to “strongly agree” and “agree” as

indicated in the table below. I ran a Pearson's chi-squared test for independence to determine if the distribution of responses between the pre and post survey were different. The difference in the Pre- and Post- surveys was significant, $t(3) = 10.304$, $p = 0.01615$. Since this is below a reasonable alpha level of 0.5, I can conclude that the differences are not independent, but more likely dependent. The frequencies of post-intervention responses are significantly different from the pre-treatment responses. A summary of these responses can be seen in Table 4.

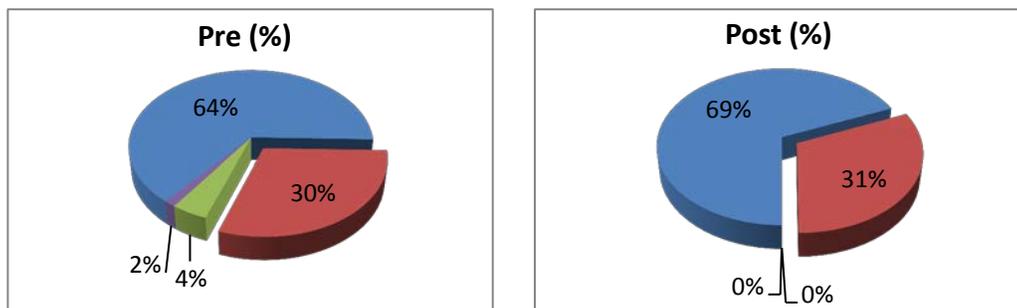
Table 4
A Comparison of Pre and Post Responses on the Scientific Research Survey (N=230)

Selections:	Strongly Agree	Agree	Not Sure	Disagree
Pre-Survey	128	78	17	7
Post-Survey	134	85	3	8
Pre-Survey (%)	55.7	33.9	7.4	3
Post-Survey (%)	58.2	37.0	1.3	3.5

While there is an overall indication that the intervention did affect confidence levels towards the positive end of the scale, a closer look at the survey categories do reveal some surprises. The category that deals with science knowledge and application, were statistically significant. The small percentage of responses in the “not sure” and “disagree” columns present in the pre-survey disappeared in the post-survey. However in the category that gauges scientific skill, there was actually a slight increase in the percentage of “disagree” responses. This shift seems to center around two particular statements; “I am able to organize extended science projects and manage time well,” and “I think that I have the basic skills to be a research scientist.”

It appears that over time and with exposure to empirical study, some students realized that while they have good scientific knowledge, they were not experienced in conducting an independent study. As a result, a few chose to “correct the record” on their post-survey responses. Likewise in the category of scientific thinking and innovation, a small percentage of responses shifted to the right of the scale. These changes also centered around two statements; “I am a good observer and can often notice things that others do not,” and “I have the ability to think creatively and propose innovative solutions to scientific problems.” By the end of the intervention, some students realized that perhaps they overestimated their ability, and thus their confidence in specific areas pertaining to scientific research. A summary of the categorical responses is seen in Figure 3 below.

Scientific Research Survey Results



Confidence in Scientific Knowledge and Application



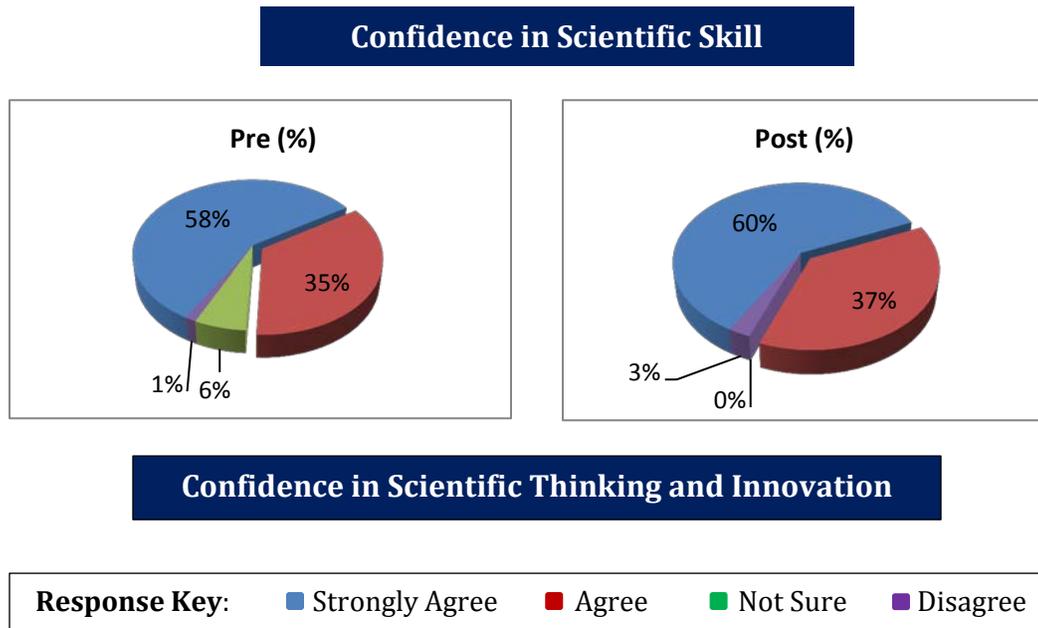


Figure 3. Percent of Student Responses: Pre vs. Post Intervention, (N=230).

Teaching Modules

During phase II, I was able to engage students in a series of teaching modules. There I was able to informally evaluate their progress on short responsive tasks and offer feedback before proceeding to the scored assessment tasks. Upon completion of the teaching modules, students were asked to fill out a short feedback form to rate the effectiveness of the instructional modules and to provide any examples of how the modules may have changed their understanding. In the rating, 8 out of 10 students found the teaching modules “very helpful,” while 2 students indicated “helpful.” There were also some notable comments made by the students. With regard to the nature of science, one student was surprised to discover that “most scientific knowledge is based on modification of ideas rather than outright rejection of old data.” Another stated that she never thought that scientific bias could be related to “...the choice of what data to consider in the first place.” When evaluating the essential components of a science

investigation, one student responded that “I can now explain the difference between a control and a constant.” Finally one student realized that “...a good question has the potential to suggest new directions for research.”

It became evident to me at that time that the students were responding well to viewing even simple data sets before formulating an emerging scientific question. During a group discussion one student commented that “...it’s easier to think about the possibilities when you have some data right in front of you.” As will be discussed later, this viewpoint was also expressed during the post-intervention student interviews. A sample of an emerging question formulated by a student is shown in Figure 4.

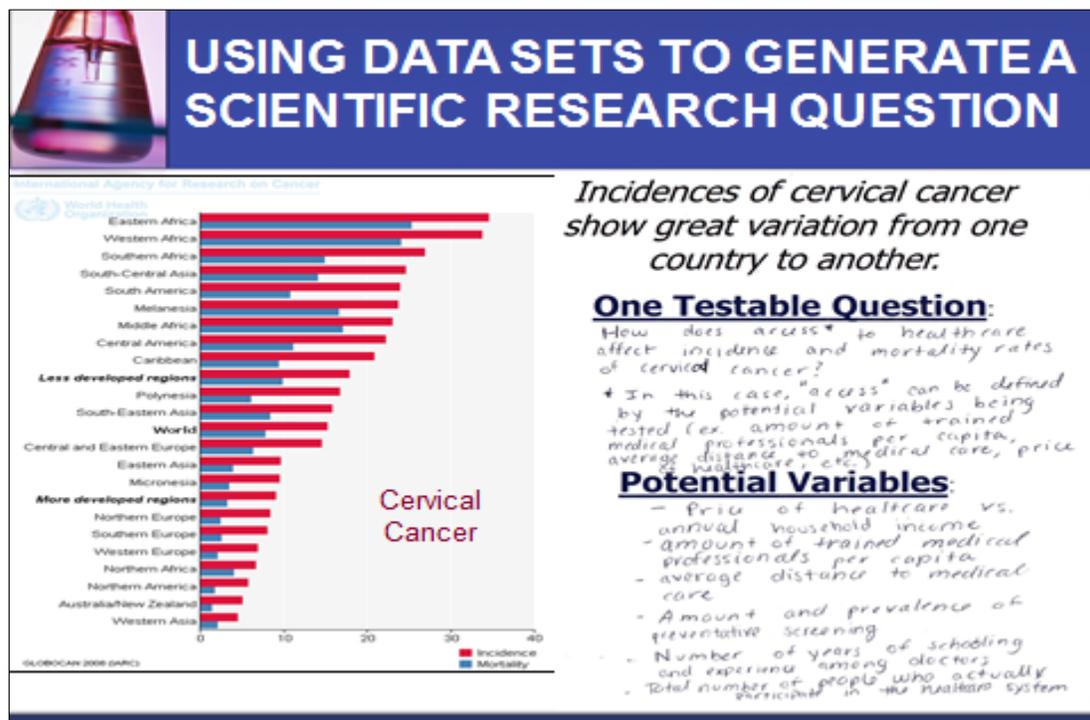


Figure 4. Sample of Student Response to a Data Set.

Scored Assessment Task

In their first scored assessment task, the students selected a science topic from an extensive list. The students were given instructions and had to complete the task by the next class period, which was two days later. Four out of the 10 students finished the task by the end of the 45 minute period while the remaining students turned in their work the following class period. I immediately scored the tasks and returned them to each student with written feedback. At that time several students asked questions concerning their scores and looked to make corrections. I noted that the greatest overall strength of the effort was in including appropriate references and identifying a possible cause and effect relationship. The areas that needed improvement were on clearly identifying measurable variables and defining the parameters of the proposed experiment. With only one exception at this early stage, all of the questions formulated by the students were scientifically testable.

In the second scored assessment task, students selected a prepared data set sheet from a variety of science topics. They used the given data and feedback from the previous task to again formulate a testable scientific research question with measurable variables, clearly defined parameters and possible cause and effect relationships among the defined variables. They were encouraged to further research their topic before completing the task and turning it in on the next class period. On this occasion, all of the students took full advantage of the time given and no one turned in their assignment early. When this task was scored, all 10 students demonstrated an overall improvement

in their scores. The average point gain on the second task was 4.2, while the maximum number of points that could be earned is 20. This can be seen in Figure 5.

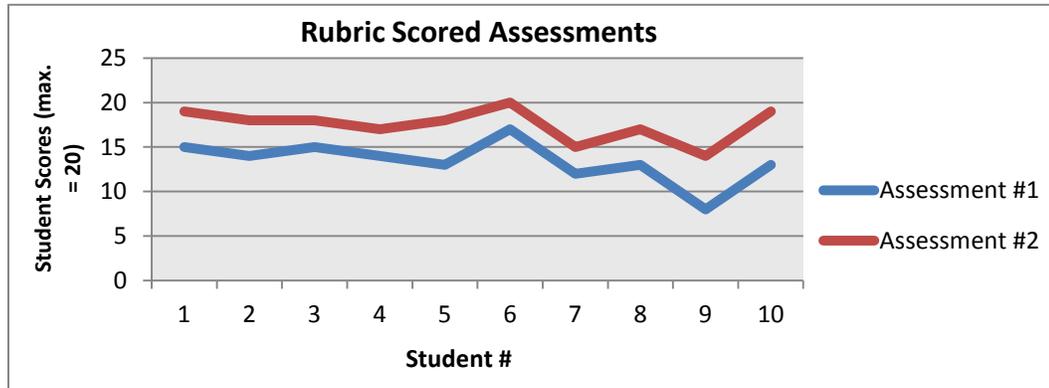


Figure 5. A Comparison of Scores on Assessment Tasks, ($N=10$).

By the end of the second task, all students showed proficiency in formulating a testable scientific question from their respective data sets. Three students in particular crafted scientific questions that were deemed exemplary (with assessed scores of 19, 19, and 20). Improvement with the identification of measurable variables and defining investigative parameters was also noted. Subsequently the returned scores generated a lot of discussion and expressed satisfaction on the part of the students. A more complete view and comparison of the assessment task scores is offered in Table 5.

I performed a two tailed, dependent t-test to determine the t-distribution between the two assessment tasks. The difference between assessment task #1 and assessment task #2 is significant, $t(9) = -11.699$, $p < 0.000001$. With an alpha level of 0.5, the calculated t-stat far exceeds the associated critical value of ± 2.262 . This indicates that

the improvement of scores is statistically significant and may disclose that the treatment did affect the dependent variable of student scores.

Table 5

A Comparison of Scores on Assessment Task #1 vs. Assessment Task #2, (N=10)

Note: Highest possible score on each assessment element is 4 points. The maximum score

Student #	1	2	3	4	5	6	7	8	9	10
Assessment Task #1 (Topical) Total Score	15	14	15	14	13	17	12	13	8	13
Testable Question	3	3	3	2	2	3	2	2	1	2
Measurable Variables	3	3	2	2	2	3	2	2	2	3
Investigative Parameters	2	2	3	3	2	4	2	2	1	2
Cause and Effect	3	3	3	3	4	4	3	3	2	3
References	4	3	4	4	3	3	3	4	2	3
Assessment Task #2 (Data Set) Total Score	19	18	18	17	18	20	16	17	14	19
Testable Question	4	4	3	3	3	4	3	3	3	4
Measurable Variables	4	4	3	3	3	4	3	3	2	4
Investigative Parameters	3	3	4	3	4	4	3	3	2	3
Cause and Effect	4	3	4	4	4	4	4	4	3	4
References	4	4	4	4	4	4	3	4	4	4
Change (pts.)	+4	+4	+3	+3	+5	+3	+4	+4	+6	+6
Normalized Gain (%)	4.7	4.7	3.5	3.5	5.7	3.6	4.5	4.6	6.5	6.9

per assessment is 20 points.

At this point, it seemed useful to determine if there was any correlation between the assessment scores and the scores on the nature of science (NOS) quiz. I selected the post-quiz scores and the scores of assessment task #2 for all 10 students. When I ran a Pearson's correlation calculation, it returned a positive correlation coefficient of $r = 0.7412154$. Since a correlation coefficient that exceeds 0.7 indicates a significant relationship, there is evidence to infer that there is a relatively strong connection between these two sets of scores.

Scientific Inquiry Questionnaire

As part of the pre-assessment in phase I, all students completed a Scientific Inquiry Questionnaire. In the post-assessment of phase IV, these instruments were returned to the students and they were asked to make any additions or modifications to their earlier responses. All of the students took the opportunity to both amend and add to their previous responses. A few commented that they were surprised to read what they had written some several weeks before. As I reviewed the questionnaire responses and revisions, a few patterns emerged.

When asked if independent scientists could ask the same question, use the same methodology and come to different conclusions, 6 out of 10 students initially said it would only happen if experimental errors were made. However upon post-intervention reflection, 5 of those 6 students added that unchecked bias may affect how data is interpreted. Regarding the scientific method being the only pathway in scientific investigations, 5 out of 10 students altered their initial, more rigid view into one more dynamic. In their new comments, students generally expressed that science is not a matter of just following a set of steps, but is instead an approach that combines

knowledge, creativity, imagination and sometimes luck. Lastly, when asked if “data” are the same as, or different from “evidence,” three of the students changed their comments. They moved from, yes they are the same; to no they are not the same, but are related. One student summed it up this way, “data [sic] is raw numerical or subjective observation, while the proper analysis of data provides evidence.”

Student Interviews

In the final part of phase IV, I was able to conduct semi-structured student interviews in order to get a sense of how the intervention may have personally impacted their understanding on the nature of science and writing questions for scientific inquiry. I was also interested in how this process fit into their overall experience as science students. When asked how they decide if a research topic is of applicable interest to them, all 4 of the students interviewed indicated that it would first depend upon their previous knowledge base. If they felt they were familiar with a topic and had some prior experience with it, they were more likely to pursue a particular aspect of that topic. As a secondary consideration, 3 out of the 4 students said that time and available resources also had an impact as to whether or not a topic is applicable to them.

Discovering what the students found to be the most difficult or challenging part in writing a good scientific question was also addressed in the interviews. The answers that the students gave touched on a variety of issues; however a common theme throughout was the struggle to clearly define measurable variables and set specific parameters for experimentation. The students indicated that they had the tendency to be too general and too broad in their focus. One student had a particularly insightful comment. He said that his early attempts read more like “lab titles than actual questions.” Another student

indicated that it was probably better to be very narrow and expand later rather than the other way around.

In terms of the scientific method, the consensus was that the students were not really consciously considering it when attempting to formulate a scientific question. Instead they felt that the emphasis was on whether or not they could get adequate data. Rather than articulate an actual hypothesis, the students expressed a preference for “following the data.” In other words, it seems that their overall approach is more of an “if...then” proposition; If I do this, then what will happen? This type of scientific inquisitiveness is something to encourage.

I was curious whether the students had experiences in their previous science classes with writing their own questions and designing their own corresponding experiments. When asked this, all 4 of the students had some difficulty recalling such experiences. One student remembered that as a freshman he was able to select among a series of defined variables and outline his own experimental design to test these variables. Another student indicated that she was able to choose from a selection of topics for a laboratory project in AP biology. One student countered that she remembers having more choice in her art classes than she has had in the science laboratory. While none of the students interviewed seemed dismayed that they have had very limited experience in writing their own scientific question for investigation, they easily acknowledged it.

Finally, I asked the students what aspects of the learning cycles that we just completed did they find most helpful and why? The first student interviewed thought that the teaching module on the nature of science was both interesting and helpful. She commented that this was the first time that she was specifically asked to craft her own

definition of science and it “really made me think.” She also noted that the module and subsequent discussions it generated caused her to rethink how the scientific method is used. In short, she now considers the scientific method a more fluid description of the character of science rather than a step-wise process. The second student interviewed felt that the teaching module that provided samples of scientific questions and discussed the criteria of a testable question was most helpful to him. He felt that the more opportunity he got to read and evaluate “good questions,” the easier it was for him to formulate a kind of mental model to refer back to when writing his own questions. Both the third and fourth students interviewed pointed to the short responsive tasks given after each module as being useful. They preferred immediate practice and feedback and sensed that this helped them most in undertaking the scored assessment tasks that followed.

What was particularly significant to me was that all 4 students said that they found the use of online data sets to be valuable in helping them write better questions and define the scope of an investigation. Since a major premise in this capstone project is that online data sets can be effective in guiding students in the formulation of testable scientific questions, this was an important insight. I decided therefore to make this question a topic of discussion for the entire group. After the interviews, I concluded the post-intervention phase with an informal dialog on the value of using data sets. All 10 of the students agreed that the use of data sets was one of the most helpful aspects of the overall process. This seemed consistent with notion that the students tend to be data driven. A few of the students shared that it might be a good idea to do some small scale experiments first. In this way preliminary data can be reviewed to determine if the project is feasible. It was explained to the students outright why I set up the timeline of

the intervention the way I did. However the general consensus was that these learning cycles should be done earlier in the course and that more time should be afforded it.

INTERPRETATION AND CONCLUSION

The principle and over-arching goal of this capstone project was to teach and assist students in writing high quality and testable scientific research questions, ultimately for independent inquiry. To this end, I was able to employ a number of modalities and collect a variety of qualitative and quantitative data to examine both the feasibility and efficacy of this goal. In the process, I was also able to address a few secondary questions and infer how they may be connected to my primary goal. As I interpret the data and fashion some conclusions, I am mindful that I must take care not to over extrapolate from the data nor make claims that do not have sufficient evidence to support it. As a teacher, I designed the methodology and assessment tools specific to my group of students and to my particular teaching situation. With only 10 students involved, it is difficult to document patterns and draw definitive conclusions. Ultimately what may be deemed a successful endeavor is for me and my students to determine.

My primary focus question was: Does practice and feedback with online data sets impact a students' ability to write a high quality and testable scientific research question for investigation? The data indicate that this approach does indeed have a positive effect. I would first point to the observation that all 10 students involved, either by way of interview, written feedback, or class dialog, indicated that using data sets helped them identify appropriate variables and better visualize the workable parameters for investigation. They expressed a preference for this method over the selection of a generalized topic. Looking at even preliminary data helped them overcome their lack of

personal experience with independent scientific inquiry and made it “...easier to think about the possibilities...” When the students selected a science topic by which to formulate their questions (in the first scored assessment task), I found that they underestimated the challenge. Since they had little frame of reference and no data to consider, their early attempts lacked specificity and clarity, especially with regard to defining measurable variables and investigative parameters. With feedback they began to understand the importance of initial research and the fact that some preliminary experimentation may be necessary to help adjust and refine their research questions. As is often the case, a good scientific question is dynamic, evolving and subject to modification.

A comparison of the scores between the two assessment tasks demonstrates a meaningful improvement (Figure 5; $N=10$). The average student score increased by 4.2 points and the average normalized gain was 4.8% (Table 5; $N=10$). It was noted in the data analysis that a dependent t-test of these scores returned a p-value with a magnitude of 10^{-7} , suggesting that the probability that these sets of scores are independent of one another is virtually zero. In addition, the two elements of greatest weakness identified in Task #1 (measurable variables and investigative parameters), showed improvement in Task #2. In fact, all students advanced their scores with at least one of these elements, while 7 out of 10 demonstrated an increase with both (Table 5; $N=10$). I therefore think that it is reasonable to surmise that practice and feedback with data sets does improve my students' ability to write a higher quality and testable scientific research question for investigation.

A secondary question for consideration is whether my students' understanding of the Nature of Science (NOS) is impacted as they learn to write good scientific questions and engage in independent research. A review of the pre and post intervention quiz scores on the Nature of Science shows an average gain of 14.4% and an average normalized gain of 4.7% (Table 3; $N = 10$). What was especially interesting is the relatively strong correlation coefficient ($r = 0.7412154$) between the improved scores on the Nature of Science post-quiz and the scores on the data set assessment, Task #2. While this does not establish a cause and effect relationship, it does suggest a connection between the two. Further investigation into the nature of the relationship might present an interesting area of pursuit for the future.

The revisions and additional comments made by the students on the Scientific Inquiry Questionnaire also provide an indication of change with regard to their views on the nature of science. Particularly notable is the shift made by several students away from a more static view of the scientific method towards one that is more expansive and integrated. Likewise, the students responded to concepts such as peer review and bias by clarifying the distinctions between data and evidence and by acknowledging that some scientific investigations are relational and descriptive rather than empirical in type. When asked on the teaching module feedback form to provide an illustration of how their thinking with regard to the nature of science has changed, one student stated that "science cannot prove anything with absoluteness, so some uncertainty will always remain." I think that there is sufficient evidence to suggest that the students' grasp on the nature of science and scientific inquiry developed in a direction that is more consistent with both

the historical and current practice of what scientists do and how knowledge is generated within the various scientific communities (Schwartz, Lederman G., Lederman J., 2008).

The final question of focus deals with student confidence levels. I wanted an indication as to how the students assessed themselves in the areas of scientific knowledge, scientific skill and scientific innovation, both before and after the intervention. As mentioned in the data analysis, I suspected that at the onset my students would lean towards “agreement” in their initial responses, based on both their positive view and affirming experiences in science. While the changes between the pre and post tallies of the confidence surveys may at first appear subtle, I believe that the differences might reflect a sincere reality check on the part of some students (Table 4; $N = 230$). Having had substantial teaching, practice and investigative experience with independent scientific inquiry over the last few months, the students came to realize and appreciate the unique challenges such an endeavor necessitates.

There was little change reflected in their confidence levels in the area of scientific knowledge and application. They are, and remain, assured in this area. However, 3 out of 10 students reflected a slightly lower level of confidence at the end of the intervention with regard to their ability to manage extended projects and maintain accurate and detailed records in the laboratory. One student in particular appeared to reexamine her suitability to be a research scientist. Based on the chi-squared test results of the confidence survey (p value = 0.01615), there seems to be some evidence that the differences noted in the pre versus post survey results reflect a dependence predicated upon the intervention. While the exact mechanism of this change is unknown, I would suggest that this shift may reflect a greater appreciation on the part of some of my

students for the rigor of authentic inquiry. While overall confidence levels did show an increase, the cautiousness of the post intervention responses show some mitigation on the part of students. As their teacher, I think that is a good thing.

It has not gone without notice that a substantial portion of my results are consistent with studies that I included in the literature review. Several researchers have demonstrated that learning scientific content and engaging in authentic inquiry need not be mutually exclusive endeavors. Instead, scientific questions that are centered about student interest show great potential for stimulating learning and can be further fashioned into testable research questions (Chin & Osborne, 2008; Cuccio-Schirripa & Steiner, 2004; Keys, 1998; Windschitl, 2008). In this project, I have found that my students are quick to research topics that are meaningful to them and are eager to learn how to develop their own problems of investigation.

Likewise several studies show that a constructivist approach which includes some type of scaffolding or rubric guided self-inquiry tasks along with frequent feedback will enhance a students' ability to write a clear and concise question. In addition, modeling techniques can help students to understand the important qualities of a good question (Deiner, Newsome & Samaroo, 2012; Marbach-Ad & Sokolove, 2000). These are certainly things that I kept in mind as I developed my methodology of intervention. I discovered that my students responded well to the use of teaching modules and focused assessment tasks. With feedback and even limited practice, my students were able to improve the quality of their questions and reflect a deeper and more accurate understanding of the nature of science and scientific inquiry.

VALUE

For the past two decades, it is clear that the literature consistently calls for an increased emphasis on inquiry based science and authentic investigations into the nature of science. In 2010, the National Academy of Sciences, the American Association for the Advancement of Science, and the National Science Teachers Association initiated a process to develop what has come to be known as the Next Generation Science Standard (NGSS). The goal of these science standards is to increase and stimulate interest in science, technology, engineering and mathematics (STEM), so that students will develop strong science based skills and inquiry based problem solving for our future national needs (NGSS, 2013). New Jersey is one of several states involved in this endeavor and may at some future point, adopt these standards.

In light of this, I have found it surprising that there still remains a somewhat disproportionate emphasis on traditional lecture designs and rigid laboratory exercises in many science classrooms today. In discussion with many of my colleagues it seems that there is increased state and administrative pressure to add more material to the courses of study without additional time to engage students in scientific self-inquiry, experimentation and argumentation. Delving into the nature of science and engaging in authentic scientific inquiry requires a fair amount of time, smaller class sizes and a degree of academic freedom on the part of administrators, teachers and students. Since there is ample research suggesting that such an approach is effective and advantageous in developing critical scientific skills, it is unfortunate that the institutional structures and paradigms still lag behind.

In one sense, this capstone project has afforded me an opportunity to consider how to best challenge and engage my students in a meaningful and genuine way; attempting to reflect what professional actually scientists do. Now that I have been through the process once, I have a sense of continuity and ample data to consider for the future. I am satisfied with the progress that I have observed with my students and am persuaded that scientific data sets can be used effectively to teach students how to write interesting, quality research questions for scientific investigation. Therefore, I think that it would certainly be worthwhile to integrate this interventional process with a new group of students, preferably earlier in the academic year.

What I most appreciated about my students throughout this capstone project was their willingness to alter both their views and practices with regard to scientific processes. Since much of their academic success has been due to a disciplined and precise adherence to the curriculum, test taking strategies and the pedagogy of their teachers, it is a challenge for them to write their own questions of inquiry and manage their own laboratory work. I think that it is important to challenge their assumptions and help them to appreciate that scientific methods are diverse, intuitive and sometimes serendipitous. I indicated in the methodology section that the most desired outcome of this intervention is for my students, post-intervention, to be able to write high quality, testable research questions, with fewer revisions, in a shorter period of time. Quite honestly I cannot state with any real certainty that this has been the case. The value of this project is that it can be continually modified, re-implemented and re-evaluated for desired outcomes.

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APPENDICES

APPENDIX A

THE NATURE OF SCIENCE PRE AND POST QUIZ

The Nature of Science Pre/Post Quiz

1. Which of the following questions is legitimate for science to consider?
 - a) When is religion better than philosophy?
 - b) Is competition good or bad?
 - c) How many seals can a killer whale consume per day?
 - d) Which type of orchid flower is most attractive?

2. An experiment is a specific test of a _____.
 - a) Variable
 - b) Control
 - c) Theory
 - d) Hypothesis

3. A (n)_____ is a prediction or explanation that can be tested by experimentation.
 - a) Theory
 - b) Scientific law
 - c) Method
 - d) Hypothesis

4. How does a scientist confirm data?
 - a) By consulting with an expert in the field
 - b) By checking calculations for error
 - c) By observing that repeating the experiments yields similar results
 - d) By making sure that technicians follow procedures properly

5. _____ is a process that uses observations and experimentation to gain knowledge about the regularities in nature.
 - a) Graphing
 - b) Hypothesizing
 - c) Science
 - d) Measurement

6. In an experiment, what is affected by the independent variable?
 - a) Dependent variable
 - b) Internal variable
 - c) Independent variable
 - d) External variable

7. A(n)___something that represents an idea or object to help people better understand it.
 - a) Observation
 - b) Model
 - c) Theory
 - d) Method

8. Which is a rule that describes the behavior of something in nature?
- Law
 - Theory
 - Construct
 - Hypothesis
9. What occurs when the expectations of a scientist change how the results of an experiment is viewed?
- Revision
 - Bias
 - Conclusion
 - Speculation
10. A collection of structures, cycles, and processes that relate to and interact with each other is a(n)_____.
- Machine
 - Organism
 - System
 - Model
11. What is the primary difference between a scientific theory and a scientific law?
- Scientific theories are absolute.
 - A theory explains why something happens and a law describes a pattern.
 - A theory does not have a large body of supporting data.
 - A theory describes a pattern and a law explains why something happens.
12. What factors can be changed in an experiment?
- Controls
 - Constants
 - Standards
 - Variables
13. Explanations of natural phenomena supported by large amounts of data are called_____.
- Theories
 - Methodologies
 - Summations
 - Conclusions
14. What type of questions cannot be solved by scientific methods?
- Difficult questions
 - Questions about outer space
 - Ethical questions
 - Questions about the interior of the earth

15. Which of the following is not useful for showing patterns in data?
- Graph
 - Table
 - Chart
 - Procedure
16. Which of the following is NOT a goal of science?
- to investigate and understand the natural world
 - to explain events in the natural world
 - to establish a collection of unchanging truths
 - to use derived explanations to make useful predictions
17. Science differs from other disciplines, such as history and the arts, because science relies on:
- Facts
 - Testing explanations
 - Observations
 - Theories
18. Suppose that a scientist proposes a hypothesis about how a newly discovered virus affects humans. Other virus researchers would likely:
- Reject the hypothesis immediately
 - Alter the hypothesis to fit their own findings
 - Assume that the hypothesis is true for all viruses
 - Design new experiments to test the proposed hypothesis
19. Which of the following is NOT a way that science influences society?
- Science provides answers to practical problems
 - Science advances technology that is useful
 - Science provides answers to difficult ethical problems
 - Science increases society's understanding of its relationship to the environment
20. Based on your observations, you suggest that the presence of water could accelerate the growth of bread mold. This is:
- A conclusion
 - A hypothesis
 - An experiment
 - An analysis
21. A personal preference or point of view is:
- A bias
 - A theory
 - A hypothesis
 - An inference

22. How does sharing ideas through peer-reviewed articles help advance science?
- a) Experiments in peer-reviewed articles do not need to be repeated
 - b) Peer-reviewed articles are published only when the ideas they contain have been accepted by most scientists
 - c) Ideas in the articles support and strengthen the dominant theories
 - d) Scientists reading the articles may come up with new questions to study
23. Suppose that a scientific idea is well-tested and can be used to make predictions in numerous situations, but cannot explain one particular event. The idea is a:
- a) Hypothesis that is incorrect
 - b) Theory that should be discarded
 - c) Hypothesis that must be retested
 - d) Theory in need of revision
24. Who reviews articles for peer-reviewed journals?
- a) The scientists who did the experiments
 - b) Companies that funded the research
 - c) Anonymous and independent experts
 - d) The editor of the journal
25. Would a scientist who studies evolution also need to learn about other branches of biology? Why or why not?
- a) Yes, the other branches of biology are more practical and important
 - b) No, the other branches of biology do not affect theories of evolution
 - c) Yes, the different branches of biology are interrelated
 - d) No, each branch of biology is a separate study

APPENDIX B
SCIENCE RESEARCH SURVEY

Science Research Survey	5	4	3	2	1
	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree
<i>Confidence in Science Knowledge and Application</i>					
Doing science changes my ideas about how the world works.					
I think about the science I experience in everyday life.					
To understand a scientific idea, I sometimes think about my personal experiences and relate them to the topic being analyzed.					
I enjoy reading about scientific discoveries.					
I am familiar with what a science researcher does.					
I have a good understanding of how the scientific method works.					
I have a good understanding of fundamental science concepts.					
I find science concepts interesting and challenging.					
<i>Confidence in Scientific Skill</i>					
I am a detail person and a good record keeper.					
I find problems involving numbers interesting and challenging.					
I have good technical and laboratory skills.					
I can critically read and review scientific literature.					
I am better at repeating experiments that others have done rather than thinking up my own.					
I am good at organizing and analyzing data.					
I think that I have the basic skills to be a research scientist.					
I am precise in following procedures and protocols					

<p style="text-align: center;">Science Research Survey</p>	<p style="text-align: center;">5 Strongly Agree</p>	<p style="text-align: center;">4 Agree</p>	<p style="text-align: center;">3 Not Sure</p>	<p style="text-align: center;">2 Disagree</p>	<p style="text-align: center;">1 Strongly Disagree</p>
	<i>Confidence in Scientific Thinking and Innovation</i>				
I can often see better ways of doing routine tasks.					
I am a good observer and can often notice things that others do not.					
I can reason logically about the physical world.					
I have the ability to think creatively and propose innovative solutions to scientific problems.					
I am not satisfied until I understand why something works the way it does.					
I have a lot of intellectual curiosity.					
I am good at combining ideas in ways that others have not tried.					
I often look for new ways of solving problems.					

APPENDIX C
SCIENTIFIC INQUIRY QUESTIONNAIRE

Scientific Inquiry Questionnaire*Name:**Date:*

The following questions have no definite right or wrong answers. Instead the questions are asking for your views related to science and scientific inquiry at the moment.

1) How do scientists decide what to investigate and how? Describe some factors that you think influence the work of scientists.	Additional comments/corrections?
2) What type of activities do scientists, of any field, do to learn about the natural world?	
3) If several scientists, working independently, ask the same question and follow the same scientific method, will they ultimately come to the same conclusion?	

Scientific Inquiry Questionnaire – continued

4) What does the term “data” mean in science? Is “data” the same as, or different from “evidence?” Explain.	Additional comments/corrections?
5) What is involved in data analysis? What does a scientist do with the data collected in research and experimentation?	
6) Do you think that scientific investigations can follow more than one method? Can you provide an example of investigations that follow different methods and are still considered scientific?	

Adapted from: The VOSI Questionnaire (Schwartz, Lederman G., Lederman J., 2008).

APPENDIX D

SCIENTIFIC RESEARCH MODULES: FEEDBACK FORM

Scientific Research Modules: Feedback Form

Student #:
1) Did the modules and discussions change your thinking with regard to the Nature of Science? Can you provide an example or illustration?
2) Did the modules and discussions help you better understand the essential components of scientific investigations? Can you provide an example or illustration?
3) Did the modules and discussion adequately explain and clarify the characteristics of a good research question? Can you provide an example or illustration?
4) Overall, how would you rate the effectiveness of the modules and exercises? (circle one)
Very Helpful Helpful Not Helpful

APPENDIX E

ASSESSMENT TASK 1: SCIENTIFIC RESEARCH

Assessment Task #1: Scientific Research**Student ID #****Date:**

1) Testable Scientific Question:	Points:
2) Clearly define variables that can be tested.	
3) State and briefly explain the conditions within which the experiment might be conducted.	
4) Predict and briefly define one likely outcome from among the variables resulting from experimentation	
5) References with citation:	

APPENDIX F

ASSESSMENT TASK 2: WRITING A SCIENTIFIC RESEARCH QUESTION

Assessment Task #2: Writing a Scientific Research Question**Student ID:****Date:**

Data Set:	Points:
1) Testable Question:	
2) Identify Measurable Variable(s):	
3) Parameters for Investigation:	
4) Potential Cause & Effect Relationship Between Variable(s):	
5) References with Citation:	

APPENDIX G

WRITING A SCIENTIFIC RESEARCH QUESTION RUBRIC

Writing A Scientific Research Question: Scoring Rubric

Teacher Name: PJ Schaefer

Student ID:

CATEGORY	4	3	2	1
Testable Question	The question is well-written, specific and scientifically testable.	The question is testable but needs to be modified for greater specificity.	A portion of the question is testable and requires modification.	The question cannot be tested scientifically.
Measurable Variables	Two or more variables are clearly and properly defined/described with all relevant details.	At least one variable is clearly and properly defined/described with all relevant details.	Variables are improperly defined and not clearly described.	Variables are incorrectly identified or improperly defined.
Investigative Parameters	The parameters of the investigation are clearly and accurately specified.	The parameters of the investigation are specified but not clearly defined.	The parameters of the investigation are not correctly specified or defined and require modification.	The parameters of the investigation are vague and do not pertain to the question.
Cause and Effect Among Variables	A cause and effect relationship is clearly stated between two or more variables.	A cause and effect relationship is clearly stated between one variable.	A cause and effect relationship is improperly stated between one or more variables.	No cause and effect relationship is clearly stated.
References with Citation	Two or more appropriate references are included and properly cited.	One appropriate reference is included and properly cited.	One or more references are included, but improperly cited.	No references are included that properly pertain to the question.
Teacher Comments:				Total

APPENDIX H
STUDENT INTERVIEW QUESTIONS

Student Interview Questions (<i>Semi-Structured</i>)	
Question:	Student Response:
How do you decide if a research topic is of interest to you?	
In your high school experience, have you had opportunities to come up with your own questions and experimental design in science classes? Can you give an example?	
What did you find is the most difficult or challenging part in writing a good scientific question?	
How do you use the scientific method? Do you think about it when you are formulating an idea or question?	
What part(s) in this process of learning and practice did you find most helpful?	

Other Comments:

APPENDIX I

ONLINE DATA SET SAMPLE

DATA SET #16**NAME:** Analyzing Asteroids**TYPE:** Empirical/Descriptive

DESCRIPTION: Asteroids are rocky or metallic objects that orbit the Sun, but are much smaller than planets. Most asteroids orbit the Sun in a belt between the orbits of Mars and Jupiter, but some have eccentric orbits, and occasionally one has an orbit that intersects the orbit of earth. The Barringer meteor crater near Winslow, Arizona is evidence of such a path! The data table below lists the largest asteroids, their date of discovery, distance from the sun (*in astronomic units (au); 1 au = distance from the Sun to Earth*), and orbital period (*years*).

Name	discovered	diameter (km)	distance (AU)	orbital period (years)
Ceres	1801	918	2.77	4.61
Pallas	1802	522	2.77	4.61
Juno	1804	244	2.67	4.36
Vesta	1807	500	2.36	3.63
Iris	1847	204	2.39	3.68
Hebe	1847	192	2.43	3.78
Hygiea	1849	430	3.14	5.59
Egeria	1850	114	2.58	4.14
Eunomia	1851	272	2.64	4.30
Kalliope	1852	188	2.91	4.97
Psyche	1852	264	2.92	5.00
Amphitrite	1854	240	2.55	4.08
Euphrosyne	1854	248	3.16	5.58
Daphne	1856	182	2.77	4.59
Eugenia	1857	114	2.72	4.49
Doris	1857	226	3.11	5.48
Europa	1858	312	3.10	5.46
Elpis	1860	174	2.71	4.47
Cybele	1861	246	3.43	6.37
Freia	1862	190	3.39	5.49
Sylvia	1866	272	3.49	6.52
Camilla	1868	236	3.49	6.50
Mathilde	1885	61	2.46	4.30
Eros	1898	33	1.46	33.00
Chiron	1977	180	13.72	50.80
Toutatis	1989	4.6	2.51	3.98



SOURCES: This file can be downloaded from sciencesourcebook.com