THE EFFECTS OF TEACHING THE NATURE OF SCIENCE ON HIGHER ORDER THINKING SKILLS IN A FRESHMEN LEVEL PHYSICAL SCIENCE HIGH SCHOOL COURSE

by

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ABSTRACT

As I have developed as a science teacher, I have become more concerned with helping students learn to 'think like a scientist' rather than memorize science content. With the release of the Next Generation Science Standards in April of 2013, I was further inspired to rework the school's current science curriculum to make time for teaching students to think. Over the summer of 2013, I developed a six week Nature of Science unit which used the eight benchmarks published in the Next Generation Science Standards. The Nature of Science focuses on the 'how' of science and I thought it would help me achieve my goal of making students become critical thinkers.

While it may seem intuitive teaching the Nature of Science may result in better higher order of thinking skills, my project focused on attempting to verify whether students improved in their ability to analyze, synthesize and evaluate scientific information. Prior to the start of the newly developed Nature of Science unit and following it, my freshmen physical science course took a previous year's standardized test (ACT Explore), completed a survey over their higher order thinking skills, developed a scientific experiment from given background during an assignment, and developed a second scientific experiment with the use of a computer simulator and collected data. The surveys provided the opportunity for me to learn about all three of their higher order thinking skills, the standardized tests shed light on their analysis and evaluation abilities, while the students developed scientific experiments provided information over their synthesis skills.

The largest gains from the Nature of Science unit were in student evaluation ability. This was evidenced by increases in the ACT Explore Test conflicting view point portion and more students self identifying through the survey of being at a higher level. Student ability to synthesize and analyze scientific information did not seem to change nearly as much. As I look to improve the unit for future years, I will be incorporating more activities which allow students the opportunity to analyze and synthesize scientific information in the context of the Nature of Science.

INTRODUCTION AND BACKGROUND

Saxony Lutheran in Jackson, Missouri is a private school which includes 9th to 12th grade. The school, with a student population of around 180 students, is attended by mostly Lutheran students. There are 25 association churches which provide financial and pastoral support (saxonylutheranhigh.org). Our school is in Cape Girardeau County with a population of around 70,000 people (factfinder2.census.gov). The primary cities we serve are Cape Girardeau and Jackson.

Saxony draws students from four feeder elementary schools in the area. In recent years, our school has been working towards aligning the curriculum between the four elementary schools and Saxony so the schools can be more unified and cohesive. As part of that endeavor, the school has been considering the future of our physical science course and what material and content it should cover. The current physical science course has two sections of 24 and 25 students and consists entirely of freshmen. The course serves as a bridge from elementary school science to the upper level sciences offered at Saxony. Since the class is foundational to the success of students' future learning and is also the benchmark for the feeder schools science curriculum, we have been thinking about what the most crucial elements of the course should be. One of these fundamental elements we arrived at was a student who is able to think like a scientist.

The Next Generation Science Standards were released on April 9th, 2013 with an emphasis on the Nature of Science (NOS) (nextgenscience.org). The NOS standards focus on the concept of science as a way of thinking, which includes ideas such as logical discourse, evaluating explanations, and the use of hypotheses to test ideas. Since these concepts are universal to all sciences, there is a potential benefit in designing the physical science course to emphasize the NOS.

An underlying theme in the NOS standards seems to be higher order thinking as outlined in Bloom's Taxonomy (Bloom, 1956). Thinking like a scientist requires the ability to analyze data, evaluate the reasonableness of a proposed explanation, and the capability of synthesizing authentic scientific experiments and theories. Incorporating the NOS into a curriculum may reduce the amount of content taught. This would be well worth it if it resulted in students developing higher cognitive function.

The addition of the NOS into the course curriculum lead to the creation of my focus statement, What are the effects of teaching the NOS on higher order thinking skills in a freshmen level high school course? My focus question was further refined into three sub-questions, with each question focusing on a single higher order thinking skill:

How does teaching the NOS influence students' ability to analyze information?

How does teaching the NOS influence students' ability to evaluate the reasonableness of a solution?

How does teaching the NOS influence students' ability to synthesize scientific experiments and thought processes?

CONCEPTUAL FRAMEWORK

The Nature of Science (NOS) deals with science as a way of thinking and how that knowledge is obtained (Abd-El-Khalic, Lederman, Bell, & Schwartz, 2001). While teaching the NOS, it is important to do so in a way that combines science process with science content without over simplifying the methodology of how science knowledge is obtained (Ault & Dodick, 2010). Many textbooks provide a disservice to the NOS by eliminating historical content in conjunction with the development of the scientific body of knowledge. Lab activities that have explicit step by step directions and prescribed convergent questions also wrongly portray the NOS (Clough & Olsen, 2004). Laboratory exercises which do not engage the student to think critically are not congruent with the NOS (Marušić & Sliško, 2012).

The NOS is an important part of a science education, however, it is neither taught nor assessed by all educators. Some of the problem lies in not everyone agreeing on a specific definition of the NOS (Duncan & Arthurs, 2012). Many of these differences stem from philosophical issues and tend to be a moot point when dealing with the education of elementary and secondary education. General views regarding the NOS should be agreed upon by most parties and are useful in education. These include the relationship between laws and theories, empirical evidence as the basis of theories, and that all theories are subjective and subject to change (Abd-El-Khalic et al., 2001). These, as well as the creative side of science and limitations of questions science can answer, are echoed by the National Science Teachers Association (McComas, 2004). The Next Generation Science Standards (NGSS), released in April of 2013, highlighted the core ideas of the NOS (nextgenscience.org):

- Scientific investigations use a variety of methods
- Scientific knowledge is based upon empirical evidence
- Scientific knowledge is open to revision in light of new evidence
- Scientific models, laws, mechanisms, and theories explain natural phenomena
- Science is a way of knowing
- Scientific knowledge assumes an order and consistency in natural systems

- Science is a human endeavor
- Science addresses questions about the natural and material world (p. 4, appendix H)

The teaching of NOS as a focal point has been on the increase in elementary and secondary education (Duncan & Arthurs, 2012). A variety of methods, such as puzzle solving and black box activities, have shown effectiveness in providing students an accurate portrayal of the NOS. The challenge of solving a brain-teaser, or similar problem, provides an opportunity for students to think and reason in a scientific manner (Clough, 1997). Pictorial-gestalt images provide insight into how the students' observations are influenced by their own personal beliefs and knowledge base, which emphasize the subjectivity of objective reality (Michaels & Bell, 2003). Teaching the historical context of the development of scientific knowledge allows students to see what other alternative ideas are available. This allows for students to have a clearer picture of the NOS and consider the scientific reasoning that went into choosing the current model. Providing limited data sets and asking students to make inferences also provide a beneficial framework for allowing students to think in context of the NOS (Clough & Olsen, 2004). In order to teach the NOS effectively, the content to be taught will need to be evaluated to determine what is most important (Day, Neiman, Stobaugh, & Tassell, 2012).

Science assessment tools have been developed to measure student understanding of the NOS and have been used on high school and college students alike. The Epistemological Beliefs Assessment for Physical Science is a 30 question example designed to assess student's views of the NOS for physics and chemistry courses, but it has been used in other science fields as well (Duncan & Arthurs, 2012). Convergent questions may have a limited role in assessing student understanding of the NOS. An open ended questionnaire, such as the Views of the Nature of Science, may provide a better understanding of their comprehension. Due to its open ended nature, the assessment of the Views of the Nature of Science is also more subjective to interpretation (Abd-El-Khalic et al., 2001). Different students may require different types of assessment to identify their comprehension of the NOS. Assessing students in a variety of methods will help the teacher gain a clearer view of student mastery of the NOS. Low achieving students may benefit most in taking non-traditional assessments (Chiu & Chang, 2005).

Teaching the NOS and focusing on process based assessments has been shown to help students reach higher levels of cognitive ability (Day et al., 2012). Student understanding of the NOS may also influence how well they understand the role of certainty in the science field (Buffler, Lubben, & Ibrahim, 2009). Curricula that have used NOS explicitly have helped students to articulate and defend scientific viewpoints (Khishfe, 2012). Using the specific pedagogy of hypothetical scientific situations and having students develop predictable experiments have shown improvement in student scientific reasoning. This also helps students in accommodating new scientific information since new information requires the ability to reason within and change student conception (Lawson, 2003). Some studies suggest that the amount and depth of science content learning may be dependent upon the ability to think and reason scientifically (Marušić & Sliško, 2012).

Higher levels of thinking, as identified in Bloom's taxonomy (Bloom, 1956), are important abilities to foster in students in order to prepare them for the future. Preparing curricula and writing assessments that aim for higher cognitive levels should be considered a goal for educators (Day et al., 2012). Dolan and Grady (2010) have designed a matrix to be used as a template to help teachers assess student cognitive level in connection to their scientific reasoning processes. This tool is recommended as a starting point to be reflected upon and modified as one assesses their own students.

Marušić and Sliško (2012) point out that a student who struggles in science may be hindered not by content but by level of cognitive ability. Many students in the high school setting may not have reached the formal operational level cognitive domain. This connection is highlighted as providing an important direction for what a science curriculum should offer, that being scientific reasoning as a vital and central goal. In a study comparing the scientific reasoning skills of Chinese and United States students, Bao (2009) addresses how both countries have drastically different curricula in the sciences but both produce students with similar scientific reasoning skills. Bao (2009) goes on to say, "It seems that it is not what we teach, but rather how we teach, that makes a difference in student learning of higher-order abilities in science reasoning" (p. 587).

METHODOLOGY

To incorporate the NOS into the curriculum, the first quarter of the freshmen physical science course was exclusively focused on teaching the NOS. Prior to the beginning of the unit, student understanding of the NOS was assessed using a NOS PreTest (Appendix A). During the unit, students were not assessed on any traditional science content as it served as a tool to improve students understanding of the NOS.

Methods used to teach the NOS included pictorial-gestalt images, black box challenges, and puzzle solving activities. Pictorial-gestalt images are pictures which at first are difficult to identify until a framework is provided or are images that have multiple interpretations (Appendix B). Black box activities required students to use indirect observation to determine what is inside of the box. One of these utilized by the unit included sealed shoe boxes with ropes protruding from the box which were connected in miscellaneous fashion inside (Appendix C). Puzzle solving activities made students use logic and creativity to determine a solution (Appendix D). These activities provided an opportunity for students to develop NOS thinking using content which is not inherently scientific. 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.

The NOS unit also included material which allowed students to utilize scientific content as a tool for developing higher order thinking relevant to the NOS. These methods were considering the historical context of certain theories, providing limited data sets which allow for inference and development of models, developing authentic science experiments, hypothetical scientific situations, performance based assessments, and significant digits in context of uncertainty of measurements. Providing historical context of scientific theories allowed students to reflect on other models used at the time and the strengths and limitations of the theories presented (Appendix E). Providing limited data sets refers to supplying students with data about the natural world and allowed them to determine probable cause, patterns, or application to the world (Appendix F). Hypothetical scientific situations involve presenting students two or more possible explanations for a set of mysterious data and provided students an opportunity to defend which was a better explanation (Appendix G). Performance based assessments required students to carry out a scientific task and demonstrate mastery of the process. Students demonstrated mastery of using triple beam balances, graduated cylinders, and being able to determine the density of an irregularly shaped object using the Density Performance Assessment (Appendix H). The inclusion of significant digits provided further opportunity for students to consider limitations of scientific knowledge (Appendix I). These lessons and methods, when appropriate, also included opportunities for students to consider relevance and application to the world at large, as well as synthesis of further questions to consider asking.

The three highest order thinking skills, analysis, evaluation, and synthesis as outlined by Bloom's Taxonomy were assessed prior to the start of the unit and at the end of the unit. Data for each of the higher order thinking skills were tallied separately to improve identification of benefits associated with the NOS. Student ability to analyze, synthesize, and evaluate was assessed through surveys, standardized tests, interviews, and written assignments. The surveys included questions which had students identify which description best matched their ability to analyze, evaluate, and synthesize. The Pre-Treatment Survey was given prior to the start of the unit. The Pre-Treatment Survey asked students what level of comfort they had in scientific analysis, evaluation, and synthesis and then identify their current skill level at performing these processes by selecting from a list which response best described their ability (Appendix J**)**. These questions which had students self identify their ability were modified from the questions created by the Valencia Community College Learning Evidence Team Self Rubric over

Critical Thinking (Appendix K). The Post-Treatment Survey had the same questions as the Pre-Treatment Survey, but included three additional questions. These three questions asked whether the student felt learning about the NOS helped them in their ability to analyze, synthesize, and evaluate scientific information and was given to the students the week after the conclusion of the unit (Appendix L). The Pre and Post-Treatment Survey utilized a Likert scale where they could strongly agree, agree, be neutral, disagree, or strongly disagree to the statement given. Some questions did not allow students to choose neutral. These surveys were evaluated by comparing the two survey results and looking for themes related to change in confidence in the three higher order thinking skills, change in self identified level of ability in the areas of cognition, and number of students reporting that they felt the unit helped them improve their ability to evaluate, synthesize, and analyze.

The Pre-Treatment Advanced Developing Scientist Written Assignment had students develop a scientific study, assisted by a simulator over pendulums, conduct the study, and subsequently draw conclusions about their results (Appendix M). The Post-Treatment Advanced Developing Scientist Written Assignment utilized the same format as the prior written assignment, but students used a mass and spring simulator to assist them (Appendix N). The students were provided 40 minutes to accomplish the Pre and Post-Treatment Advanced Developing Scientist. These written assignments had five questions which directed the students as they performed and designed the study and were evaluated by directly comparing the hypothesis, procedure, data, and conclusion from prior and following the treatment. These four components were identified by whether the level of sophistication of the response changed from before the study. The results were then analyzed, looking for themes showing improvement in ability to synthesize, evaluate, and analyze.

A similar written assignment administered prior to the unit, the Pre-Treatment Developing Scientist Written Assignment, involved students developing an experiment, after being provided background information, related to plant growth and subsequently evaluating their method chosen for data collection (Appendix P). Following the unit, students completed the Post-Treatment Developing Scientist Written Assignment, which had students develop an experiment related to insulation after being given background information (Appendix Q). Students were given 40 minutes to complete the written assignment. The Pre and Post-Treatment Developing Scientist had five questions to prompt the students as they developed their experiment. The responses were evaluated by directly comparing the level of sophistication of the hypothesis and procedure present from the Pre and Post Treatment Developing Scientist Written Assignment. The Pre- and Post-Treatment Advanced Developing Scientists results were then analyzed, looking for themes showing improvement in ability to synthesize, evaluate, and analyze.

Students took an Explore test from the previous year, test form 05A, prior to the start of the NOS unit. The freshmen were scored as a group by the percent of higher order thinking questions answered correctly as well as by categories provided by the ACT. The categories used by the ACT include data representation (graphs and tables), research summaries (descriptions of several related experiments), and conflicting viewpoints (hypotheses that are inconsistent with each other) (act.org).The current year Explore test, test form 05B, was administered to our ninth graders during an official standardized test on October 16th, a week following the conclusion of the unit. This test was also evaluated and scored as the prior Explore test. The results of these tests were then compared to one another as well as the reference groups for the year, looking for themes related to changes in ability to answer questions at different cognitive levels and category as defined by the ACT. A panel of experts evaluated the two Explore tests to identify the Bloom's level of thinking required to successfully answer the question (Appendix S, T).

Prior to and following the treatment, students were randomly selected to be interviewed about their ability to analyze, evaluate, and synthesize science information, what difficulties they still face, and how comfortable they are after learning about the NOS (Appendix U). These responses were assessed for common themes about change in ability to analyze, evaluate, and synthesize as well as ideas concerning what would help them improve in those areas. The methods of collection for each order of thinking are summarized in the Triangulation Matrix (Table 1).

Table 1
Triangulation Matrix

Focus Questions	1	2	3	4
1. How does teaching the NOS influence students' ability to *analyze* information?	Pre *and* Post Treatment Ability to Think Like A Scientist Survey	Explore Test 05A *and* Explore Test 05B	Pre *and* Post Treatment Advanced Developing Scientist Written Assignment	Interviews
2. How does teaching the NOS influence students' ability to *evaluate* the reasonableness of a solution?	Pre *and* Post Treatment Ability to Think Like A Scientist Survey	Explore Test 05A *and* Explore Test 05B	Pre *and* Post Treatment Advanced Developing Scientist Written Assignment	Interviews
3. How does teaching the NOS influence students' ability to *synthesize* scientific experiments and thought processes?	Pre *and* Post Treatment Ability to Think Like A Scientist Survey	Pre *and* Post Treatment Developing Scientist Written Assignment	Pre *and* Post Treatment Advanced Developing Scientist Written Assignment	Interviews

DATA ANALYSIS

The results of the Post Treatment Ability to Think Like a Scientist Survey indicated that 66% of students felt learning about the Nature of Science (NOS) helped them in their ability to evaluate scientific information (N = 35). Forty-six percent of students identified they were capable of creating logical conclusions which reflect their personal ideas. Twenty-three percent *strongly agreed* they were comfortable and confident in evaluating scientific information.

Student responses from the Post Treatment Ability to Think Like a Scientist Survey revealed over half of the students felt the NOS unit helped them develop their higher order thinking skills. The smallest gain was seen in synthesis, with only 57% of students saying it helped them (Figure 1). One student said, “I feel more confident in my ability to synthesize information, but still have challenges in really developing a very strong model this way.” Another student responding to their ability to synthesize scientific ideas commented, “I don’t think that has really changed. Saying what I mean is hard for me.”

Student responses regarding analyzing scientific information had the largest gain, with 69% of students *agreeing* or *strongly agreeing* that the NOS unit helped them in this area. One who agreed, expressed the limitation they still have in this way, “There will be some data that I will come to no conclusion when presented.” Improved ability to evaluate scientific information had gains slightly behind analysis, with 66% of students *agreeing* or *strongly agreeing.* One student during the interview said, “It has taught me more about how to examine science and put it into practice more often.” Two others also mentioned this idea, with one saying, “It has changed how I look at things, and now, if I research something, it is different to me.” It should be noted there was a difference of five responses between the Pre Treatment and Post Treatment Ability to Think Like a Scientist Survey, with 40 responding to the Pre Treatment Ability to Think Like a Scientist Survey and 35 responding to the Post Treatment Ability to Think Like a Scientist Survey.

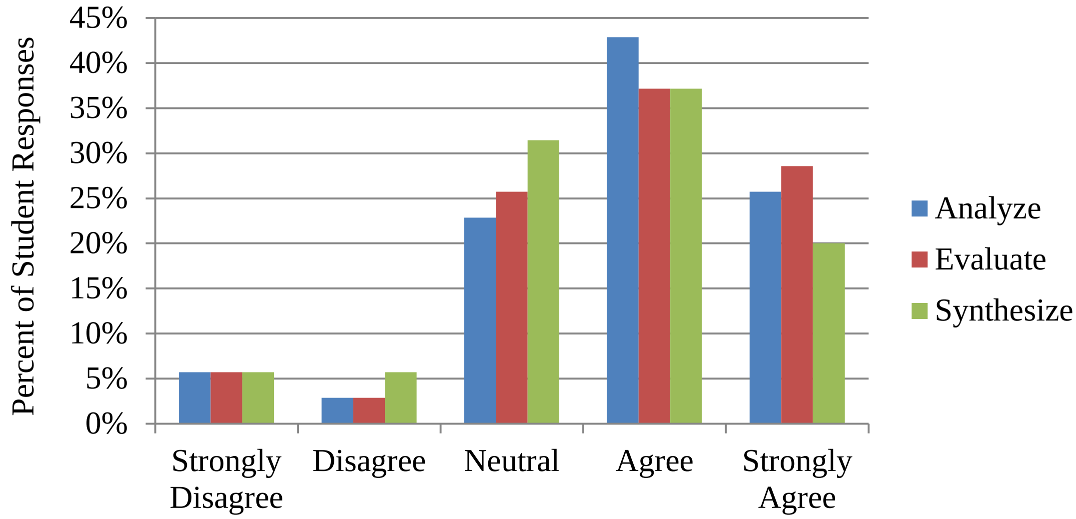

Figure 1. Student responses from the Post Treatment Ability to Think Like a Scientist Survey regarding whether they felt the NOS unit improved these abilities, (N = 35).

Analyzing scientific data, according to the Pre and Post-Treatment Surveys, increased from 18% to 51% of those *strongly agreeing* they were confident in being able to do so (Figure 2). The number of students *disagreeing* or *strongly disagreeing* decreased slightly from 13% to 6%. One student, who felt more capable of analyzing scientific information reported, "I feel comfortable analyzing it all and understanding what it tells me. It helped me think things through more and better understand them." When students categorized their ability to analyze, according to the Self Rubric for Critical Thinking, there was a decrease in perceived ability. Very little change occurred at the ends of the spectrum, but those in the middle categorized themselves as less capable of analyzing scientific information. Prior to the treatment, 40% of students labeled themselves as capable of figuring out how to use scientific data or ideas to solve problems. This number declined to 25% of students after the unit (Figure 3).

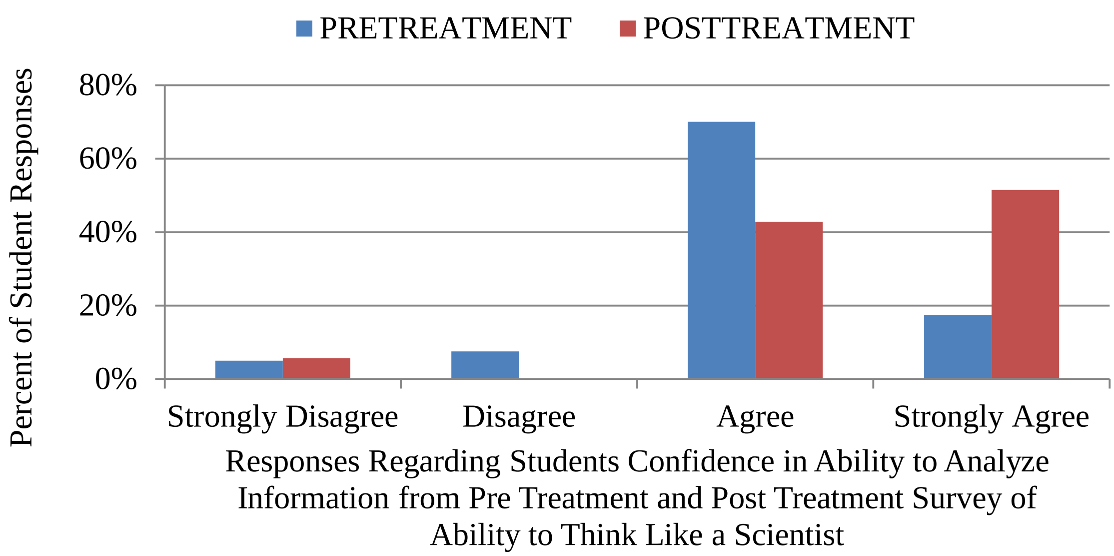

Figure 2. Student responses related to their confidence level in analyzing scientific information, (*N* = 35).

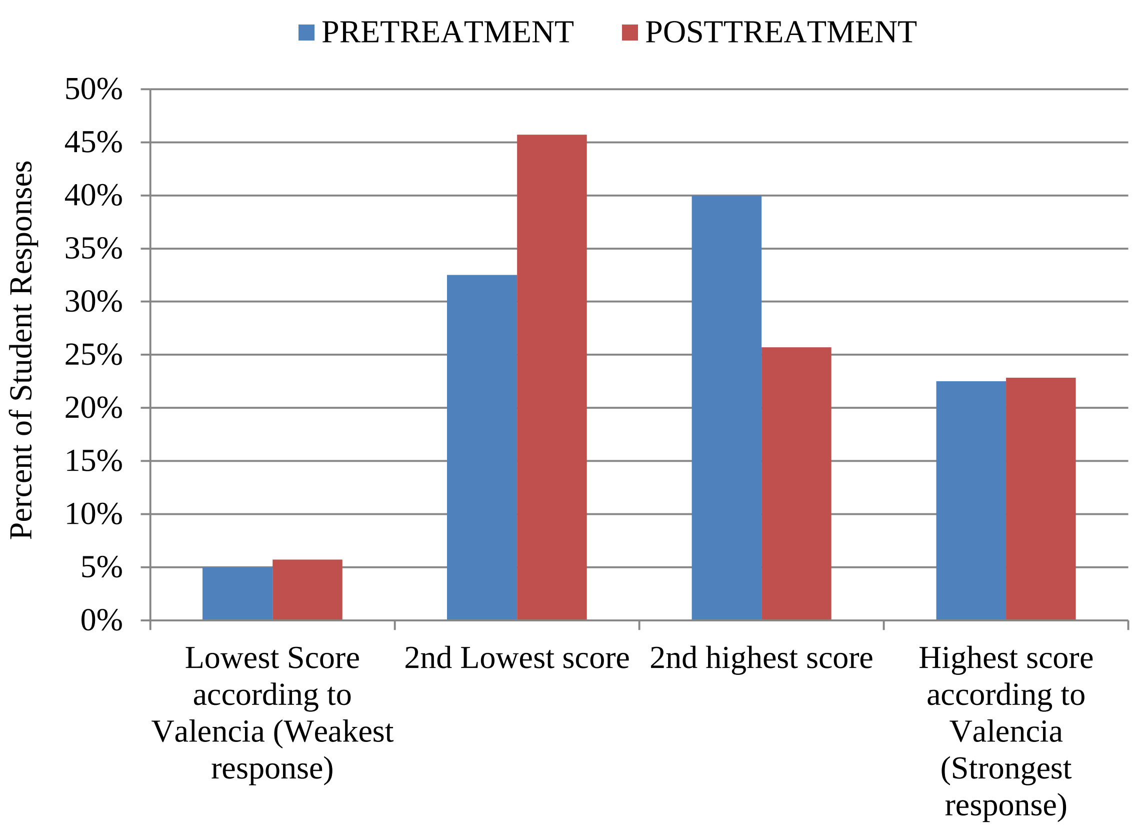

Figure 3. Student self evaluation of their analysis skill level using the rubric developed from Valencia Community College, (*N* = 35).

Results from the Pre Treatment and Post Treatment Ability to Think Like a Scientist Survey concerning synthesis were similar to the analysis data. There was an increase from 10% to 25% of students *strongly agreeing* they were confident in their ability to synthesize information (Figure 4). There was no change in results for students who previously *disagreed* or *strongly disagreed.* Informal conversations with students following the Post Treatment Developing Scientist Written Assignments indicated students felt more confident in their ability to develop a scientific experiment. Student self evaluation using the Valencia Rubric for their synthesis ability showed an increase of 12% to 17% classifying themselves as having the highest level of synthesizing scientific information. This was countered by an increase of students citing they could synthesize different scientific thoughts into a coherent idea as long as the data was not too complicated, going from 30% in the Pre Treatment to 47% in the Post Treatment. Forty-eight percent of students prior to the treatment claimed to be able to identify clear relationships when synthesizing a thought, but after the NOS unit only 31% of students made the same claim (Figure 5).

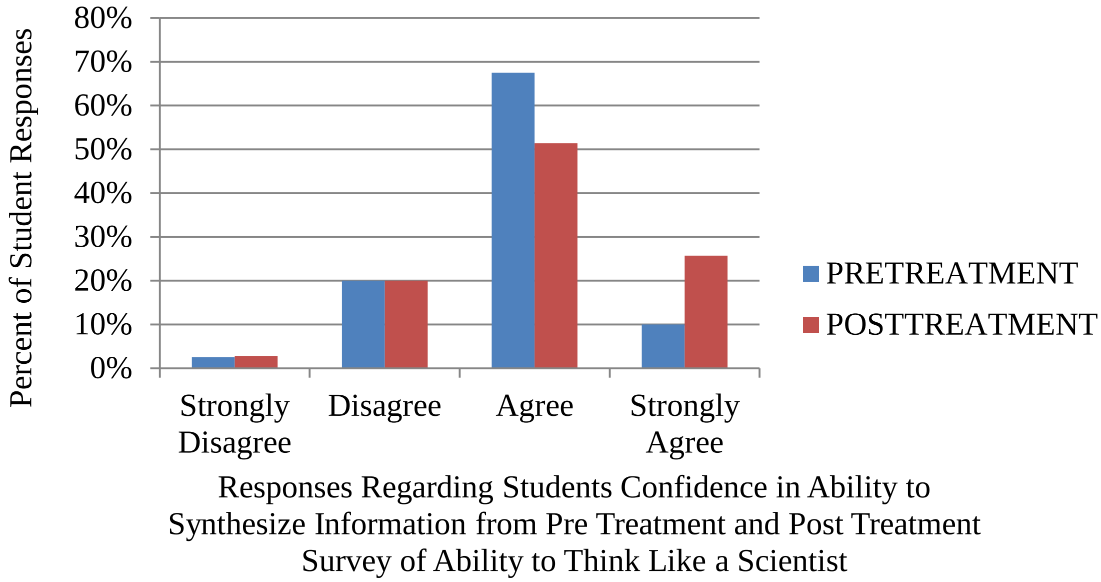

Figure 4. Student responses related to their confidence level in synthesizing scientific information, (N = 35).

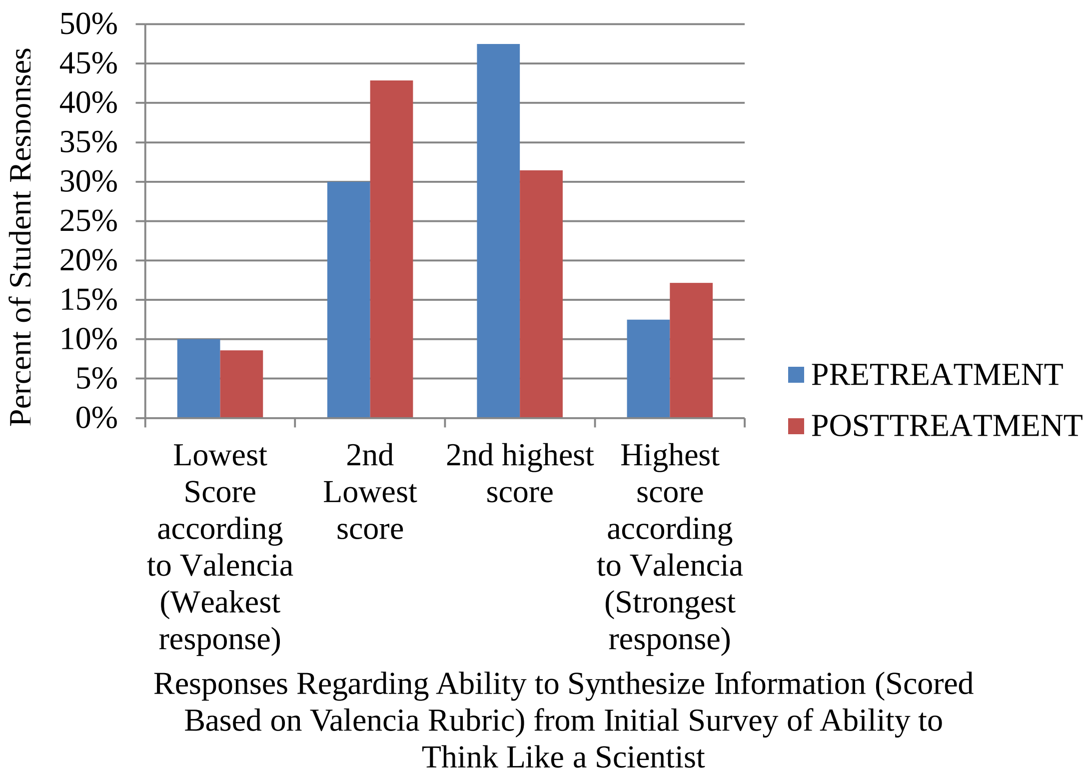

Figure 5. Student self evaluation of their synthesis skill level using the rubric developed from Valencia Community College, (N = 35).

Student confidence in evaluating scientific information had a 15% increase in those who *strongly agreed*, increasing from 8% to 23% after the unit (Figure 6). Less than ten percent of students after the unit *disagreed* or *strongly disagreed* they could evaluate scientific information. One student, who felt that the NOS helped in his evaluating scientific information, said, "I do feel confident about my scientific skill because I now have the tools to research anything." Forty-six percent of students, an increase of 16%, identified themselves as capable of creating logical conclusions that incorporated their own ideas when presented scientific information. Responses regarding the other options all showed declines of less than ten percent (Figure 7). According to the Valencia Rubric, student perception of their ability to evaluate information was higher then analysis and synthesis.

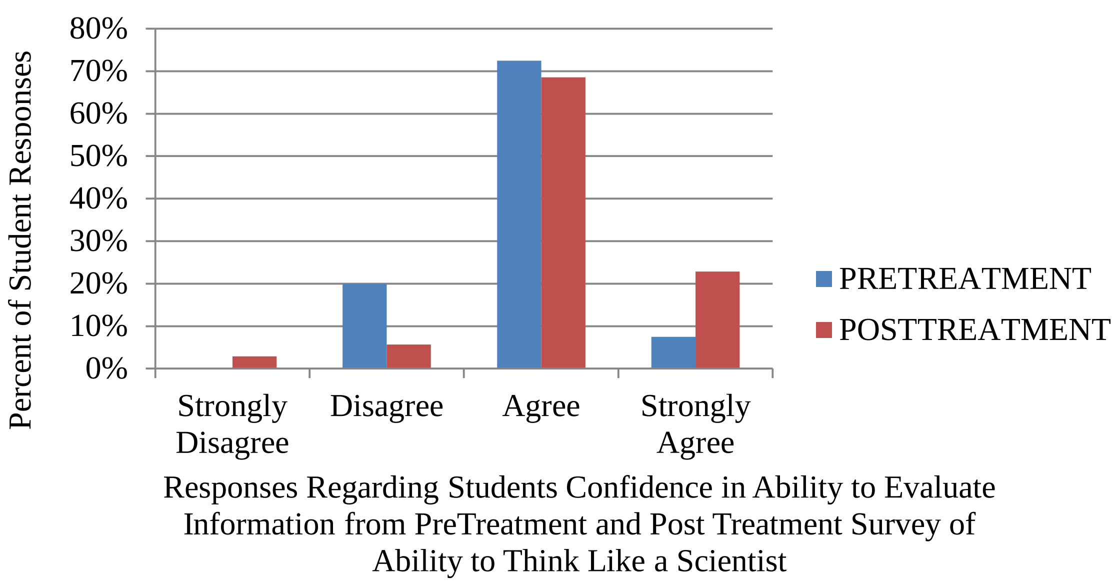

Figure 6. Student responses related to their confidence level in evaluating scientific information, (N = 35).

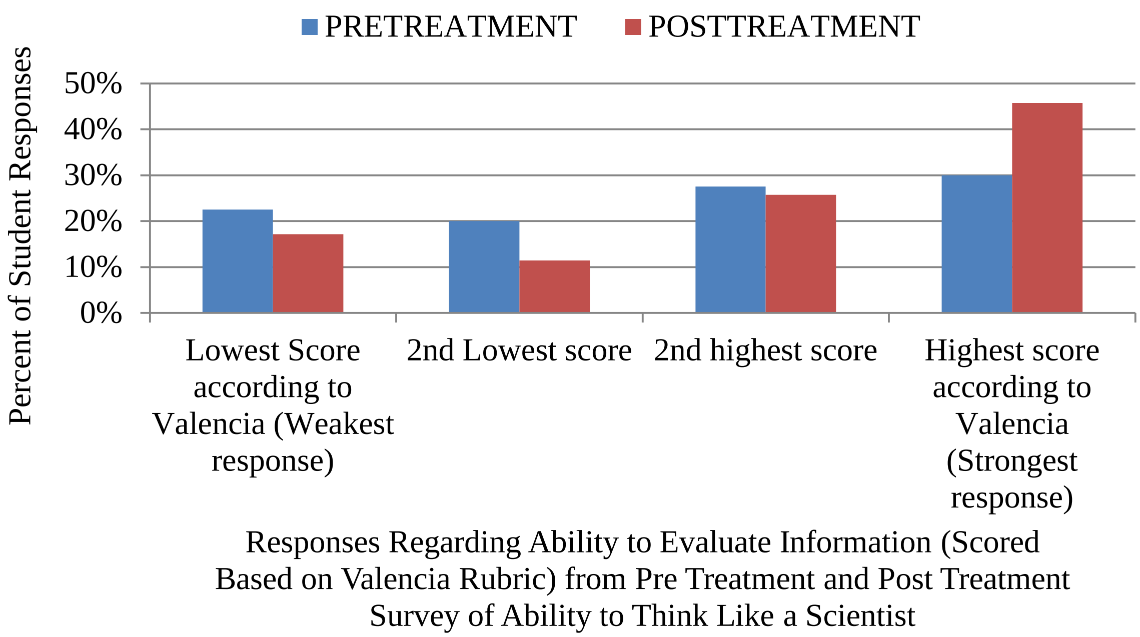

Figure 7. Student self evaluation of their evaluation skill level using the rubric developed from Valencia Community College, (*N* = 35).

The results from the Explore Tests showed little change in the ACT provided categories of research summaries and data representation with slight declines of less than five percent from the pre test to the post test. Student performance on the conflicting viewpoints questions increased by 18%, from 57% correct on the pre test to 75% correct on the post test (Figure 8). Students outperformed the reference group in both tests, however, the gap between the research summaries and data representation declined while the gap for the conflicting viewpoints increased (Figure 9). The panel of experts identified 14 questions in the Explore 05A test and 13 questions in the Explore 05B test to require analyzing and evaluating skills to solve. The student's performance on these questions comparing tests showed no change with both test groups averaging 68% on these types of questions.

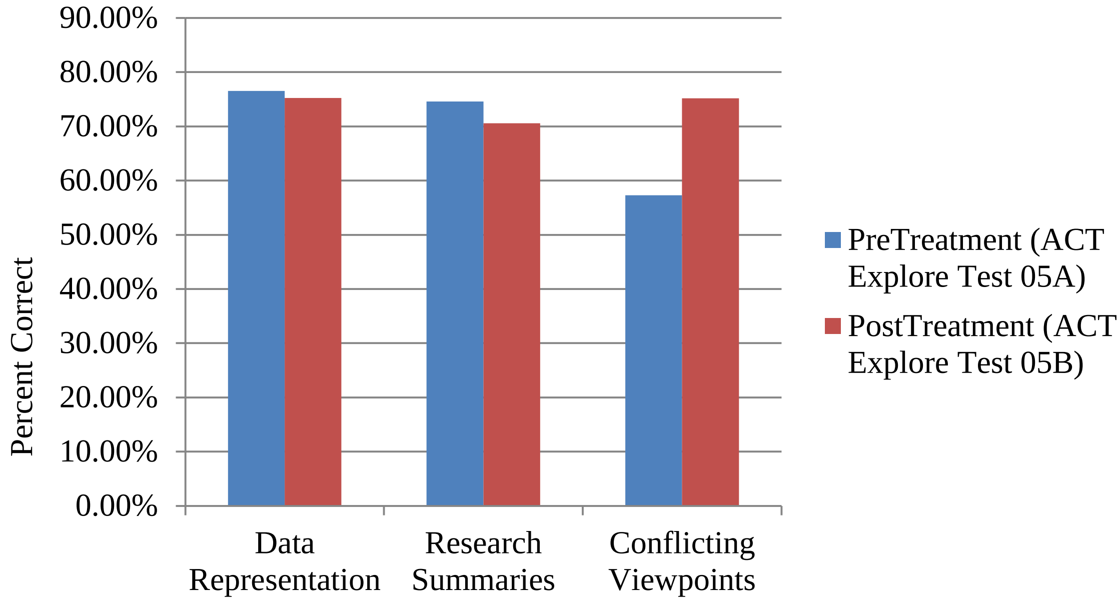

Figure 8. Student performance on types of questions as identified by the ACT, (*N* = 49).

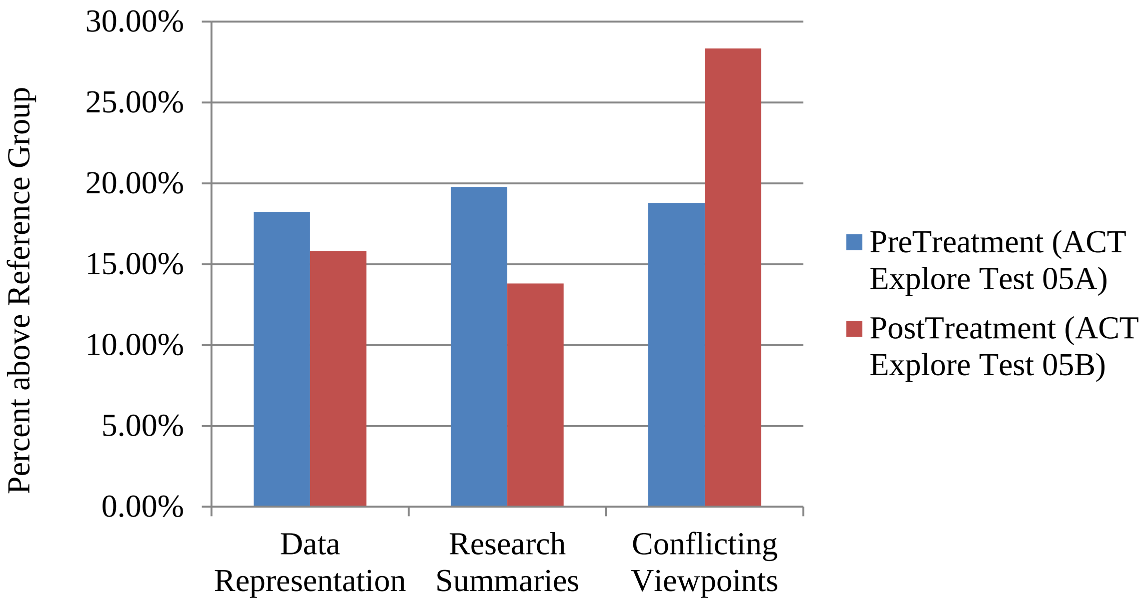

Figure 9. Student performance compared to reference groups by category, (*N* = 49).

The results of the Developing Scientist Written Assignment comparison showed no marked improvement in level of sophistication of the procedure or the hypothesis for the students as a whole group. Five percent of the hypotheses and 24% of the procedures in the post treatment showed advances in level of scientific thought (N = 41). These gains were offset by 9% of students having a less developed hypothesis and 19% of students having a weaker procedure. General observations of the procedures showed a general movement away from step by step outlined procedures to a more paragraph oriented approach from before to after the treatment.

The Advanced Developing Scientist Written Assignments had similar results to the Developing Scientist Written Assignment in regards to the procedures and hypotheses. The amount and type of data collected by the students showed 15% of students having collected more data and relevant data to answer their questions, with only 3% of students showing a regression (N = 35). The largest change from comparing the pre- and post-treatment was in the conclusions made. Thirty one percent of conclusions were deemed to be at a higher level of scientific thought than previously. Not every student was able to generate a conclusion prior to the treatment but every student managed to report a valid conclusion from their collected data following it. Conclusions from the post treatment often tended to include explanations of why the results were as they were.

INTERPRETATION AND CONCLUSION

The incorporation of the NOS into a science curriculum may assist in helping students develop their higher order thinking skills. Based on the unit plan I used, the students primarily benefited in their ability to evaluate and gained the least in synthesis.

The improved test scores on the ACT category of conflicting viewpoints highlights that the students became better able to evaluate between two scientific ideas which was a better model. The self rubric developed by Valencia Community College showed 46% of students self-identifying their ability to evaluate at the highest level. The written assignments showed a possible increase in ability to make conclusions regarding scientific information while the survey revealed that more students *strongly agreed* that they felt the unit improved their ability to evaluate scientific information.

The standards released by NGSS about the NOS are highly connected to evaluative thinking. The NOS lends itself to ask students to evaluate whether a given scientific mode current model is the best one. Identifying whether a scientific model is a strong or weak model requires students to analyze and evaluate the evidence to draw a conclusion.

While students identification of their capabilities to analyze scientific information, according to the Valencia Community College Rubric, saw a regression, I think this is plausible considering students having developed a better understanding of how complex a science model can be. The results from the survey showed that students were more comfortable analyzing information, but less capable. This makes me believe that they became more aware of their own limitations more than actually becoming worse at analyzing scientific information. Ultimately, evaluation does not happen without some initial analyzing.

Even though synthesis abilities did not seem to appreciably change in the students work, I believe this may be related to a lack of feedback during the treatment from me to the students. I did not address the students about their original written assignments per not wanting to influence the results. I feel that the current unit employed could improve the synthesis skills of the students by working with the students to develop science projects and providing feedback.

A difficulty faced when attempting to identify the level of higher level thinking skills students have is that there are levels within the levels. As I worked with my panel of experts to determine whether a question required analysis and evaluation to answer, we found there to be many levels of difficulty of question related to the concept of analysis and evaluation. The complexity of the scientific idea, the amount of information available, type of information (concrete or abstract), and the difficulty of finding any theme or trend in the data result in a wide range of levels of evaluation an individual may have. Attempting to identify the level of analysis, synthesis, and evaluation a student has is difficult to measure as two students may score the same on a standardized test but still be diverse in the depth of their higher order thinking abilities.

VALUE

The world we live in provides instantaneous scientific information for students through a variety of sources. An uninformed student may not be aware that different scientific models and information presented to them have different levels of credible scientific evidence supporting the information as well as conclusions drawn not being fully supported by the evidence. For students who are not pursuing a future in the sciences, knowledge of how science works and a questioning critical scientific mind will be of utmost importance for students as they evaluate the information they are presented or discover. For these same students, what benefit does taking a science class provide to their future if the content they learn is irrelevant? The answer, I believe, lies in developing students to be critical thinkers who can analyze, evaluate, and synthesize information.

As I have developed as a science teacher, my focus has transitioned away from content and toward developing scientific minds. Teaching the NOS to students provided the framework I have been looking for to help students ‘think like a scientist’ rather than memorize what other scientists have already learned. Using the NGSS as my guide, I had a renewed sense of focus to develop a unit plan which would help develop the students in their future. Reducing the content to make room for a unit on how science was done was well worth it as many students walked out of the unit being more capable and more confident in their ability to read, decipher, and be critical of scientific information. This groundwork has laid the cornerstone for future learning and evaluating of information they will encounter in future classes. This benefit is not isolated to science courses, but all classes that will ask them to analyze and evaluate information and synthesize their own thoughts related to that information. These skills are universal to all professions and make focusing on them through use of scientific processes well worth the cost of loss of minor science content.

Attempting to measure the thinking abilities of students provided me a personal opportunity to get to know more about the different levels of thinking outlined by Bloom’s taxonomy. I realized during my research, analyzing standardized tests, and reflecting upon my old tests how a question is asked can change how difficult the question is to answer, even if the learning goal and content was the same. For many years, I have often wondered why certain questions were missed by students when I thought they knew the content well. Becoming more aware of the level of thinking required to answer questions has provided me an opportunity to ensure that my future tests are written in a manner to ensure I am assessing what I truly meant to assess.

While the focus of my research was how much the NOS helped students improve in their thinking, another positive benefit included a high level of involvement of students in the daily lessons geared to make them solve scientific puzzles. I never heard the comment “Why do I need to know this?” while teaching the unit. Instead, I felt that students came to class excited to see what idea they would be exploring, problem they would be solving, or data they would be interpreting.

The value of this study and similar studies could provide further insight into the biological development and capabilities of adolescents’ brains as to whether the brain develops its abstract and reasoning skills on a natural biological timeline or if these abilities of the brain truly can be learned at a younger age. It is not uncommon to hear or read about scientific literature which discusses the development of different areas of the brain and how certain areas of the brain become more active as a child grows. While I feel that for many of the students I taught had some gains associated with teaching the NOS, it also very well could be connected to the process of the brain just merely developing and becoming more able to reason or their brain had reached a level of development where it was capable of learning to reason. A potential further study would be to teach the NOS of science to younger students and measure changes in higher level thinking.

Teaching the NOS to students at the high school level provides a platform for students the opportunity to learn how to think like a scientist. At its roots, thinking like a scientist makes students attempt to analyze, evaluate, and synthesize information. While the content of science class becomes secondary to the process of science, for many students the process of learning how to think critically is more valuable than knowing scientific laws and principles when it comes to their growth as a capable and lifelong learner.

While I have spent the last eight years teaching the content of science and how science is done, becoming involved in the action research process the last two years through Montana State University has helped me to see that I also must continue to be a scientist willing to learn. I have challenged students for years to learn how science is done and analyze scientific data to interpret, while at the same time not taking the additional time myself to decipher the effectiveness of my teaching by putting it under the microscope. I have become more reflective about my teaching practices and found increased joy in getting to be a scientist of my own classroom as I collect data and sift it to find information which tells me how the students are doing, which is important, but also what it reveals about the pedagogy I employ. This process of self-evaluation has renewed my focus to be a better teacher and provided myself with a method to evaluate whether I am heading the right direction. The action research model has given me an avenue to continue doing what I have loved since I was young: science.

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APPENDICES

APPENDIX A

NOS PRETEST

Nature of Science Pre-Test Name __________________

For each statement, circle whether you strongly agree, agree, disagree, or strongly disagree. Then explain your rationale.

1. The scientific method is the only way that science knowledge is gained.

Strongly Agree Agree Disagree Strongly Disagree

2. Having an open mind is important when investigating scientific data.

Strongly Agree Agree Disagree Strongly Disagree

3. Scientific theories are scientist opinions.

Strongly Agree Agree Disagree Strongly Disagree

4. Scientific ideas and knowledge are subject to change.

Strongly Agree Agree Disagree Strongly Disagree

5. Over time and with enough evidence, scientific theories become laws.

Strongly Agree Agree Disagree Strongly Disagree

6. All scientific studies are equally valid.

Strongly Agree Agree Disagree Strongly Disagree

7. Scientific theories can be strong or weak.

Strongly Agree Agree Disagree Strongly Disagree

8. Scientists backgrounds and personal beliefs can influence how they interpret the findings of a scientific study.

Strongly Agree Agree Disagree Strongly Disagree

9. Anyone can be a scientist if they want to.

Strongly Agree Agree Disagree Strongly Disagree

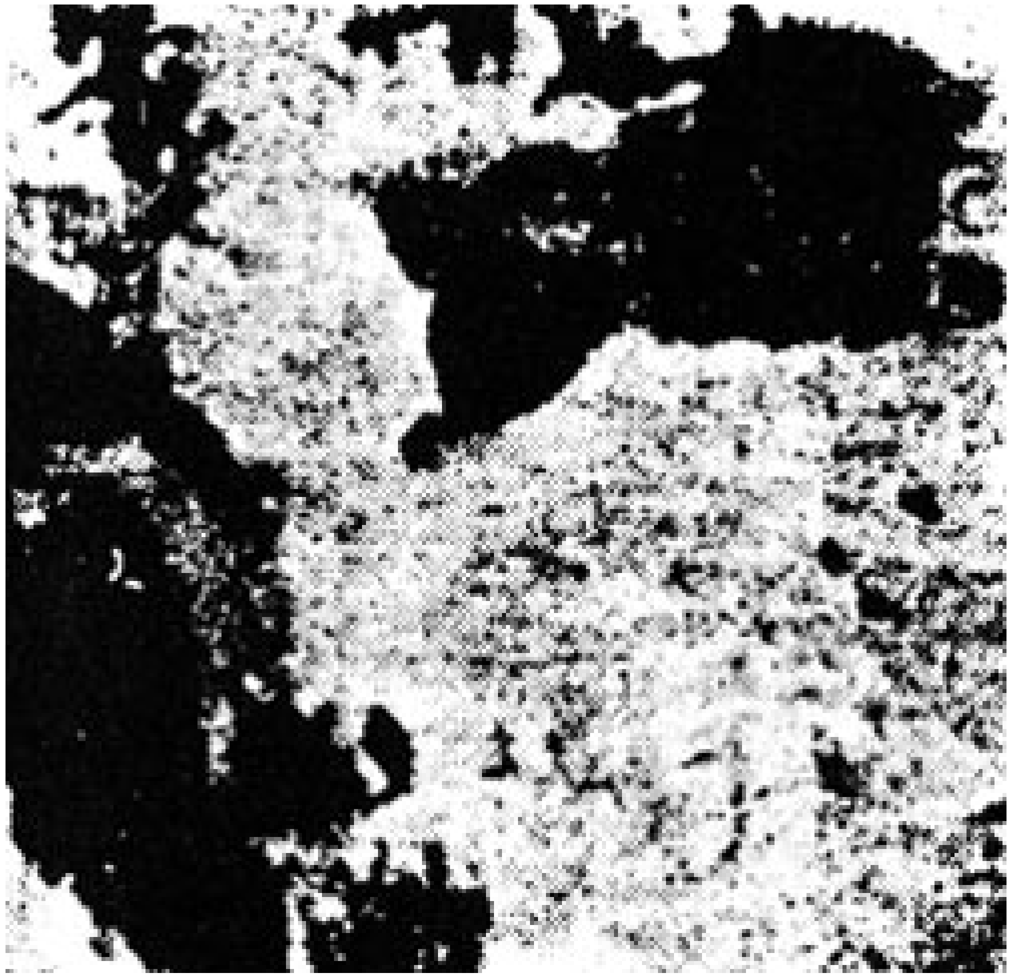
10. It is important to be as objective as possible when collecting scientific data.

Strongly Agree Agree Disagree Strongly Disagree

APPENDIX B

PICTORIAL GESTALT IMAGE

Sample of a pictorial gestalt image used during the teaching of the NOS



APPENDIX C

BLACK BOX ACTIVITY

Below are sample images of black box activities which required students to determine ‘how it worked’ without actually opening up the object.

APPENDIX D

PUZZLE SOLVING ACTIVITY

Example Puzzle Solving Activity.

The following diagram was cut out for students. Students originally were given four of the five pieces. Students were given no further instructions. After most students had created a square, the ‘x’ piece was handed out to them as new scientific information.

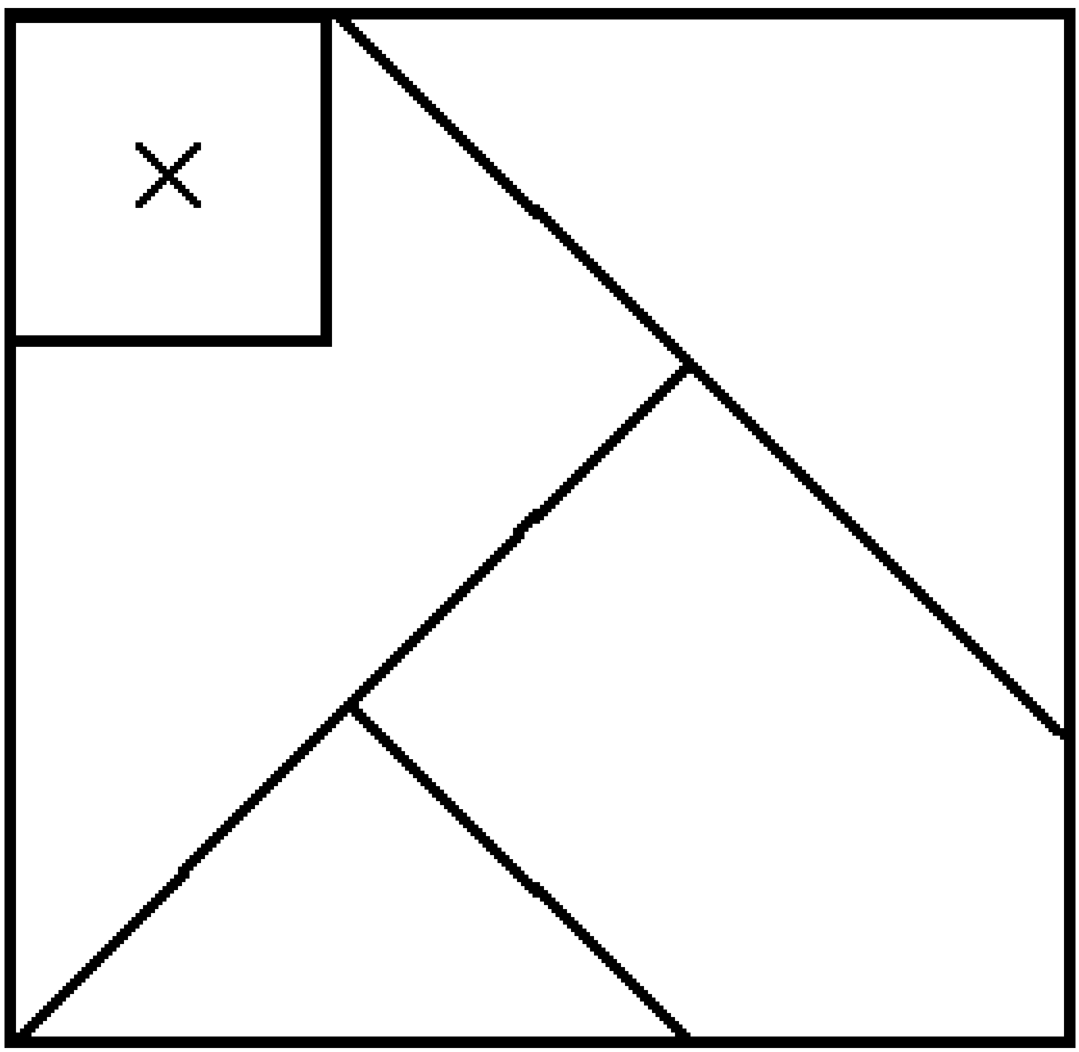


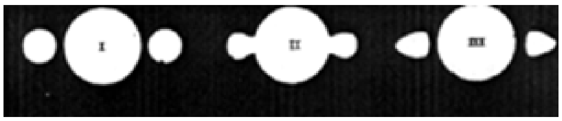
Figure 1

APPENDIX E

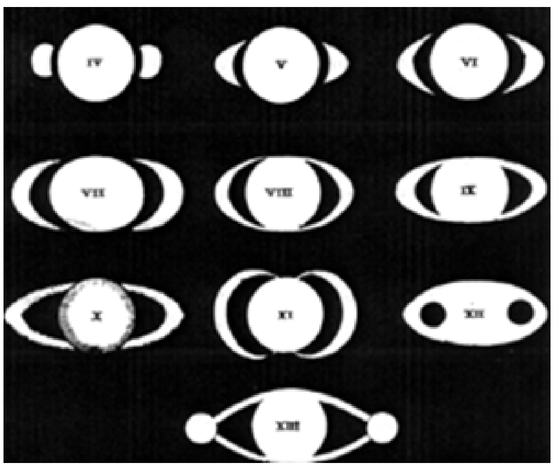
HISTORICAL CONTEXT

Example of Historical Context

The following images taken from telescopes at the time of Galileo provided an opportunity to discuss how the concept of rings orbiting Saturn came to be.



Galileo's first observations of Saturn. Images looked like moons, Galileo assumes that what he is seeing is moons.



Further observations by Galileo muddy the water and Galileo has no way to explain what he is seeing. It took the open mindedness of another scientist to uncover the mystery of Saturn.

A Look Back in Time: The Mystery of the Rings around Saturn

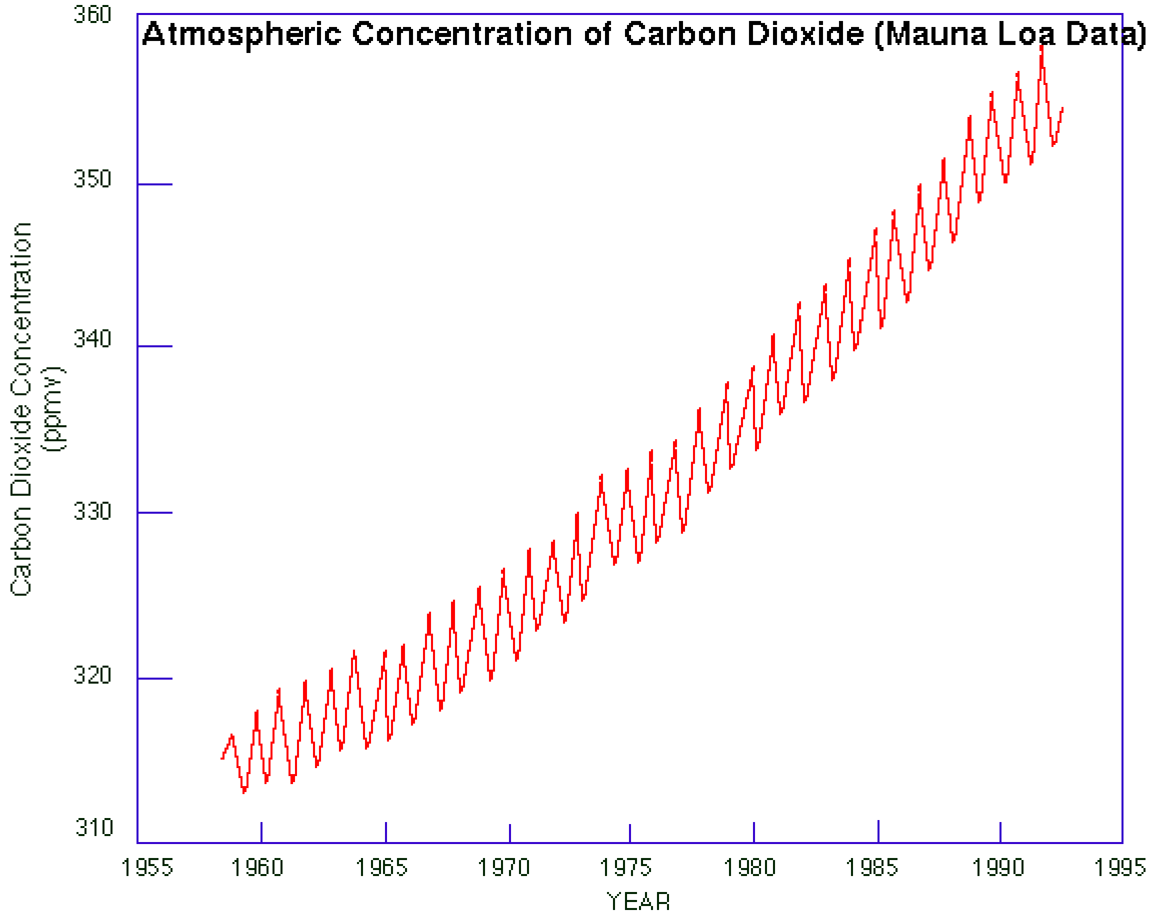
The images to the left are what early astronomers, such as Galileo, saw when looking at Saturn. At the time, no one had even conceived the idea that a planet could have rings. After Galileo discovered the moons of Jupiter, his mind assumed that what he was seeing was moons around Saturn. When the moons begain to change shape and disappear at times, Galileo was confused. It wasn't until Huygen had the idea that it may be a ring around Saturn that the scientific community was able to put together a more accurate model of Saturn

APPENDIX F

LIMITED DATA SET ACTIVITY

Sample Limited Data Set Activity

Students were provided with a variety of graphs and data and asked to draw conclusions and develop theories related to the cause of the data.

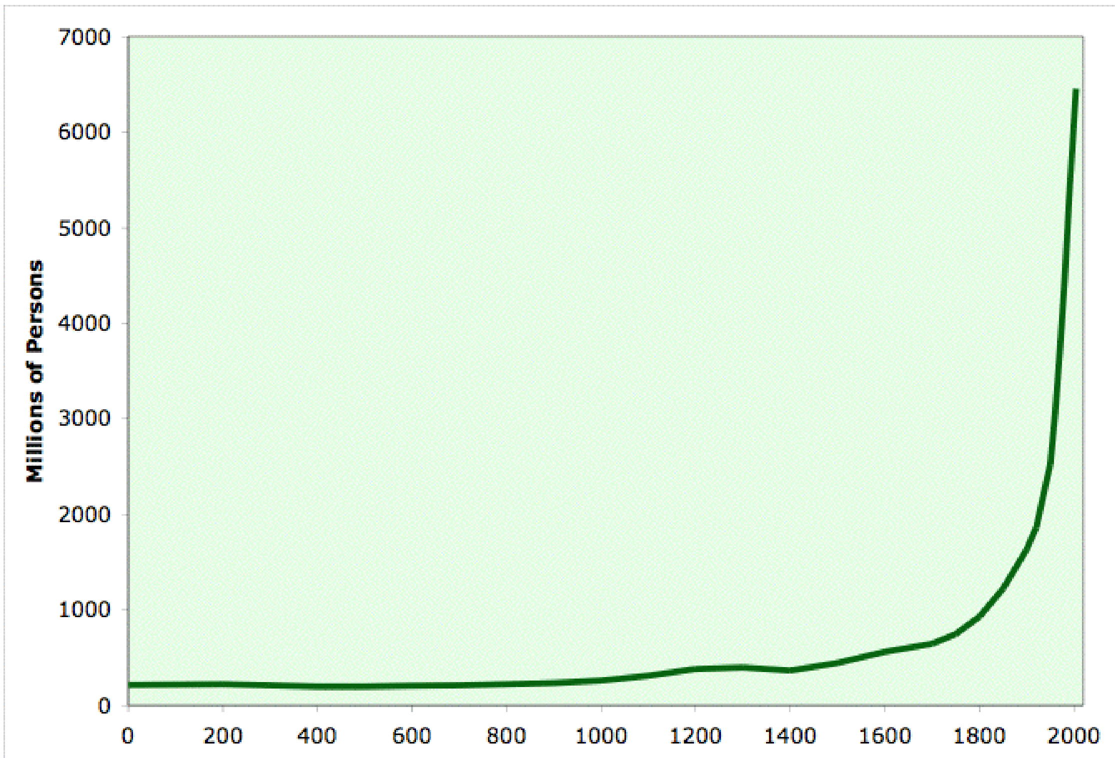


APPENDIX G

HYPOTHETICAL SCIENCE SITUATION

Sample Hypothetical Science Situation

Students were provided the following graph and were asked to defend whether the results are the result of better agriculture or better medicine. Other ideas were also allowed to be included. Graph is a population of the world since 0 A.D.



APPENDIX H

DENSITY PERFORMANCE ASSESSMENT

Density Score Sheet for Performance Assessment

Students were asked to find the density of an unknown and irregularly shaped object. The following rubric was used to score their performance.

Massing

_____ Made sure balance was 'balanced.' Adjusted as necessary.

_____ Used largest masses first, then moved to smaller masses

_____ Aligned grooves

_____ Used proper amount of accuracy

_____ Balanced the scale to the object

Volume

_____ No parallax error

_____ Read from bottom of meniscus

_____ Proper scale (ascending)

_____ Used proper accuracy

_____ Recorded the proper volume

Density

_____ Recorded volume before placing object in

_____ Carefully placed object in

_____ Recorded volume after placing object in

_____ Determined volume of object

_____ Determined density of object

_____ / 15 Score

APPENDIX I

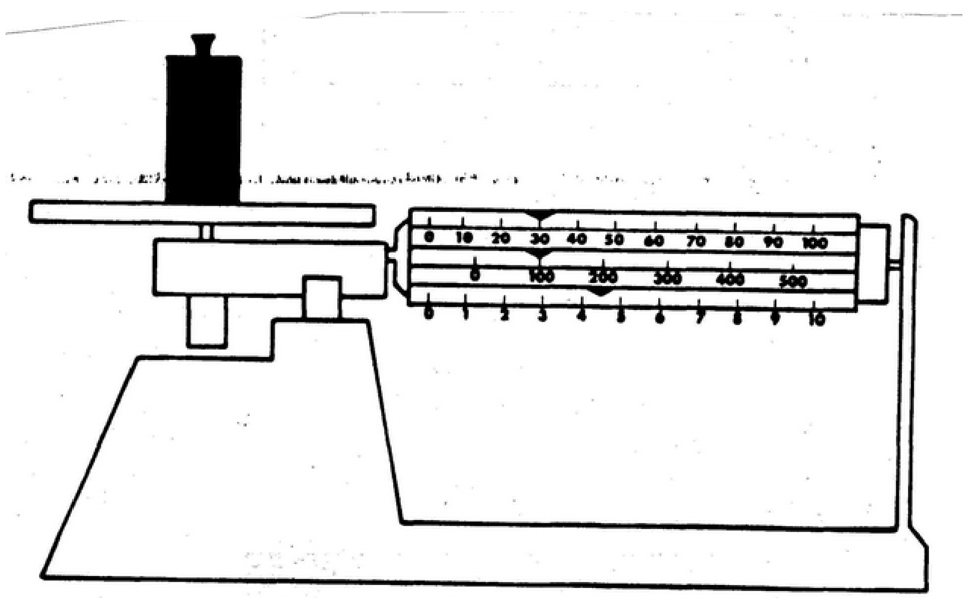
SIGNIFICANT DIGIT INCLUSION CONTENT

Sample Significant Digits Questions

The following types of questions were used to teach and assess students understanding of significant digits.

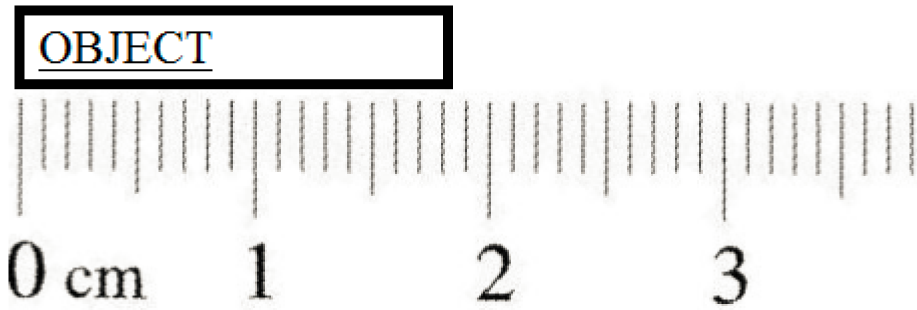
_____ Using proper accuracy, what would be the mass of the object below? The dark triangles denote where the balance masses are.

a) 230 g b) 104.5g c) 204.5 g d) 234.5 g e) 134.5 g



_____ Using proper accuracy, what would be the length of the object below?

a) 1.8 cm b) 2 cm c) 1.9 cm d) 1.82 cm e) 1.92 cm



APPENDIX J

PRETREATMENT SURVEY

Initial Student Survey of Ability to Think Like a Scientist

A big goal of the physical science class you are taking is helping you to learn to think like a scientist. Thinking like a scientist uses skills such as analyzing, evaluating, and synthesizing scientific information. Please let me know how confident you are in these areas by answering the following questions honestly. NOTE: Participation is voluntary, and you can choose to not answer any question that you do not want to answer, and you can stop at anytime. Participation in this research is voluntary and participation or non-participation will not affect a student's grades or class standing in any way

* Required

I feel confident and comfortable in my ability to analyze scientific information *

For example, analyzing scientific information includes being able to look at a chart, graph, or data table and understand what the information is telling you.

- Strongly Disagree
- Disagree
- Agree
- Strongly Agree

I feel confident and comfortable in my ability to evaluate scientific information *

For example, evaluating scientific information involves being able to look at a science fair project or study and judge whether the project was done properly, gained meaningful data, and whether the conclusion given is appropriate.

- Strongly Disagree
- Disagree
- Agree
- Strongly Agree

I feel confident and comfortable in my ability to synthesize scientific thought *

For example, synthesizing scientific thought involves coming up with a hypothesis or a scientific study (science fair project) to answer a question.

- Strongly Disagree
- Disagree
- Agree
- Strongly Agree

When I analyze information, data (facts and figures), or ideas *

Note: Question created by Valencia Community College by the Learning Evidence Team in 2005.

- Generally, I can report what I have read or heard with only a few mistakes. For example, When there are reading comprehension questions, I usually get most of them right. For example, When a friend gives me directions to her house, I can find it without getting lost.
- I can figure out how to use data and ideas to solve problems or complete assignments that are similar to examples I have seen. For example, When I see the examples in the textbook, I understand how to do the homework. For example, After we studied the Renaissance in humanities, I could pick out a Renaissance painting.

- I often copy the work of others and still may make mistakes.   For example, I like it when the teacher gives me a copy of the notes because mine don't make much sense. For example, I try to work problems the way they are done in the book, but sometimes I get the wrong answer.
- I can provide in-depth analysis of the data or ideas that I use to solve problems or complete assignments. For example, Once I determine how to solve a problem, I can help other students understand how to solve it.

When I try to come to a conclusion about something I am thinking… *
Note: Question created by Valencia Community College by the Learning Evidence Team in 2005.

- I can create a conclusion that is logical and that reflects my ideas, too. For example, In one of my classes, I analyzed different theories about what stimulates innovation and developed my own theory of why innovation occurs. For example, After seeing the other team's presentation, I was able to add my thoughts to theirs to create a joint proposal we could all agree on.
- My conclusion matches the evidence that has been presented. For example, In the Laci Peterson investigation, I made my conclusion about Scott Peterson's guilt based on the evidence I saw and read about. For example, When I write papers in American government, I am careful that my conclusions are based on the information I included in my paper.
- I can comfortably restate what has been said. For example, When I give a speech on something like alcohol addiction, I can add a quick recap for my conclusion. For example, I am usually more comfortable saying what has been said than coming up with my own conclusions.
- I have trouble thinking of anything to say. For example, I have problems with conclusions, especially when writing papers. For example, I had trouble explaining to my group what I was going to say in my speech.

When I try to pull ideas together to get the big picture… *
Note: Question created by Valencia Community College by the Learning Evidence Team in 2005.

- I can arrange the ideas into a pattern that includes clear relationships among ideas. For example, With my friends, I always I arrange the stuff we all want to do and then we do it. For example, I like to watch CSI, where I watch for the little clues that tell me who the murderer was.
- I   I can arrange most ideas into a pattern, if it's not too complicated. For example, I can pull together various ideas when trying to get the big picture. For example, I can learn a new dance routine if it doesn't have too many steps.
- I often see the pieces better than the big picture. For example, Sometimes it's easier and less complicated to go piece by piece. For example, I am a here-and-now thinker. I usually don't think about the big picture.
- I can link ideas together in complicated patterns and explain complex relationships. For example, Before the War in Iraq, I predicted what might happen if we invade a country that never attacked us. For example, I can explain the differences between breast and prostate cancer.

Is there anything else you would like me to know about this topic?

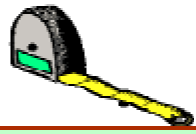
Submit

Never submit passwords through Google Forms.

APPENDIX K

SELF RUBRIC OVER CRITICAL THINKING FOR VALENCIA COMMUNITY COLLEGE

Retrieved from http://valenciacollege.edu/learningevidence/



Measuring My Critical Thinking

For each question, select the answer that best describes you.

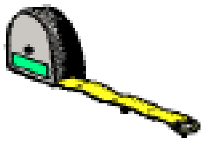
1. When I analyze information, data (facts and figures), or ideas, either at work or in class…	
(a)	**Generally, I can report what I have read or heard with only a few mistakes.** For example: ▪ When there are reading comprehension questions, I usually get most of them right. ▪ When a friend gives me directions to her house, I can find it without getting lost.
(b)	**I can figure out how to use data and ideas to solve problems or complete assignments that are similar to examples I have seen.** For example: ▪ When I see the examples in the textbook, I understand how to do the homework. ▪ After we studied the Renaissance in humanities, I could pick out a Renaissance painting.
(c)	**I often copy the work of others and still may make mistakes.** For example: ▪ I like it when the teacher gives me a copy of the notes because mine don't make much sense. ▪ I try to work problems the way they are done in the book, but sometimes I get the wrong answer.
(d)	**I can provide in-depth analysis of the data or ideas that I use to solve problems or complete assignments.** For example: ▪ At work I take calls all day long. I can interpret, research, and respond to any question about my area. ▪ Once I determine how to solve a problem, I can help other students understand how to solve it.

2. When I try to apply formulas, procedures, principles, or themes to a new problem, assignment, or situation…	
(a)	**I have trouble thinking of the right formula or concept to use.** For example: ▪ I never remember which formula to use without someone reminding me. ▪ When my boss asked me how the new deep fryer worked, all I could say was "good."
(b)	**I can use formulas or concepts accurately to solve new problems or new situations.** For example: ▪ I was given a new assignment at work. Although I was unfamiliar with the paperwork, I figured out how to complete it correctly. I even made suggestions for improving the forms. ▪ If I see a question or a formula, I first decode the information contained in the question or formula and then I know how to use it.
(c)	**I can use the right formula or concept accurately–if the situation or problem is familiar.** For example: ▪ I can usually pick the right formula or concept if the problem isn't too complex, like figuring out what to do on a vacation each day. ▪ If I see a right triangle, I will remember which formulas apply.
(d)	**Usually, I can think of the right formula or concept, but I often have trouble using it correctly.** For example: ▪ When I listen to a politician speaking, I have trouble deciding if she is a Democrat or a Republican. ▪ I may choose the right formula or concept, but because I don't have faith in my thinking, I will question whether I am right.

3. When I try to think about a subject, problem, or situation from more than one point of view…	
(a)	**I can see two sides of any issue, but tend to think one of them is right.** For example: ▪ I can usually see where the other person is coming from, but like to think I'm right. ▪ My boyfriend and I split up because he wanted a break. I understand, but I don't think he is right.
(b)	**Most of the time, I can think of only one way to see it.** For example: ▪ My science teacher says that I need to be open-minded, but I can't see why. ▪ I don't like it when someone shows me more than one way to do something.
(c)	**I can see the value in viewing things from many points of view.** For example: ▪ When my Mom gets mad at me, I put myself in her shoes so that I can understand why she is mad. ▪ I can argue multiple points of view or play devil's advocate, even if I feel strongly about an issue, because looking at something from many points of view builds mature convictions and opinions.
(d)	**I can see most issues from multiple points of view.** For example: ▪ When my friends debate, I can see both sides of the issue. ▪ Writing my persuasive essay in ENC 1101 was difficult because I had to choose one side when I saw both sides of the issue.

4. When I try to come to a conclusion about something I am thinking…	
(a)	**I can create a conclusion that is logical and that reflects my ideas, too.** For example: ▪ In one of my classes, I analyzed different theories about what stimulates innovation and developed my own theory of why innovation occurs. ▪ After seeing the other team's presentation, I was able to add my thoughts to theirs to create a joint proposal we could all agree on.
(b)	**My conclusion matches the evidence that has been presented.** For example: ▪ In the Laci Peterson investigation, I made my conclusion about Scott Peterson's guilt based on the evidence I saw and read about. ▪ When I write papers in American government, I am careful that my conclusions are based on the information I included in my paper.
(c)	**I can comfortably restate what has been said.** For example: ▪ When I give a speech on something like alcohol addiction, I can add a quick recap for my conclusion. ▪ I am usually more comfortable saying what has been said than coming up with my own conclusions.
(d)	**I have trouble thinking of anything to say.** For example: ▪ I have problems with conclusions, especially when writing papers. ▪ I had trouble explaining to my group what I was going to say in my speech.

5. When I try to pull ideas together to get the big picture…	
(a)	**I can arrange the ideas into a pattern that includes clear relationships among ideas.** For example: ▪ With my friends, I always I arrange the stuff we all want to do and then we do it. ▪ I like to watch CSI, where I watch for the little clues that tell me who the murderer was.
(b)	**I can arrange most ideas into a pattern, if it's not too complicated.** For example: ▪ I can pull together various ideas when trying to get the big picture. ▪ I can learn a new dance routine if it doesn't have too many steps.
(c)	**I often see the pieces better than the big picture.** For example: ▪ Sometimes it's easier and less complicated to go piece by piece. ▪ I am a here-and-now thinker. I usually don't think about the big picture.
(d)	**I can link ideas together in complicated patterns and explain complex relationships.** For example: ▪ Before the War in Iraq, I predicted what might happen if we invade a country that never attacked us. ▪ I can explain the differences between breast and prostate cancer.



Measuring My Critical Thinking

Add up the total for your answers:

1(a) = 2	2(a) = 1	3(a) = 2	4(a) = 4	5(a) = 3
1(b) = 3	2(b) = 4	3(b) = 1	4(b) = 3	5(b) = 2
1(c) = 1	2(c) = 2	3(c) = 4	4(c) = 2	5(c) = 1
1(d) = 4	2(d) = 3	3(d) = 3	4(d) = 1	5(d) = 4

If you scored from 1-5, you are probably just beginning to think critically. While many Valencia students begin here, you can expand your critical thinking abilities by becoming actively involved in classroom assignments and extracurricular activities.

A **BEGINNING** critical thinker:

- Relies on copying the work of others, sometimes inaccurately, to solve problems or complete assignments
- Has trouble thinking of the right formula or concept to use
- Sees issues from only one side
- Has difficulty forming a conclusion
- Sees the pieces better than the big picture

If you scored from 6-10, you have developed some critical thinking skills. You can expand your critical thinking abilities by challenging yourself to take on more difficult courses and extracurricular experiences that will expand your thinking.

A **DEVELOPING** critical thinker:

- Reports what s/he has read or heard when solving a problem or completing an assignment
- Thinks of the right formula or concept, but has trouble using it correctly
- Sees two sides of an issue, but knows which one is right
- Forms a conclusion by restating what has been said
- Arranges ideas into a simple pattern

If you scored from 11-15, you are probably pretty good at critical thinking, but you shouldn't rest there. Seek out courses and extracurricular projects that will help you refine your critical thinking abilities and develop your leadership skills.

A **COMPETENT** critical thinker:

- Figures out how to use data and ideas to solve problems or complete assignments that are similar to familiar examples
- Uses the right formula or concept accurately if the situation or problem is familiar
- Sees most issues from multiple points of view
- Makes conclusions that match the evidence presented
- Arranges ideas into clear patterns

If you scored from 16-20, you are probably very adept at critical thinking. You have learned that critical thinking is one of the most valuable skills in any profession or situation and—like anything—when you can do it well, it's just plain fun! You'll be excited to know that your critical thinking skills continue expanding throughout your lifetime.

An **ACCOMPLISHED** critical thinker:

- Provides in-depth analysis of data or ideas used to solve problems or complete assignments
- Uses formulas or concepts accurately to solve new problems or assignments
- Sees the value in viewing things from multiple points of view
- Creates conclusions that are logical, unique and personal
- Links ideas together in complicated patterns and explains complex relationships

APPENDIX L

POST-TREATMENT SURVEY

Final Student Survey of Ability to Think Like a Scientist

A big goal of the physical science class you are taking is helping you to learn to think like a scientist. Thinking like a scientist uses skills such as analyzing, evaluating, and synthesizing scientific information. After learning about the Nature of Science, how has this hindered / helped you in these areas?
NOTE: Participation is voluntary, and you can choose to not answer any question that you do not want to answer, and you can stop at anytime. Participation in this research is voluntary and participation or non-participation will not affect a student's grades or class standing in any way

* Required

I feel confident and comfortable in my ability to analyze scientific information *
For example, analyzing scientific information includes being able to look at a chart, graph, or data table and understand what the information is telling you.

- Strongly Disagree
- Disagree
- Agree
- Strongly Agree

I feel confident and comfortable in my ability to evaluate scientific information *
For example, evaluating scientific information involves being able to look at a science fair project or study and judge whether the project was done properly, gained meaningful data, and whether the conclusion given is appropriate.

- Strongly Disagree
- Disagree
- Agree
- Strongly Agree

I feel confident and comfortable in my ability to synthesize scientific thought *
For example, synthesizing scientific thought involves coming up with a hypothesis or a scientific study (science fair project) to answer a question.

- Strongly Disagree
- Disagree
- Agree
- Strongly Agree

When I analyze information, data (facts and figures), or ideas *
Note: Question created by Valencia Community College by the Learning Evidence Team in 2005.

- Generally, I can report what I have read or heard with only a few mistakes. For example, When there are reading comprehension questions, I usually get most of them right. For example, When a friend gives me directions to her house, I can find it without getting lost.
- I can figure out how to use data and ideas to solve problems or complete assignments that are similar to examples I have seen. For example, When I see the examples in the textbook, I understand how to do the homework. For example, After we studied the Renaissance in humanities, I could pick out a Renaissance painting.

- I often copy the work of others and still may make mistakes. For example, I like it when the teacher gives me a copy of the notes because mine don't make much sense. For example, I try to work problems the way they are done in the book, but sometimes I get the wrong answer.
- I can provide in-depth analysis of the data or ideas that I use to solve problems or complete assignments. For example, Once I determine how to solve a problem, I can help other students understand how to solve it.

When I try to come to a conclusion about something I am thinking… *
Note: Question created by Valencia Community College by the Learning Evidence Team in 2005.

- I can create a conclusion that is logical and that reflects my ideas, too. For example, In one of my classes, I analyzed different theories about what stimulates innovation and developed my own theory of why innovation occurs. For example, After seeing the other team's presentation, I was able to add my thoughts to theirs to create a joint proposal we could all agree on.
- My conclusion matches the evidence that has been presented. For example, In the Laci Peterson investigation, I made my conclusion about Scott Peterson's guilt based on the evidence I saw and read about. For example, When I write papers in American government, I am careful that my conclusions are based on the information I included in my paper.
- I can comfortably restate what has been said. For example, When I give a speech on something like alcohol addiction, I can add a quick recap for my conclusion. For example, I am usually more comfortable saying what has been said than coming up with my own conclusions.
- I have trouble thinking of anything to say. For example, I have problems with conclusions, especially when writing papers. For example, I had trouble explaining to my group what I was going to say in my speech.

When I try to pull ideas together to get the big picture… *
Note: Question created by Valencia Community College by the Learning Evidence Team in 2005.

- I can arrange the ideas into a pattern that includes clear relationships among ideas. For example, With my friends, I always I arrange the stuff we all want to do and then we do it. For example, I like to watch CSI, where I watch for the little clues that tell me who the murderer was.
- I I can arrange most ideas into a pattern, if it's not too complicated. For example, I can pull together various ideas when trying to get the big picture. For example, I can learn a new dance routine if it doesn't have too many steps.
- I often see the pieces better than the big picture. For example, Sometimes it's easier and less complicated to go piece by piece. For example, I am a here-and-now thinker. I usually don't think about the big picture.
- I can link ideas together in complicated patterns and explain complex relationships. For example, Before the War in Iraq, I predicted what might happen if we invade a country that never attacked us. For example, I can explain the differences between breast and prostate cancer.

Learning about the Nature of Science helped me in my ability to analyze scientific information *

- Strongly Disagree
- Disagree
- Neutral
- Agree

- Strongly Agree

Learning about the Nature of Science helped me in my ability to evaluate scientific information *

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

Learning about the Nature of Science helped me in my ability to synthesize scientific thought *

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

Is there anything else you would like me to know about this topic?

Submit

Never submit passwords through Google Forms.

APPENDIX M

PRETREATMENT ADVANCED DEVELOPING SCIENTIST WRITTEN ASSIGNMENT

Advanced Developing Scientist One: Pendulum Simulator

In today's developing scientist you are to develop a science experiment using the PhET simulator "Pendulums" and then actually carry out the experiment drawing conclusions from what was learned

Background Information

The simulator provides at your disposal a pendulum (option for two). These pendulums will swing back and forth if given an initial lift.

Things you are able to adjust using the simulator:

- The planet you are on which will change the gravitational strength
- The amount of friction present
- The length of the string
- The amount of mass pulling on the pendulum

Measuring devices you can use with the simulator:

- A ruler
- A photogate timer (special type of stowatch)
- A stopwatch (other tools option)
- The simulator can also tell you how much energy is present
- The simulator also allows you to pause and / or adjust how fast the simulator moves

Instructions

Go to the following website. You can either copy and paste the below link into your browser, or search for "PhET Pendulum Lab." Mr. Love can help you find the site as well.

http://phet.colorado.edu/sims/pendulum-lab/pendulum-lab_en.html

Spend a few minutes becoming familiar with the simulator, adjusting different things, and gathering some initial observations. Then, when you are ready…

1. Propose a question (hypothesis) which could be studied related to the topic given.

2. Please include a detailed description of your proposed study below, including methods, variables, how you would acquire data and assess it, etc...

3. Record all data taken in a neat an organized data table

4. Write a conclusion based off the data generated. The conclusion should be supported by the data collected.

5. Develop a hypothesis for another experiment which would help justify your conclusions and predict what the results would be.

APPENDIX N

POSTTREATMENT ADVANCED DEVELOPING SCIENIST WRITTEN ASSIGNMENT

Advanced Developing Scientist Two: Masses & Spring Simulator

In today's developing scientist you are to develop a science experiment using the PhET simulator "Masses & Springs" and then actually carry out the experiment drawing conclusions from what was learned

Background Information

The simulator provides at your disposal three springs. These springs will oscillate, which means vibrate up and down, when a mass is hung upon them.

Things you are able to adjust using the simulator:

- The planet you are on which will change the gravitational strength
- The amount of friction present
- The stiffness of the spring (spring 3 only)
- The amount of mass pulling on the spring

Measuring devices you can use with the simulator:

- A ruler
- A stopwatch (above the show help)
- The simulator can also tell you how much energy is present
- The simulator also allows you to pause and / or adjust how fast the simulator moves

Instructions

Go to the following website. You can either copy and paste the below link into your browser, or search for "PhET Masses and Springs." Mr. Love can help you find the site as well.

http://phet.colorado.edu/sims/mass-spring-lab/mass-spring-lab_en.html

Spend a few minutes becoming familiar with the simulator, adjusting different things, and gathering some initial observations. Then, when you are ready…

1. Propose a question (hypothesis) which could be studied related to the topic given.

2. Please include a detailed description of your proposed study below, including methods, variables, how you would acquire data and assess it, etc...

3. Record all data taken in a neat an organized data table

4. Write a conclusion based off the data generated. The conclusion should be supported by the data collected.

5. Develop a hypothesis for another experiment which would help justify your conclusions and predict what the results would be.

APPENDIX O

ADVANCED DEVELOPING SCIENTIST RUBRIC

Advanced Developing Scientist Rubric

0 – Non-existent
1 – Beginning / Developing Ideas: Not always useful information, relevancy not present
3 – Competent Response: Clear response which provides some justification and shows relevancy
5 – Accomplished / Complex Ideas : Explains accurately, thoroughly, and well justifies response

Related to Question One **SYNTHESIS**

1. Proposed hypothesis
   0 – No hypothesis generated
   1 – Hypothesis generated not related to topic
   3 – Hypothesis generated which is related to topic but too open ended and not a focused question.
   5 – Hypothesis generated is a highly focused question which is related to topic and a measurable prediction is given.

Related to question two **SYNTHESIS**

2. Proposed procedure is highly detailed and includes all relevant information

   0 – No procedure written
   1 – Procedure is missing many important details / does not adequately inform reader of what is actually happening / not sequential / many steps are missing or written in a confusing manner. Procedure not capable of answering questions related to topic.
   3 – Some procedure steps are understandable / most lack details. Procedure may result in relevant data to question posed.
   5 - Procedure is written in such a way that the reader is completely informed, knowing exactly what is happening. It is logical and easy to follow. Highly relevant data will be gathered by use of the proposed procedure.

Related to Question Four **ANALYSIS / EVALUATION**

1. Appropriate conclusions given
   0 – No conclusions given
   1 – Conclusion given does not utilize the data generated
   3 – Conclusion given utilizes the data generated but is not accurate / not interpreting data properly
   5 – Conclusion given utilizes the data generated and provides an accurate analysis of the data

APPENDIX P

PRETREATMENT DEVELOPING SCIENTIST WRITTEN ASSIGNMENT

Developing Scientist One: Growing Plants

In today's Developing Scientist, your job is related to developing a scientific study of plants growing.

Background Information

Every single plant has basic needs in order to grow. Not every type of plant requires the same amount as others, but below is a condensed list of needs:

- Proper amount of minerals in the soil. Some elements, such as lead and aluminum, tend to be toxic to plants growing. Others, such as magnesium, nitrogen, potassium, phosphorus, and calcium, are generally fairly important for different plants to grow. Fertilizers fall into this category of making the soil richer in the right kind of minerals. There are different mixtures for fertilizers, each with the right proportion of minerals for the plant to be grown.
- Proper pH of the Soil. Some plants thrive in acidic soils, some plants don't. Some plants are able to survive in acidic and basic soils and even may produce different colors of flowers in different acidity levels.
- Proper amount of water. Every plant needs some water. However, a cactus in the desert probably has different demands for water when compared to a plant growing in the rain forest.
- Air Quality. Plants take in carbon dioxide from the air in order to produce sugar. More carbon dioxide in the air may help plants grow better.
- Sunlight. Without sun, the plant will not be able to use photosynthesis and use the energy of the sun to grow. Some plants require more sun than others. Some plants prefer direct sunlight while others can grow in indirect sunlight (plants on bottom of rainforest).
- Proper soil temperature. I wouldn't recommend planting your spring garden in February. Most seeds will not grow into a plant if planted then. Every plant has a different soil temperature which will optimize its growth.
- Proper air temperature. Related to soil temperature, some plants will not tolerate 100 degrees and others will not tolerate freezing temperatures.
- Pollination. In order to make 'more plants,' most plants use sexual reproduction. This requires pollen (male gametes) to find the ovule (female gamete) of the plant. Plants can either cross pollinate (be pollinated by another type of plant) or self pollinate (be pollinated by same type of plant). Insects and wind do the ground work to get the two gametes together.

1. Propose a question (hypothesis) which could be studied related to the topic given.
2. Please include a detailed description of your proposed study below, including methods, variables, how you would acquire data and assess it, etc...
3. What do you see as possible outcomes of your study and what conclusions could be drawn from these?
4. Choose one of your possible outcomes and conclusions from question two above. Then, develop a hypothesis for another experiment which would help justify your conclusions and predict what the results would be.
5. What are some other possible methods which could have been used to measure your results? What benefits did your method have over the others which made it a better choice to be used? What are some of the limitations of your chosen method and data it can obtain?

APPENDIX Q

POSTTREATMENT DEVELOPING SCIENTIST WRITTEN ASSIGNMENT

Developing Scientist Two: Insulating the Home

In today's Developing Scientist, your job is to develop a scientific study related to the insulation of your home.

Background Information

Insulators are materials which resist the transfer of heat. A better insulator will minimize how quickly heat is lost or gained. For example, a good coffee mug is capable of keeping the heat from leaving the coffee. A good ice cooler keeps heat from entering in.

Heat is transferred when two objects or areas of space (warm room / cold room) have different temperatures. The larger the temperature difference, the faster the energy is transferred.

- <u>Type of Insulation used.</u> The type of insulation your home has may influence how much money you spend on heating and cooling your home. Some common materials used to insulate your attic include
  - Fibreglass. This material tends to perform better in dry conditions. Attics in humid locations may make the insulation damp and change the effectiveness of the fiberglass.
  - Cellulose. This material is more expensive but more resistant to damp conditions.
  - Mineral wool. This material does not absorb water at all and is a permanent insulation for your home. While the others may be moved around by convection currents in attic (wind) the mineral wool will not be displaced

  It should also be noted that for fiberglass and cellulose the way the insulation is installed may influence the level of insulation as well. These materials can be blown into the attic, making the attic floor look like it is covered in cotton candy, or the materials can be installed as a large singular cut out piece, which is rolled out in between the wood frames for the attic.
- <u>Type of Insulation used part II.</u> Walls are built out of different materials than your attic insulation. Concrete, brick, wood, and steel are all different materials which may be used to build your walls. Each of these will provide a different level of insulation
- <u>Thickness of Insulation used.</u> Your spring jacket and winter coat may be made out of the same material, but each provides different levels of insulation. The thickness of the insulation changes how resistant it is to heat being lost.
- <u>Windows</u>. Windows tend to be large sources of heat loss. Generally the glass is much thinner than the rest of the wall. Some windows are double paned, which means the glass is two layers thick with a thin layer of air in-between the panes to improve insulation. Some people even put cellophane wrap on the window to help trap more air to try to minimize heat lost.
- <u>Doors.</u> The door may or may not fit completely snug in the frame and this may result in energy lost through the cracks. It is possible to buy rubber strips to help minimize this heat lost.

- Thermostat. While the thermostat will not change how well insulated your home is, it may influence how fast it loses energy. The larger the temperature difference, the more energy that will be lost. If you set your thermostat to 50 F in the summer, your house will be much colder than the outside, resulting in more energy being absorbed by the home.

6. Propose a question (hypothesis) which could be studied related to the topic given.
7. Please include a detailed description of your proposed study below, including methods, variables, how you would acquire data and assess it, etc...
8. What do you see as possible outcomes of your study and what conclusions could be drawn from these?
9. Choose one of your possible outcomes and conclusions from question two above. Then, develop a hypothesis for another experiment which would help justify your conclusions and predict what the results would be.
10. What are some other possible methods which could have been used to measure your results? What benefits did your method have over the others which made it a better choice to be used? What are some of the limitations of your chosen method and data it can obtain?

APPENDIX R

RUBRIC FOR DEVELOPING SCIENTIST

Developing Scientist Rubric

General score and type of response

0 – Non-existent

1 – Beginning / Developing Ideas: Not always useful information, relevancy not present

3 – Competent Response: Clear response which provides some justification and shows relevancy

5 – Accomplished / Complex Ideas : Explains accurately, thoroughly, and well justifies response, conveys

Related to Question One **SYNTHESIS**

3. Proposed hypothesis
   0 – No hypothesis generated
   1 – Hypothesis generated not related to topic
   3 – Hypothesis generated which is related to topic but too open ended and not a focused question.
   5 – Hypothesis generated is a highly focused question which is related to topic and a measurable prediction is given.

Related to question two **SYNTHESIS**

4. Proposed procedure is highly detailed and includes all relevant information

   0 – No procedure written
   1 – Procedure is missing many important details / does not adequately inform reader of what is actually happening / not sequential / many steps are missing or written in a confusing manner. Procedure not capable of answering questions related to topic.
   3 – Some procedure steps are understandable / most lack details. Procedure may result in relevant data to question posed.
   5 - Procedure is written in such a way that the reader is completely informed, knowing exactly what is happening. It is logical and easy to follow. Highly relevant data will be gathered by use of the proposed procedure.

Related to Question Three **ANALYSIS / SYNTHESIS**

5. Possible outcomes given
   0 – No possible outcomes given
   1 – Possible outcomes given but they are not appropriate to the topic and experiment
   3 – One possible outcome which is probable given / other outcomes given not appropriate
   5 – Multiple possible outcomes given which are highly appropriate to the study

6. Appropriate conclusions given
   0 – No conclusions given
   1 – Possible conclusions given but they are not appropriate given the suggested outcome
   3 – One possible conclusion given which is appropriate / others inappropriate
   5 – Multiple appropriate conclusions given which are appropriate to study

APPENDIX S

PRETREATMENT EXPLORE TEST FORM 05A LEVEL OF THINKING

Results of the Explore 05A Test and Panel of Experts Decision on Level of Question

Question	Non-Analysis / Evaluation	Analysis / Evaluation
1	89.58%	0.00%
2	0.00%	79.17%
3	91.67%	0.00%
4	70.83%	0.00%
5	87.50%	0.00%
6	83.33%	0.00%
7	0.00%	70.83%
8	0.00%	79.17%
9	0.00%	87.50%
10	95.83%	0.00%
11	70.83%	0.00%
12	0.00%	58.33%
13	64.58%	0.00%
14	89.58%	0.00%
15	0.00%	91.67%
16	0.00%	68.75%
17	0.00%	47.92%
18	79.17%	0.00%
19	0.00%	72.92%
20	0.00%	79.17%
21	39.58%	0.00%
22	0.00%	66.67%
23	72.92%	0.00%
24	56.25%	0.00%
25	0.00%	54.17%
26	60.42%	0.00%
27	0.00%	58.33%
28	0.00%	41.67%
	75.15%	68.30%

APPENDIX T

POSTTREATMENT EXPLORE TEST 05B LEVEL OF THINKING

Results of the Explore 05B Test and Panel of Experts Decision on Level of Question

Question	Non-Analysis / Evaluation	Analysis / Evaluation
1	82.00%	0.00%
2	63.00%	0.00%
3	0.00%	92.00%
4	0.00%	82.00%
5	96.00%	0.00%
6	94.00%	0.00%
7	0.00%	67.00%
8	0.00%	61.00%
9	43.00%	0.00%
10	96.00%	0.00%
11	80.00%	0.00%
12	0.00%	80.00%
13	0.00%	67.00%
14	92.00%	0.00%
15	67.00%	0.00%
16	0.00%	84.00%
17	0.00%	55.00%
18	0.00%	47.00%
19	90.00%	0.00%
20	84.00%	0.00%
21	80.00%	0.00%
22	0.00%	69.00%
23	0.00%	63.00%
24	0.00%	65.00%
25	86.00%	0.00%
26	65.00%	0.00%
27	63.00%	0.00%
28	0.00%	47.00%
	78.73%	67.62%

APPENDIX U

INTERVIEW QUESTIONS

Final Student Interview Questions over NOS and Thinking Skills

NOTE: Participation is voluntary, and you can choose to not answer any question that you do not want to answer, and you can stop at anytime. Participation in this research is voluntary and participation or non-participation will not affect a student's grades or class standing in any way

The first set of questions to be administered prior to treatment.

1. Tell me about how confident and comfortable you are in your ability to evaluate scientific information. This includes looking at a science fair project or study and judging whether the project was done properly, gained meaningful data, and whether the conclusion given is appropriate.
2. Tell me about how confident and comfortable you are in your ability to analyze scientific information. This includes things like being able to read a graph, chart, or data table.
3. Tell me about how confident and comfortable you are in your ability to synthesize scientific information. This includes developing a science fair project or a hypothesis, designing something.
4. Is there anything else you would like me to know?

The next set of questions to be administered after treatment.

1. How has learning about the Nature of Science changed your perception of scientific information?
2. Do you feel more confident and comfortable in your ability to evaluate scientific information after learning about the Nature of Science? What challenges do you still face with evaluating scientific information?
3. Do you feel more confident and comfortable in your ability to synthesize scientific thought after learning about the Nature of Science? What challenges do you still face with synthesizing scientific thought?
4. Do you feel more confident and comfortable in your ability to analyze scientific information after learning about the Nature of Science? What challenges do you still face with analyzing scientific information?
5. Do you feel that learning about the Nature of Science was helpful in developing better thinking skills, or do you feel that learning about the Nature of Science neither helped nor possibly even hindered you in improving these skills?
6. What could be done differently next year to help improve students' ability to think like a scientist? Are there certain activities which were not useful or are there something we could add which would help?
7. Is there anything else you would like me to know?