METHODOLOGY

To incorporate the Nature of Science (NOS) into the curriculum, the first quarter of the freshmen physical science course was exclusively focused on teaching 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 A). 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 B). Puzzle solving activities made students use logic and creativity to determine a solution (Appendix C). 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 (Appendix D).

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 involved 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 application and relevance to the world at large, as well as synthesis of further questions to consider asking.

Prior to any NOS instruction, the students were administered the NOS Pre-test (Appendix J). This 28-item test covered concepts related to the Nature of Science, including, but not limited to graphing and graph interpretation, experimental design and more. The results of each student's test were compared to the NOS Post-test and analyzed using a normalized gain statistical analysis. The results were reported in box and whisker plots.

The Pre-Treatment Think Like a Scientist Survey asked students the 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 K). The same 17 question survey was administered as the Post-Treatment Survey. The Think Like a Scientist 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 administered through Google Docs and were evaluated by comparing the two surveys results, 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 Think Like A Scientist pre/post Survey scores were analyzed using the Wilcoxson Signed Ranked Test.

Additionally, 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 L). 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. These data were analyzed for common themes and used as evidence to support other data analysis claims. 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

APPENDICES

APPENDIX A

IRB APPROVAL

MONTANA STATE UNIVERSITY

INSTITUTIONAL REVIEW BOARD

For the Protection of Human Subjects
FWA 00000165

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Cheryl Johnson
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MEMORANDUM

TO: Shari Generaux and John Graves

FROM: Mark Quinn, Chair *Mark Quinn cj*

DATE: November 12, 2013

RE: *"The Effects of the 5E Learning Cycle on Student Integration of Vocabulary"* [SG111213-EX]

The above research, described in your submission of November 12, 2013, is exempt from the requirement of review by the Institutional Review Board in accordance with the Code of Federal regulations, Part 46, section 101. The specific paragraph which applies to your research is:

_X_ (b) (1) Research conducted in established or commonly accepted educational settings, involving normal educational practices such as (i) research on regular and special education instructional strategies, or (ii) research on the effectiveness of or the comparison among instructional techniques, curricula, or classroom management methods.

_X_ (b) (2) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior, unless: (i) information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; and (ii) any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability, or be damaging to the subjects' financial standing, employability, or reputation.

____ (b) (3) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior that is not exempt under paragraph (b)(2) of this section, if: (i) the human subjects are elected or appointed public officials or candidates for public office; or (ii) federal statute(s) without exception that the confidentiality of the personally identifiable information will be maintained throughout the research and thereafter.

____ (b) (4) Research involving the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens, if these sources are publicly available, or if the information is recorded by the investigator in such a manner that the subjects cannot be identified, directly or through identifiers linked to the subjects.

____ (b) (5) Research and demonstration projects, which are conducted by or subject to the approval of department or agency heads, and which are designed to study, evaluate, or otherwise examine: (i) public benefit or service programs; (ii) procedures for obtaining benefits or services under those programs; (iii) possible changes in or alternatives to those programs or procedures; or (iv) possible changes in methods or levels of payment for benefits or services under those programs.

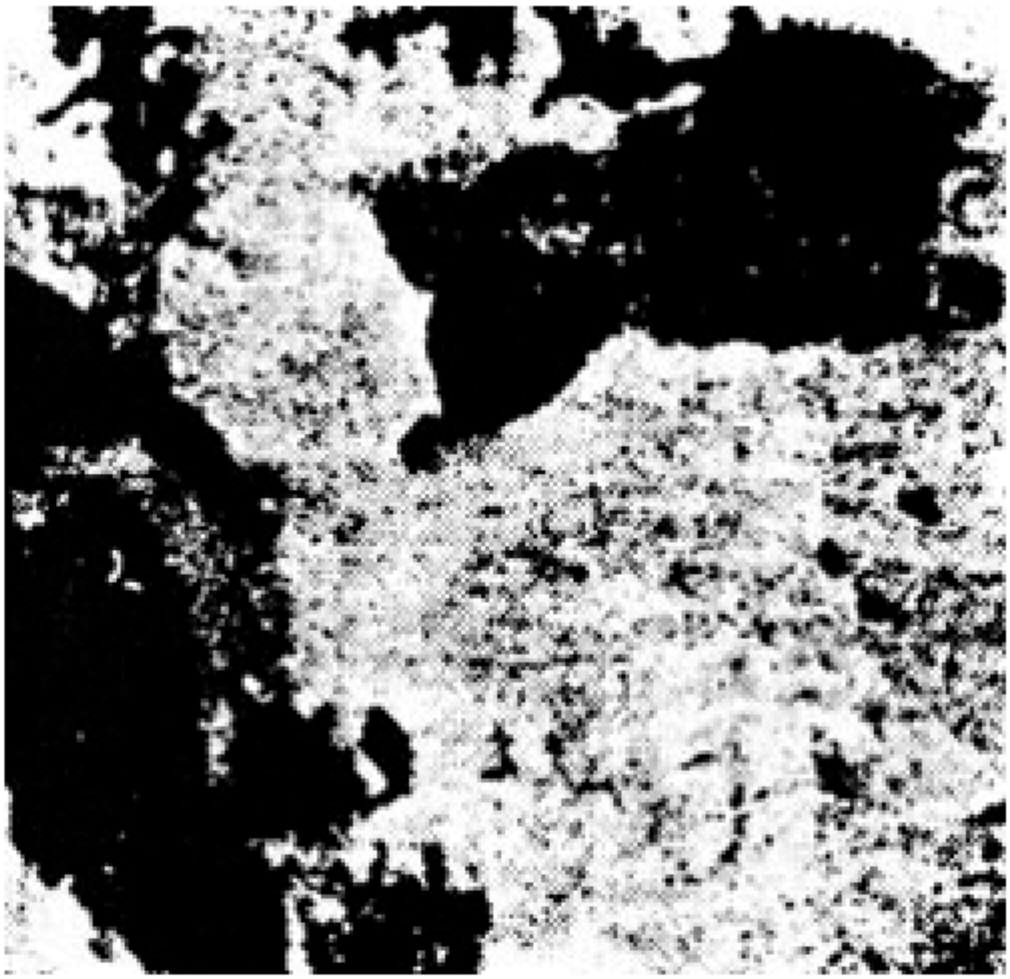
____ (b) (6) Taste and food quality evaluation and consumer acceptance studies, (i) if wholesome foods without additives are consumed, or (ii) if a food is consumed that contains a food ingredient at or below the level and for a use found to be safe, or agricultural chemical or environmental contaminant at or below the level found to be safe, by the FDA, or approved by the EPA, or the Food Safety and Inspection Service of the USDA.

Although review by the Institutional Review Board is not required for the above research, the Committee will be glad to review it. If you wish a review and committee approval, please submit 3 copies of the usual application form and it will be processed by expedited review.

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.

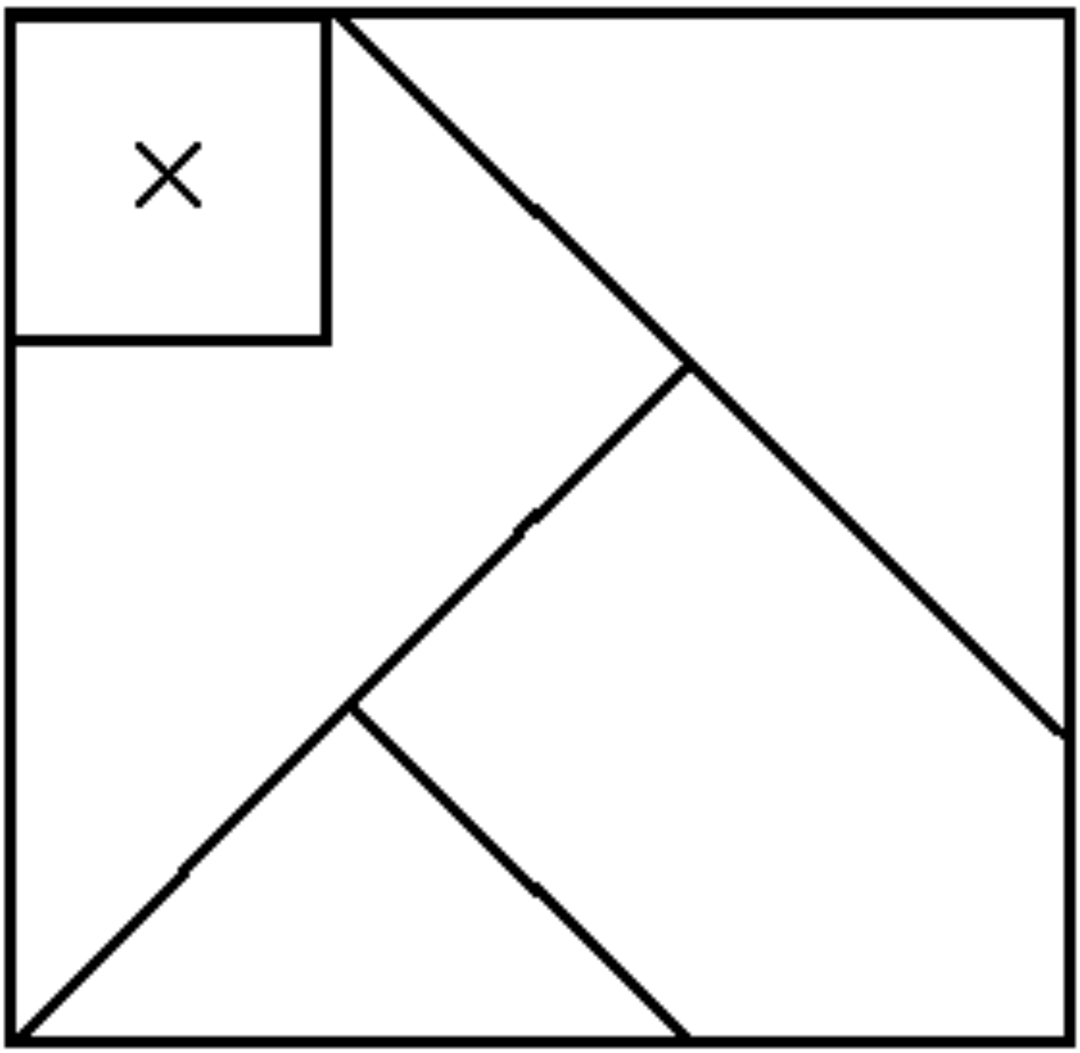


Figure 1

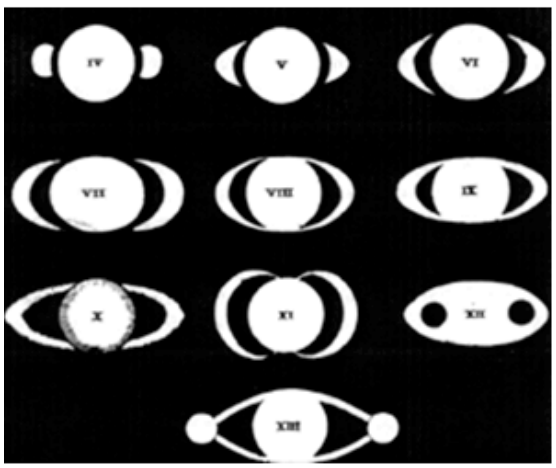
APPENDIX E

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

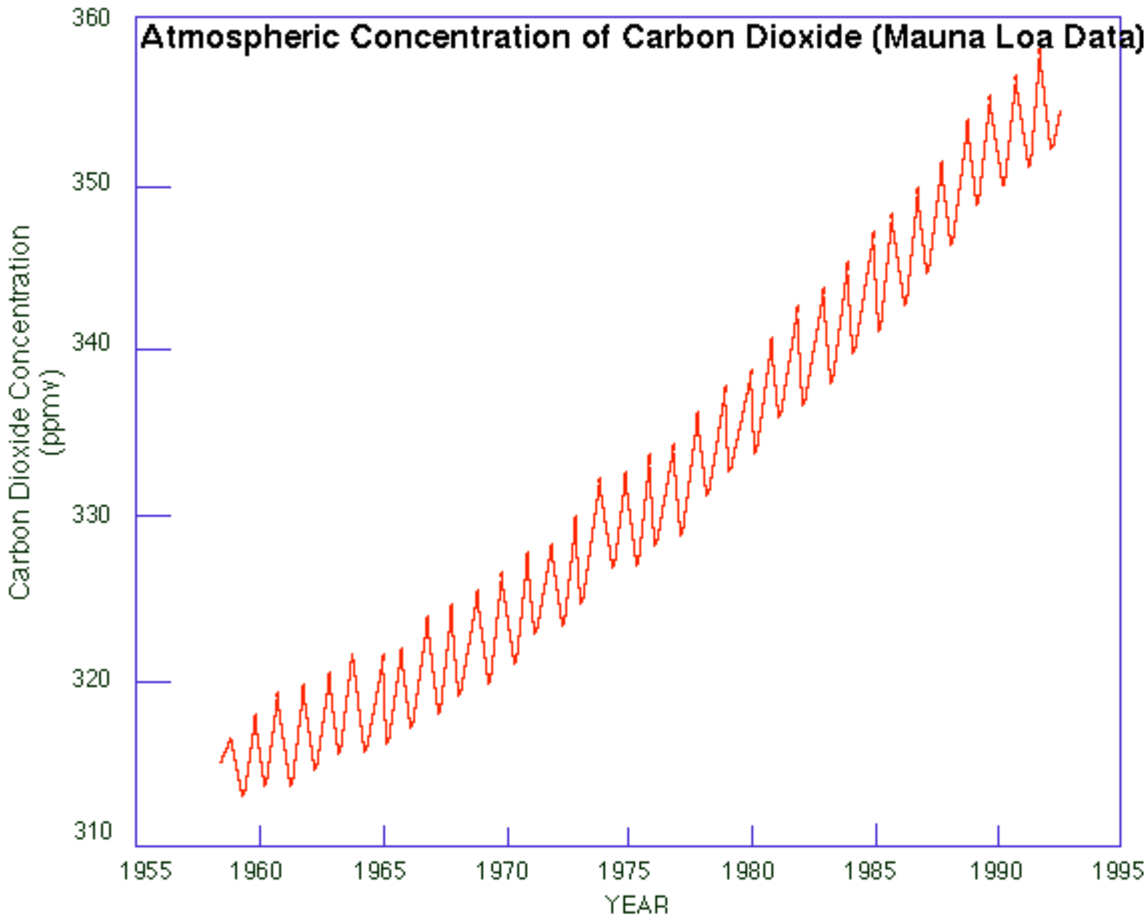
The images to the left are what early astronomers, such as Galileo, saw when looking at Saturn. At the time, no one had even conceived the idea that a planet could have rings. After Galileo discovered the moons of Jupiter, his mind assumed that what he was seeing was moons around Saturn. When the moons 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.

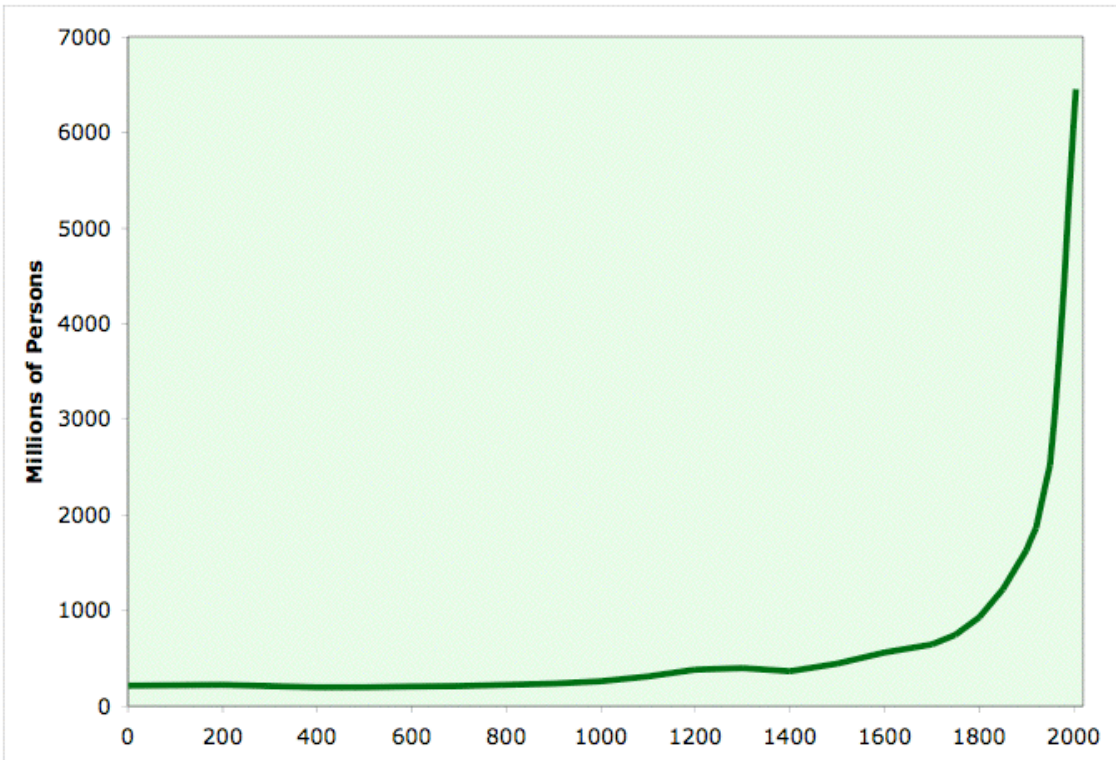


APPENDIX G

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

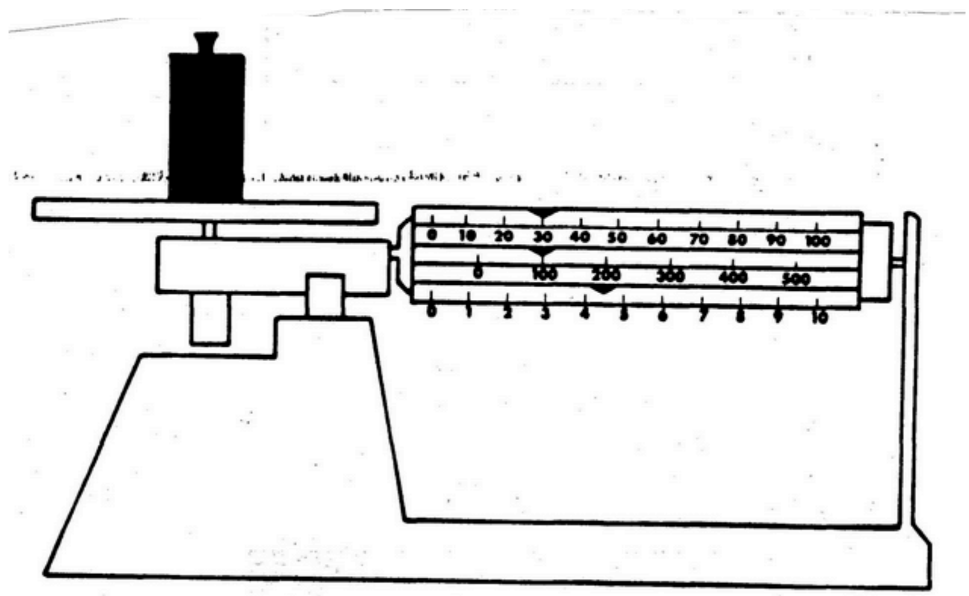
SIGNIFICANT DIGIT INCLUSION CONTENT

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

NOS PRE/POST-TEST

Note: For the purpose of this example, only the first page of the appendix item is included

TEST 4: SCIENCE TEST

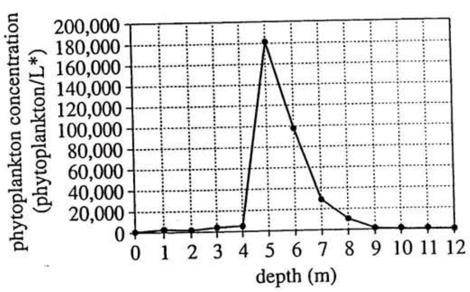
30 Minutes—28 Questions

DIRECTIONS: There are six passages in this test. Each passage is followed by several questions. After reading a passage, choose the best answer to each question and fill in the corresponding oval on your answer folder. You may refer to the passages as often as necessary.

You are NOT permitted to use a calculator on this test.

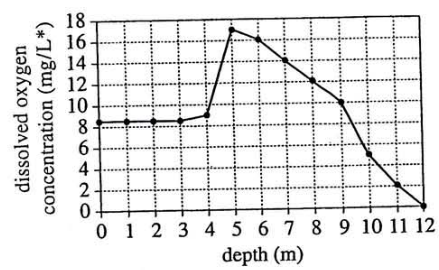
Passage I

Scientists studied how conditions in Lake A change as the depth of the water changes. They collected a sample of lake water at the lake's surface (depth = 0 m) and at 1 m intervals below the lake's surface. For each sample, the scientists determined the concentration of *phytoplankton* (microscopic organisms that use sunlight to make food) and the concentration of dissolved oxygen (see Figures 1 and 2, respectively). The scientists also measured, at 1 m intervals below the lake's surface, the percent of sunlight that penetrated the water (see Figure 3).



*L = liter

Figure 1



*mg/L = milligrams per liter

Figure 2

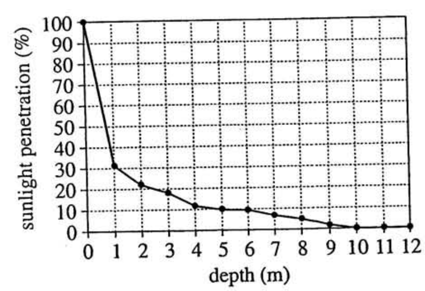


Figure 3

GO ON TO THE NEXT PAGE.

APPENDIX K

PRE/POST THINK LIKE A SCIENTIST SURVEY

Note: For the purpose of this example, only the first page of the appendix item is included

Pre &

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.

APPENDIX L

POST TREATMENT INTERVIEW

Final Student Interview Questions over NOS and Thinking Skills

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. 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 is there something we could add which would help?
7. Is there anything else you would like me to know?