

PRIMARY LITERATURE IN THE SCIENCE CLASSROOM

by

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ABSTRACT

Currently, Science, Technology, Engineering, and Mathematics (STEM) degrees and career pathways are seeing a declining number of people entering these fields. Because of this decline in interest and preparation in these fields, there is a shift in focus in science education to pedagogy methods that are more student-centered and allow students to engage in more authentic scientific practices. Along with declining interest, many students do not have the abstract scientific reasoning skills to be successful in upper-level coursework necessary for these fields. In order to better prepare students and keep them engaged in science coursework, methods that are both scientific inquiry based and can help students develop their scientific reasoning skills are needed. A group of students at Frenchtown High School used a scaffolded reading technique, called the CREATE method, to interpret and understand two scientific primary literature articles, and were compared to students that did not engage in the reading activities. Both groups of students took pre and posttests that measured their understanding of scientific inquiry and scientific reasoning, the treatment group's concept maps were also assessed for reading comprehension. The treatment group saw increased understanding in several areas of scientific inquiry, increased abstract thinking skills, and better reading comprehension from the first article to the second article. These results suggest that this modified CREATE method could be used as a pedagogical tool in the science classroom that would help students better understand how scientists carry out scientific inquiry and increase scientific reasoning skills.

INTRODUCTION AND BACKGROUND

Frenchtown High School is in Frenchtown, Montana, a small rural community about 12 miles outside Missoula Montana. There are 400 students who attend the high school. The demographics at the high school are about 87% White, 3% American Indian or Alaskan Native, and 3% Asian. Frenchtown has rigorous graduation requirements for math and science. Every student must take three years of both math and science. Because of this requirement, there are many students who sign up to take Chemistry I as a junior. There are three sections of Chemistry I at Frenchtown with about 15 students in each section. In the chemistry classes there are 6 seniors, 32 juniors, and 2 sophomores ("GEMS," 2016).

The chemistry classes are for students who are interested in going into the healthcare or science, technology, engineering, math (STEM) field. The Chemistry I class is part of the advanced upper level science electives offered in the Frenchtown Science department. There is a strong focus in my classroom on scientific inquiry and developing scientific reasoning skills. This is because most of the students in my Chemistry I classes will go on to college and take advanced science or math course work. To make sure that students are well prepared for such advanced coursework after high school, and to also stimulate interest in pursuing scientific lab work, I implemented my action research-based project in my Chemistry I classes.

Coming from an academic research background, I understand the importance of students learning to read scientific papers and articles and wanted to include more real world scientific practices into my classroom. While reading scientific texts is such an

important practice for students to learn, it is often viewed as not being part of inquiry-based learning or is replaced with having students read a textbook. However, to conduct scientific research, scientists have to read to gain the necessary background knowledge. In reality, reading is a crucial element to the inquiry process that scientists employ on almost a daily basis. Also, scientific textbooks typically do not present scientific knowledge in the language or format that scientists use, instead the information is presented as facts not to be questioned. This makes scientific textbooks a poor substitute for modeling how scientists gain background knowledge for a research project.

Along with creating more realistic scientific practices, I am also focused on implementing *Next Generation Science Standards* in my classroom. A major part of these standards is teaching students about the nature of science. The nature of science includes aspects, such as how scientists use varied methods to gather data, scientific knowledge is constantly being revised and updated, scientists use empirical evidence to support claims, and that science is a human endeavor (*NGSS Lead States, 2013*). Trying to incorporate these aspects of the nature of science into the classroom may seem daunting, but by integrating the reading of scientific texts into my classroom I felt I could seamlessly include the nature of science.

After a thorough literature review on using scientific articles in the classroom, and an examination of the *Next Generation Science Standards*, I decided on the following research question, how will the incorporation of scientific texts and implementation of reading strategies to comprehend these texts affect students' understanding of the scientific practices and how scientists employ these practices. Additionally, the following

sub-question was researched, how will the incorporation of scientific articles affect students' cognitive development level?

CONCEPTUAL FRAMEWORK

In recent years concerns have been raised about the state of science education in the United States. Now more than ever, the general American public is responsible for making decisions that affect scientific policy, funding, and a number of other scientific areas. It has been noted that the American public lacks a clear understanding of how science is conducted or the basic principles that make up the scientific field of study. Most Americans receive their scientific information from secondary sources such as newspapers, magazines, televisions, or the internet. This information has been filtered from primary scientific literature sources and may get distorted during this filtering process (Hoskins, 2010). Because scientific policy decisions rely so heavily on the American public perception, it is important that students have a solid understanding of the nature of science and how to interpret and analyze scientific information.

In 2012, American students from around the country participated in the Program for International Student Assessment, an assessment that is administered to sixty-five different countries to determine academic achievement at the international level. The United States was ranked 23rd in science and 20th in reading literacy out of these countries (Next Generation, 2016). These results demonstrated the need for improvement in a number of different academic areas, especially science. Also, in 2011, eighth-grade students from around the country took the National Assessment of Education Progress to determine how well students were performing in science at the national level. While the

report showed a 2-point improvement in average test score for the science section from 2009 to 2011, many areas still need major improvement. This assessment showed that over one-third of eighth graders are below the basic proficiency level. It also, showed that a gap continued to exist between white students and minority students, and a gender gap still exists between male and female students (Lee, Grigg, & Dion, 2007).

Recently ACT released the annual *Condition in STEM Report 2015*, which discussed the state of STEM (science, technology, engineering, and math) education in the United States based on ACT Science test scores. The report mentioned that interest in STEM degrees and careers have remained stable over the last 6 years, at 49%, and the percentage of students meeting the Science benchmark was 51%. The benchmark score is the probability that a student taking an introductory level class will have a 50% chance of getting a “B” or higher and a 75% chance of getting a “C” or higher (ACT, 2016). Upon further analysis, it was determined that students going into STEM degrees needed to take higher-level math and science courses than the introductory level courses used to determine the benchmark score. This meant that the benchmark scores for students interested in a STEM degree were adjusted to 27 for math and 25 for science. Because of the higher ACT benchmark score for STEM degrees, the number of students that met the adjusted benchmarks in math and science dropped to 37% and 16% respectively. This drastic decrease in the number of students meeting STEM ACT benchmarks highlighted the fact that many high school graduates in the United States did not have the basic skills to be career or college ready in a STEM field (Mattern, Radunzel, & Westrick, 2015).

Another aspect of student success in STEM is scientific reasoning skills.

Scientific reasoning skills are a necessary skill to be successful in the coursework needed to do well in high school and college-level coursework. Studies have shown that small numbers of high school students and college freshman have the necessary abstract thinking skills to be successful in introductory courses in chemistry and physics.

(Cracolice, Deming, & Ehlert, 2008). Scientific reasoning skills are essentially the ability of a student to think abstractly about various scientific phenomenon. These abstract thinking skills can be based on Piagetian operational stages: concrete, early transitional, late transitional, and formal. Where students in the concrete operational stage lack the ability to think abstractly about scientific concepts and students in the formal operational stage are able to think abstractly about scientific concepts (Lawson, 1978).

While these statistics and information about STEM education in the United States might seem depressing, many steps have been taken recently to drastically change the state of STEM education in the United States. In the early 2000's the National Research Council in partnership with many other science education stakeholders formed a committee to write a new philosophy on science education called, *A Framework for K-12 Science Education*. The main goals of *A Framework for K-12 Science Education* were to create a cohesive structure for science education that tied together the various grade levels, develop a three dimensional outlook on science instruction, and focus more on the scientific process instead of scientific facts. This committee made the following suggestions: a progression of core disciplinary ideas to be taught at the various grade levels, a focus on incorporating the scientific/engineering practices in with science

instruction, and a concentration on the main scientific concepts to allow for more inquiry-based learning (National Research Council, 2012).

The work of this committee and *A Framework for K-12 Science Education* lead to the development of the Next Generation Science Standards (National Research Council, 2012). These standards were released in 2013 and have been adopted by many states. Within the standards is the concept that science instruction is not merely one-dimensional but is actually three-dimensional, which includes the practices that scientists and engineers use to conduct science and the connection between the various scientific concepts. An important scientific and engineering practice that is included in the Next Generation Science Standards is obtaining, evaluating, and communicating information (NGSS Lead State, 2016).

For students to truly appreciate science they must understand how science is conducted, especially how to obtain, evaluate, and communicate scientific information. Even with the current emphasis to incorporate inquiry-based learning into the science classroom, often times reading and writing is overlooked. Scientists cannot conduct scientific research and endeavors without reading, mainly primary literature in peer-reviewed journals. For science to be accurately considered inquiry-based learning, it must include reading scientific texts. Students should learn how to read scientific texts, apply what was read to their current understanding of a scientific concept, and evaluate claims made in the readings. This ability to read and understand scientific texts is referred to as scientific literacy. In contrast, scientific literacy can also mean a student's/person's understanding of scientific concepts and practice (Pearson, Moje, & Greenleaf, 2010).

Reading scientific texts is a complex and difficult activity for most students. A great indicator of how well a student will do in a science class or on a science-based test, such as the ACT, is the ability to read the scientific texts that are used in that class or test. Because a student's success in the science classroom is tied so closely to scientific literacy skills, it is important that science teachers spend the time to instruct students on techniques that help demystify the scientific texts. Certain reading strategies have been found to be more beneficial for students than others. When compared to concept mapping or re-reading texts, summarization of a scientific text was found to be more effective in helping students remember content from the text. Also, annotation was another helpful reading strategy to teach in the science classroom. Annotation requires that students identify various different components of text such as main idea, supporting idea, and conclusion. When students used this technique during a test concerning comprehension of a scientific text these students performed better than their peers that did not use annotation (Diep, 2016).

There are numerous formats of scientific texts that exist for students to read. A more general and readily accessible format is a media scientific report, like an article that is written for *Scientific American*. These types of scientific texts are typically written about a primary literature paper but have been written by a journalist in a more simplistic and condensed format that the general public can understand. An adapted primary literature (APL) report takes a primary literature paper and adapts the paper for a particular reading level. The APL paper keeps many of the research aspects of the primary literature paper, but only adjusts and removes certain aspects that would be too

advanced for the intended audience. Both types of articles have benefits when used in the classroom. Media scientific reports are easier for students to understand, and do not require much effort on the teacher's part to prepare for use in the classroom. APL papers require more scaffolding in place to help the students comprehend the text, but better demonstrate the epistemology of science (Falk & Yarden, 2011).

Since APL papers present a more accurate representation of how scientists communicate knowledge and use scientific practices like argumentation and analyzing results, APL is better suited for teaching students about the nature of science. A scaffolding method that can be used to teach these more difficult texts is the CREATE (Consider, Read, Elucidate hypotheses, Analyze and interpret the data, and Think of the next experiment, Extend) method. This method has students consider the data and results discussed in the paper as their own. The students read and analyze the results and methods section of the paper, and work backwards to determine how the results were generated using the methods. Then students determine a hypothesis or hypotheses based on the results section of the paper and suggest further experiments that could be conducted based off what they learned in the paper (Hoskins, Stevens, & Nehm, 2007). In conjunction with the CREATE method reading strategies such as annotation, annotated drawing, and concept mapping can be used to increase student comprehension. In an undergraduate biology course, the CREATE method had a number of impacts on the students' ability to do scientific practices and understand the nature of science. Improvement was seen in the students' ability to interpret data that they collected from

their own experiments, along with their understanding of who, why, and how science is conducted (Hoskins, Lopatto, & Stevens, 2011).

METHODOLOGY

The purpose of this study was to introduce students to peer-reviewed journal articles from *Science in the Classroom*. These articles have been adapted for the high school classroom to help students better understand the process of scientific inquiry and increase their scientific reasoning skills. The subjects for this study were 38 high school students: 2 sophomores, 32 juniors, and 4 seniors. One section of students was the non-treatment group, which meant that 12 of the juniors did not receive the treatment. This research project was reviewed and approved for an exemption by the Montana State University Institutional Review Board (Appendix A).

Articles from *Science in the Classroom* were used for this study (Appendix B). The articles had to be modified slightly to meet the formatting necessary to use a modified CREATE method for analyzing papers (Hoskins, Stevens, & Nehm, 2007). These articles were broken down into the individual sections: Introduction, Methods, Results, Discussion, and Conclusion. The Results, Methods, and Discussion sections were summarized so that only the main methods were shared with the students. The Results and Discussion of these results were also shortened to match up with the selected methods. This was done to help keep students from getting too overwhelmed with several advanced methodologies and data analysis. The articles selected for use in the classroom were chosen based on appropriate reading level, discussed a major scientific issue, and demonstrated the varied nature of scientific inquiry.

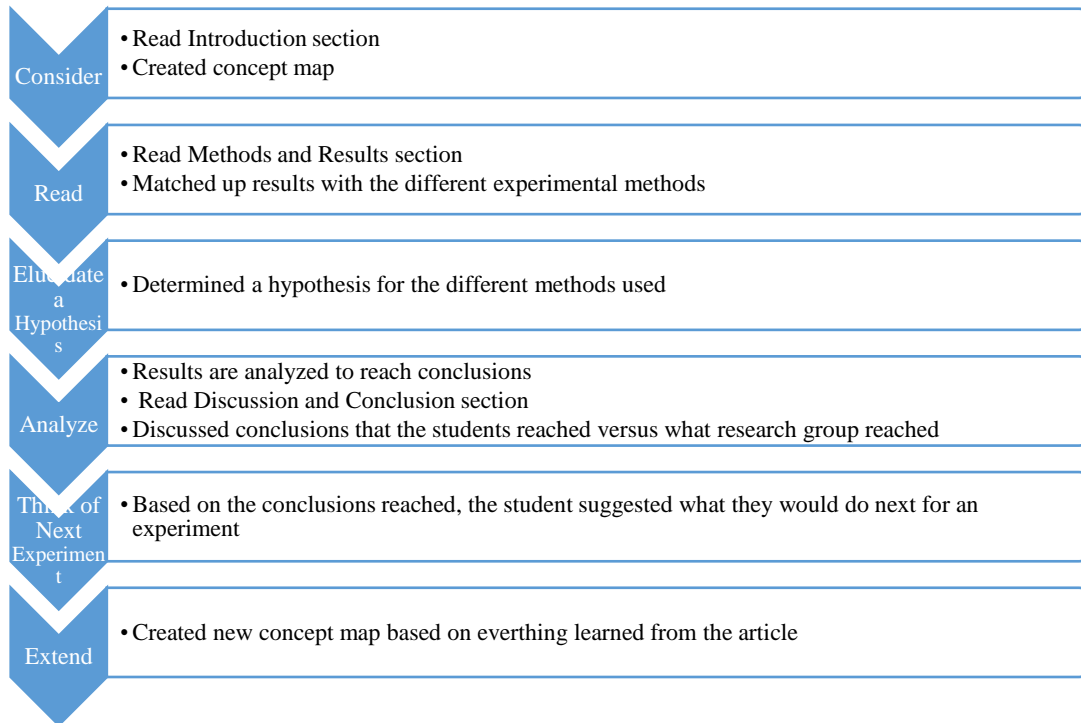


Figure 1. Sequence of the CREATE method.

The CREATE Method

The first step of the CREATE method is *Consider*. In this step students were given the Introduction to the article, read it, and created a concept map that showed the key terms and ideas in the section and how these terms/ideas were linked together. Students used annotation while reading this section to identify these terms and ideas, along with the purpose of the study. The purpose of the study served as the center bubble in the concept map, which is the central idea (Hoskins, Stevens, & Nehm, 2007).

The next step in the CREATE method is *Read*. Students were given the Methods and Results section for each paper and instructed to read through both sections. After reading through both sections, the students worked to determine which figures in the Results matched up with an experimental method in the Methods section by filling out the analysis template (Appendix C). Students then created a drawing or diagram that

showed what was done in each experiment, annotated the figures in the Results section by adding labels in their own words, and described each cartoon and figure in their own words. Once completing the three steps for the Read part of the process, students then *Elucidated a hypothesis* for each experiment. For this step, students had to determine the hypothesis the researchers were testing for each of the methods they diagrammed and described previously (Hoskins, Stevens, & Nehm, 2007).

After *Elucidating a hypothesis*, the students *Analyzed* the data in the article and used this data to reach conclusions. Students used the analysis template to work through the different figures and graphs in the Data section of the paper and then related these findings back to the hypotheses that were determined in the *Elucidate* step. After completing the analysis template, students compared the conclusions they reached with the conclusions that the authors of the paper proposed in the Discussion section of the paper. Finally, the students proposed a new experiment (*Think of a new experiment*) that would build off of the findings in the article. The whole class discussed the conclusions in the Discussion section and why they may have reached different conclusions from the authors, and shared what the next experiment could be and how they would carry out this experiment. To summarize the whole process, students created a new concept map for the purpose of the study that included methods, results, data, and conclusions. The pre and post reading of the article concept maps were collected and the number of bubbles and number of connections were counted and compared using a bar graph (Hoskins, Stevens, & Nehm, 2007).

Treatment

The entire CREATE method was carried out the first time in the classroom setting. Students worked with a partner to complete all the steps of the CREATE method as a scaffold to help students better understand the process and not be intimidated by the complex texts they were reading. After the first article, students were given some class time to complete the first three steps, but the last steps were assigned as homework. The next class we discussed the conclusions and next experiments, and after the discussion, students created their concept maps.

Data Collection

To determine the effectiveness of the treatment, three data collection methods were used (Table 1). The *Views About Scientific Inquiry* survey was used to measure student gains in understanding of the scientific process and how scientists use this process for inquiry (Appendix D). The responses to each question were read and compared to an ideal *Student Response Rubric* (provided by the author of VASI) and categorized as *naïve*, *mixed*, *informed*, or *unclear*. The frequency for each category for the different questions on the VASI was plotted in a stacked bar graph for both the pretest and posttest, and then compared to see how the frequency for each category changed after receiving the treatment (Lederman et al., 2013).

Both concept maps from the *Read* and *Extend* portion were collected after reading each article. The concept map from the *Extend* portion of the CREATE method was used for analysis of student comprehension of the article. The ability of the student to identify the central idea (purpose of the study), the number of total ideas (bubbles), the number of

linkages, ideas having two or more linkages, and error in linking ideas. These data were counted for each individual student and then analyzed using a bar graph.

The *Classroom Test for Scientific Reasoning* was used to measure students' scientific reasoning skills (Appendix F). The multiple choice responses were graded in pairs (1 and 2, 3 and 4, etc.), except for problems 23 and 24 which were stand-alone questions. The number of correct responses was added up and then used to categorize students into Piagetian categories: 0-4 *concrete thinkers*, 5-7 *early transitional*, 8-10 *late transitional*, 11-13 *formal thinker* (Lawson, 1978). If one question in a pair was marked wrong, the entire pair was considered wrong and not counted towards the final score. The scores for the treatment and non-treatment group were then organized into bar graphs and histograms for easy comparison of how students scored on the test. Pre and posttest box and whisker plots were also generated for compare improvement based on quartile scores for the treatment and non-treatment groups.

Table 1
Data Triangulation Matrix

<i>Questions</i>	Data Source 1	Data Source 2
<i>Focus Question:</i> How will the incorporation of scientific texts and implementation of reading strategies to comprehend these texts affect students' understanding of the scientific practices and how scientists employ these practices.	Views About Scientific Inquiry	Concept Maps
<i>Sub-question:</i> How will the incorporation of scientific articles affect students' cognitive development level?	Classroom Test of Scientific Reasoning	

DATA ANALYSIS

Of the students taking the *Classroom Test of Scientific Reasoning* in the treatment group for the posttest the number of students categorized as *concrete*, students who have very limited ability to think abstractly about scientific concepts, decreased to 25%; the number of students categorized as *early transitional*, students who are just starting to develop abstract thinking skills, decreased to 30%. The *late transitional*, students who have developed some ability to think abstractly about scientific concepts, decreased to 30%; and *formal*, students who can think abstractly about a wide range of scientific concepts, increased to 15% (Figure 2A). For the non-treatment group's posttest scores no students were categorized as *concrete*, 18% were categorized as *early transitional*, 72% were categorized as *late transitional*, and 18% were categorized as *formal* (Figure 2B).

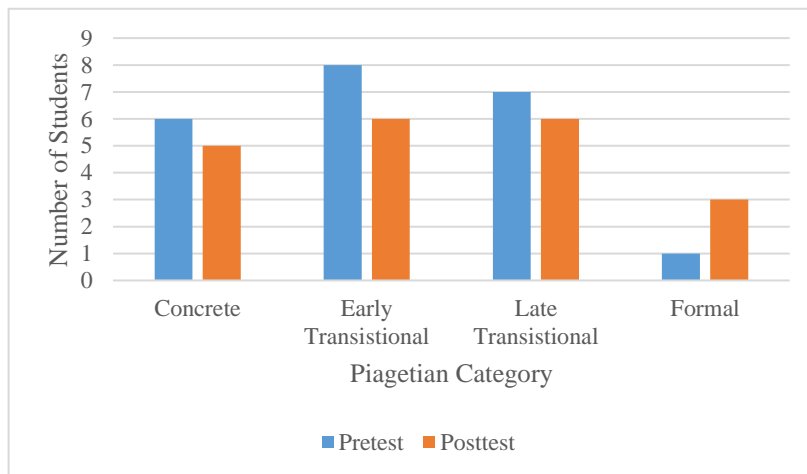


Figure 2A. Bar graph of the number of students in the treatment group for each Piagetian Category based on pretest and posttest score on the *Classroom Test of Scientific Reasoning*, ($n=22$, $n=20$).

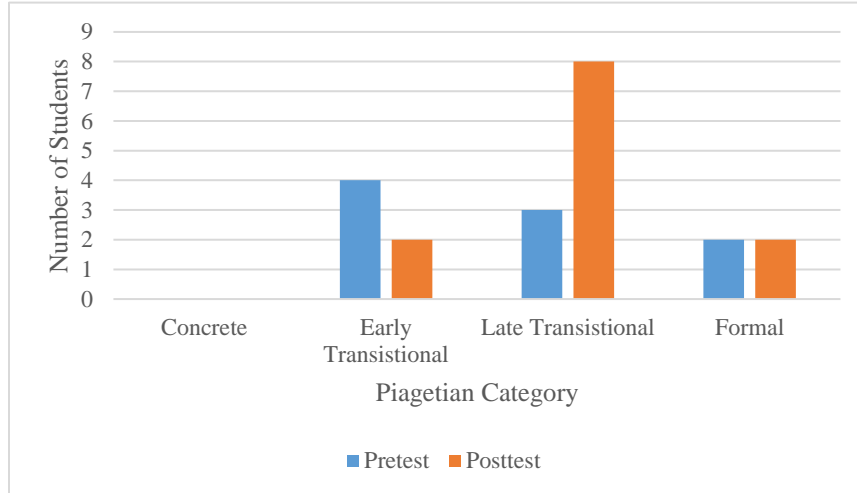


Figure 2B. Bar graph of the number of students in non-treatment group for each Piagetian Category based on pretest and posttest score on the *Classroom Test of Scientific Reasoning*, ($n=9$, $n=11$).

The *CTSR* scores for the treatment group pretest shows a spread of scores with the minimum score at 2 and the highest score at 12. The posttest for the treatment increased to the higher end of the range of scores with the minimum score at 3 and the highest score still at 12, but the greatest increase is seen in the median which shifted from 6.5 to 7. The non-treatment group pretest scores were less spread out and were on the higher end of the range with a minimum score of 6 and maximum score of 12. The posttest scores for the non-treatment group saw a major shift with the majority of scores falling in the 7-10 range (Figure 3).

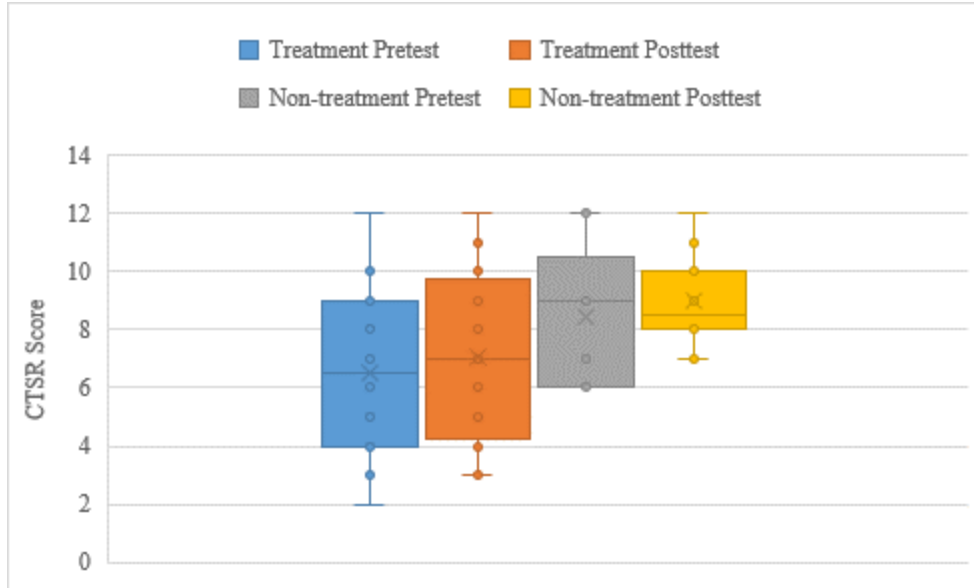


Figure 3. Box and whisker plot for both treatment and non-treatment group's pre and posttest scores for the *CTSR*.

Overall, the treatment group improved in several aspects of scientific inquiry that were measured by the *VASI*. One of the categories that increased in the number of students that made an *informed* response was being able to correctly identify the difference between data and evidence (Question 4), which increased from 42.1% to 50% (Figure 4 and 5). The non-treatment group also showed improvement on this question from pre to posttest. The non-treatment group had no students that were able to correctly identify the difference and had 40% with *mixed* views and 60% *naïve* views (Figure 6). For the posttest 27.3% had *informed* views, 27.3% had *mixed* views, and 45.5% had *naïve* views (Figure 7).

The treatment group also showed improvement on identifying using the correct procedure to answer the investigation question (Question 5). On the pretest, 68.42% of the answers on the *VASI* were considered *informed*, and on the posttest, 85% were

informed (Figure 5). The non-treatment group neither improved or decreased for this question since 100% of the answers were considered *informed* for both the pre and posttest (Figure 6 and 7). Students in both the treatment and non-treatment group improved their understanding of needing an investigation question to start a scientific investigation (Question 2). The treatment group improved the number of *informed* responses by 27%, and the non-treatment group increased the number of *informed* responses by 21.8% (Figure 5 and 7). However, the treatment group had decreases in the ability to determine what makes an investigation a scientific experiment (Question 1b) and how scientists draw conclusions (Question 7b). The treatment group decreased in the number of *informed* responses by 8.2% and 28.7% respectively (Figure 5).

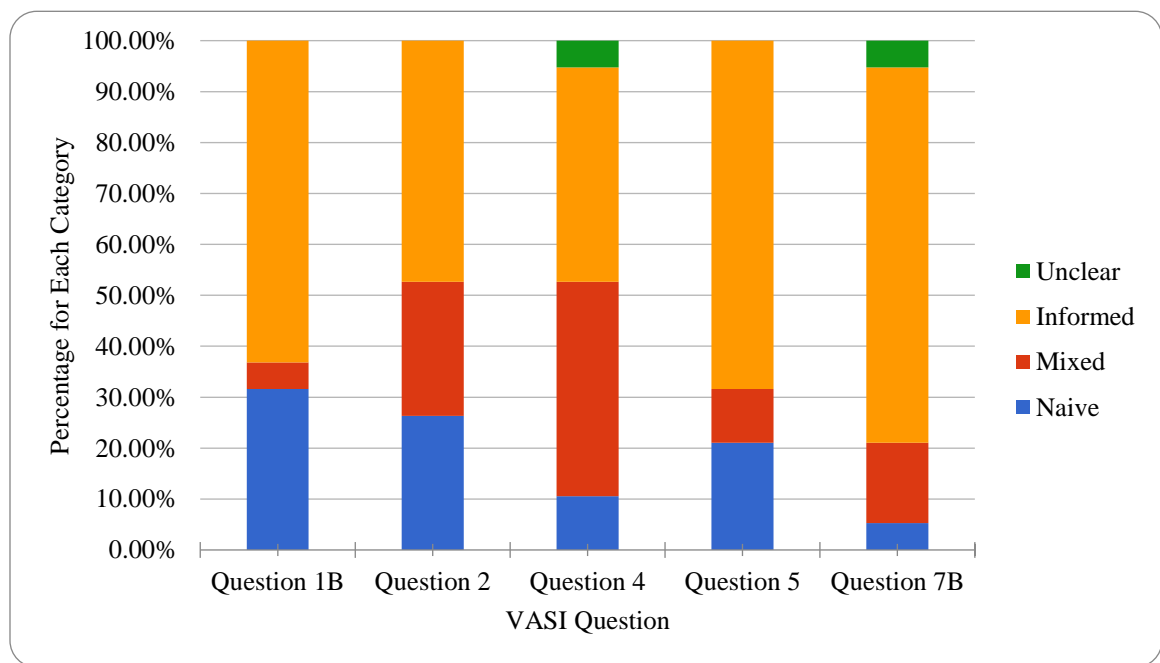


Figure 4. Stacked bar graph of the number of students in the treatment group for each of the different scoring categories on the VASI pretest. Each question was graded either *informed*, *mixed*, *naïve*, or *unclear*, ($N=21$).

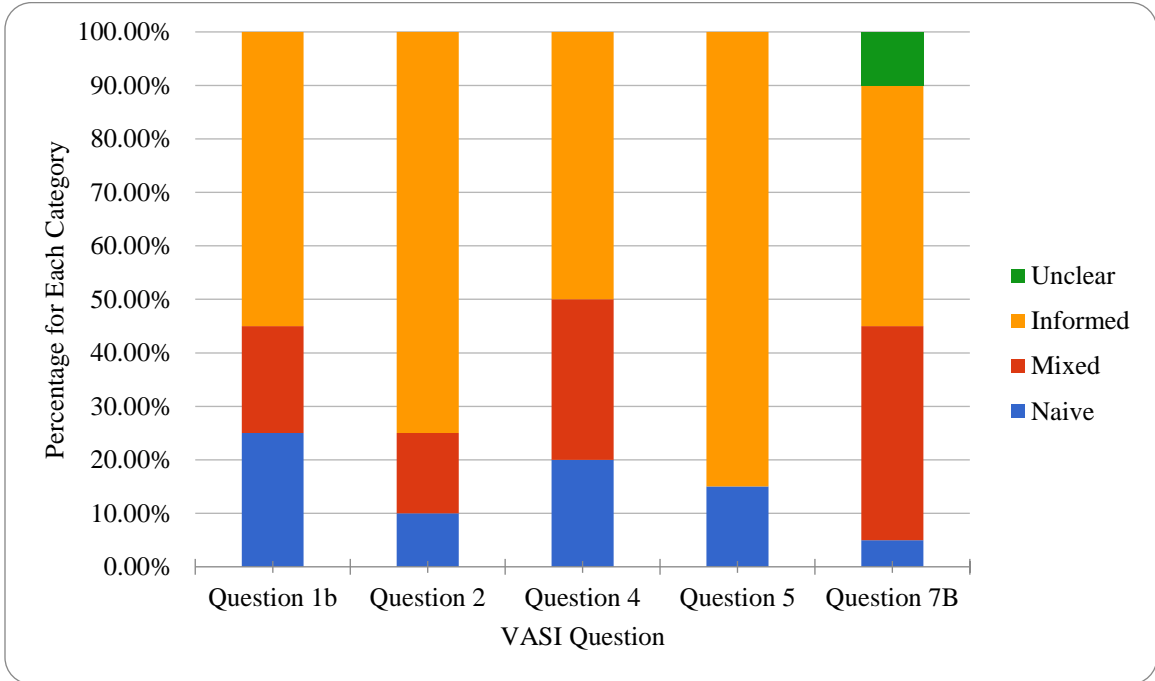


Figure 5. Stacked bar graph of the number of students in the treatment group for each of the different scoring categories on the VASI posttest, (N=20).

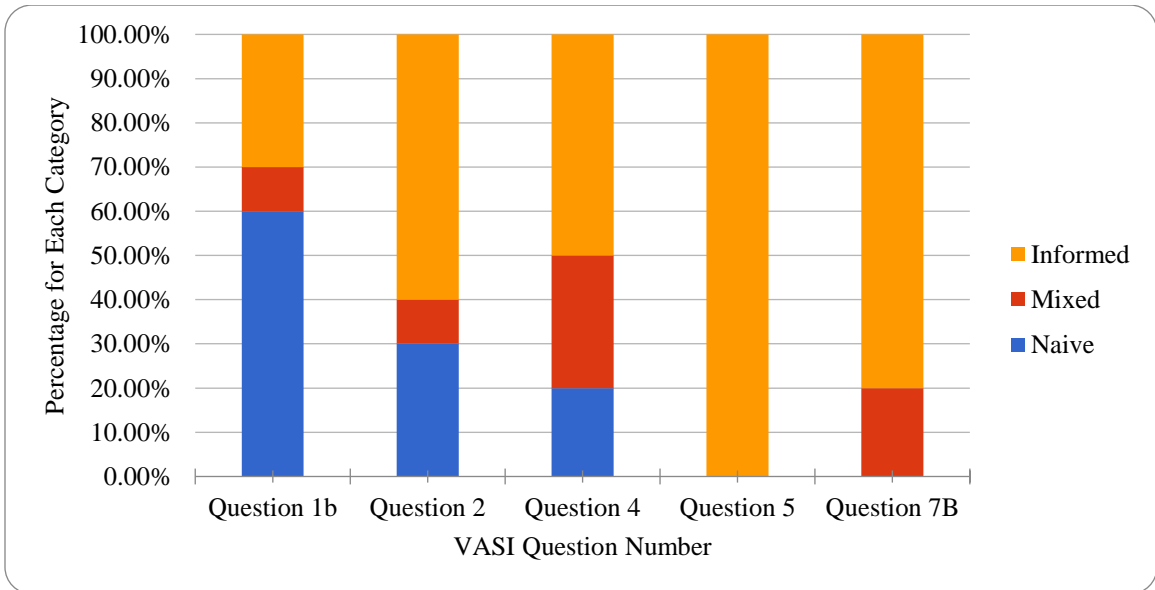


Figure 6. Stacked bar graph of the number of students in the non-treatment group for each of the different scoring categories on the VASI pretest, (N=9).

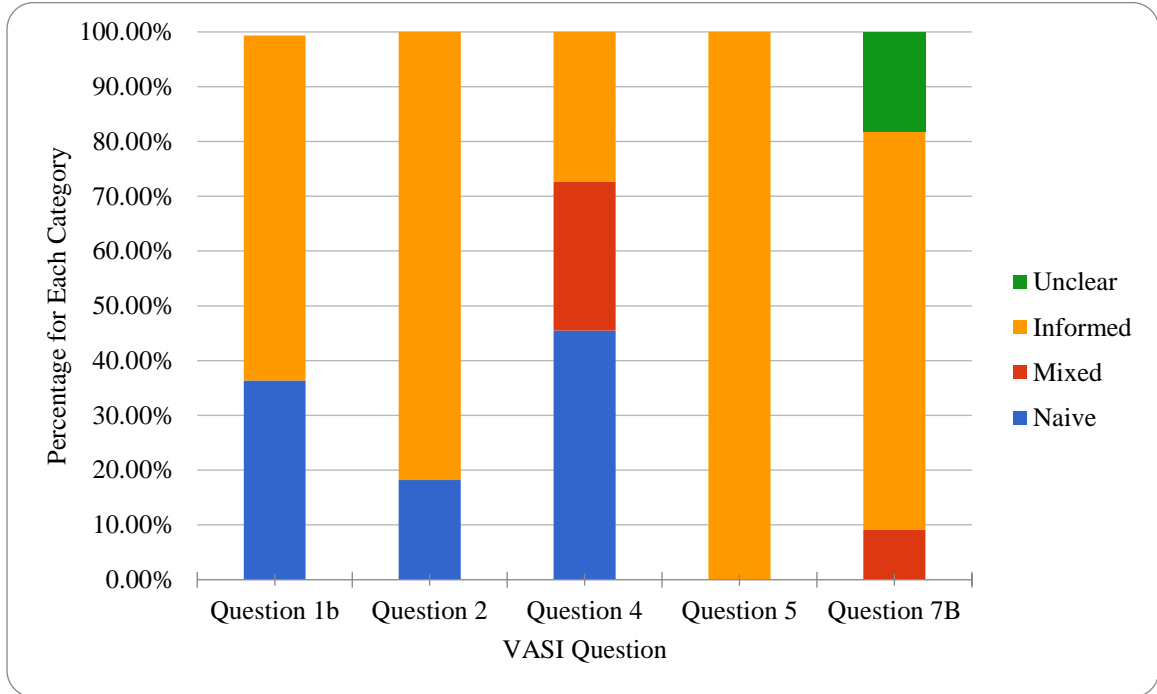


Figure 7. Stacked bar graph of the number of students in the non-treatment group for each of the different scoring categories on the *VASI* posttest, ($N=11$).

The number of students able to identify the purpose of the study in the article increased by 17% from the first to second article (Figure 8). While the number of bubbles and linkages increased by 16%, the number of bubbles with two or more linkages increased by 10%, and the number of errors in the concept map increased by 38% from the first to second article (Figure 9).

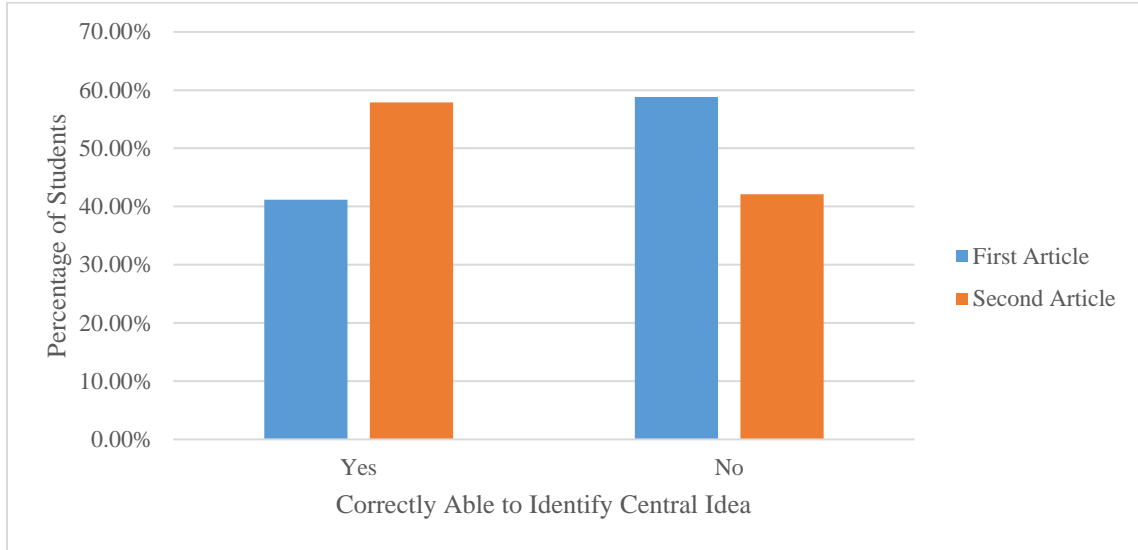


Figure 8. Bar graph showing the number of students who were able to correctly identify the central idea of the concept map by using the purpose of the study after reading the first and second article ($n=17$, $n=19$).

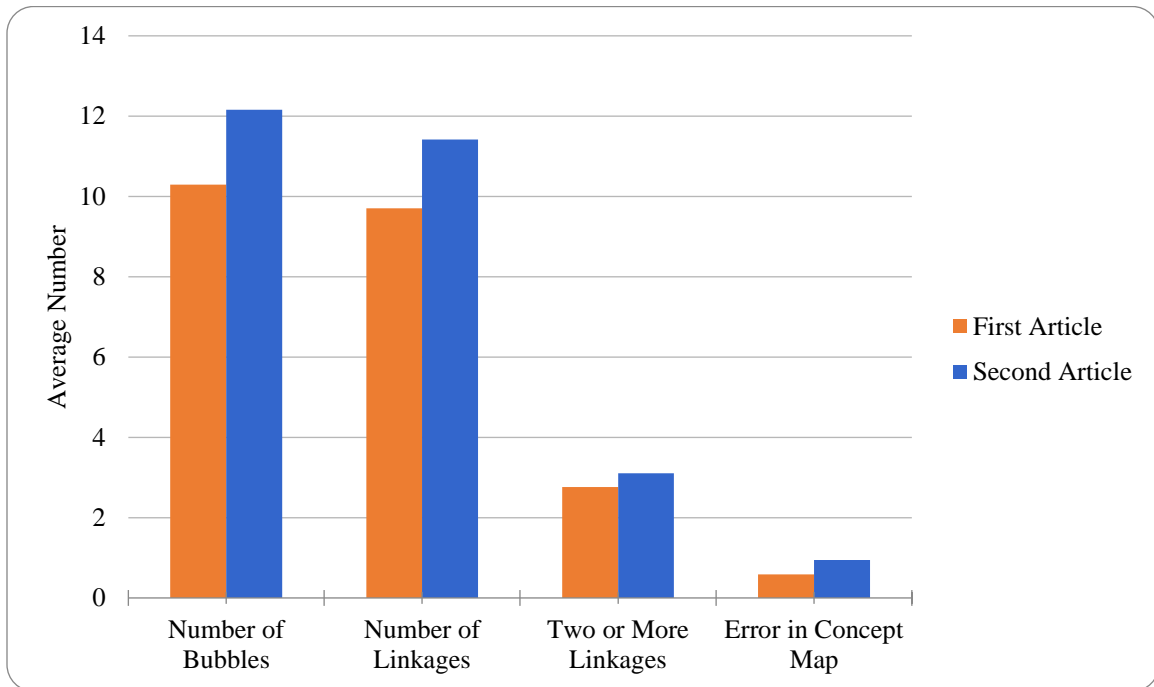


Figure 9. Bar graph showing the average number of bubbles, linkages between bubbles, bubbles that were linked to two or more bubbles, and the errors in the concept maps for the first and second article, ($n=17$, $n=20$).

INTERPRETATION AND CONCLUSION

Students who used the CREATE method to read and interpret peer-reviewed science journal articles showed increases in their scientific reasoning skills. The number of students in the *concrete* reasoning range decreased slightly and these students then shifted into the *early transitional* range. Another promising result of this pedagogical tool was that the number of students in the *late transitional* range decreased and these students moved into the *formal* cognitive range. The increase from 0.05% to 15% of students in the treatment group categorized as *formal* shows that this technique could be one of the tools a teacher could use to help students increase their abstract thinking skills and prepare for higher level STEM coursework.

The range of scores for the non-treatment group shifted toward the higher range, the median for the test scores decreased from 9 to 8.5. This shift indicates that students at the lower end increased their scores and the students at the higher end actually decreased their scores slightly. While the range of scores for the treatment group shifted toward the mid to higher range of scores and the 1st, median, and 3rd quartile all increased. The median for the treatment group increased by 0.5. Overall, this indicates that the implementation of the modified CREATE method and article reading was able to help most students increase their scientific reasoning skills. While the results in the treatment group were minor this method does show promise in helping students develop their abstract thinking skills to be more successful in STEM coursework.

The major focus of this study was to help students improve their understanding of the scientific process and the inquiry practices that scientists use to carry out the scientific

process. For most areas tested on the *VASI*, the treatment group improved their understanding of scientific inquiry after using the modified CREATE method. Question four from the *VASI* asks students to differentiate the difference between data and evidence, which is an essential distinction that students must make to develop a strong claim or to be able to assess other's claims. Fifty percent of the students in the treatment group had an *informed* response to question four, while only 27% of students in the non-treatment group were able to make an informed response. The higher amount of students in the treatment group being able to provide an *informed* response to this question is likely connected to these students analyzing the data provided by the article's authors, and then determining what conclusions the author drew from this data.

Another important area that students improved in on the *VASI* was determining why or why not a scientific investigation must begin with a scientific question (Question 2). Forty-seven percent of students in the treatment group responded on the pretest with an *informed* response that scientific investigations must begin with a scientific question, and only 60% of the students in the non-treatment group provided an *informed* response on the pretest. After using the modified CREATE method to read two scientific journal articles the treatment group increased by 28%, and the non-treatment group increased by 21%. The treatment group likely increased more than the non-treatment group due to reading about real-life scientific investigations that involved multiple investigation questions and then having to identify these questions and relate them to the methods that the authors used.

There was a 17% increase in *informed* responses for identifying and explaining what procedure best answers the investigation question (Question 5) for the treatment group, while the non-treatment group had 100% *informed* responses for both the pre and posttest (See Figure 4-7). Reading the scientific journal articles using the CREATE method required students to practice identifying the scientific questions that the article's authors were trying to answer, relate these questions to specific methods outlined in the article, and then connect these methods to the results and conclusions the authors drew. It appears that from this practice gained from using the modified CREATE method students in the treatment group were better able to apply this practice to a situation different than the primary literature articles.

There were two areas 1) what makes an experiment a scientific investigation and 2) how scientists reach conclusions (Question 1b and 7b), where the treatment group decreased in the number of *informed* responses while the control group increased the number of *informed* responses. For question 1b and 7b the number of *mixed* responses increased, decreasing the number of *informed*, which was due to providing incomplete answers. Since the students only provided partial answers, they did not provide enough detail to determine if they completely understood the concept the question was testing. The increase in incomplete answers could be due to the time of year that this testing was completed, which was after standardized tests were completed. Students may have been feeling testing fatigue and so did not put in full effort to complete these questions. Also, the areas of scientific inquiry were not directly addressed while using the modified CREATE method, so more explicit instruction on these areas while reading and

interpreting the articles could better help students improve their understanding of these aspects of scientific inquiry.

The other area of focus in this study was to help students develop tools to better understand complex scientific texts. After reading the first article fewer students were able to identify the purpose of the study in their concept map when compared to after reading the second article. Demonstrating that with practice with this method they were better able to comprehend the article and identify the purpose of the study being described in the article. Also, the number of bubbles, linkages between bubbles, and bubbles with two or more linkages in the concept map increased from the first article to the second article. Showing that students increased their capability to discern more aspects and details being described in the article and also determine more connections between these aspects by connecting them to multiple other ideas in the concept map. With repeated practice using the modified CREATE method, students can develop their

VALUE AND LIMITATIONS

Using the modified CREATE method to read and interpret scientific journal articles showed promise as a tool to help students better understand scientific inquiry and increase scientific reasoning. One of the major components of scientific inquiry that gets overlooked in the classroom is the use of scientific journals to learn about current scientific ideas. Scientists spend a large amount of time reading journal articles to inform their own research. Using scientific journal articles in the classroom can often be overwhelming for teachers and students due to the complexity of the texts. The modified CREATE method used in this study provided a scaffolded approach that allowed the

students to read and interpret the text in chunks and also provided points for students to stop and make connections between different sections of the text, for example connecting the hypotheses to the methodology.

This method was easy to implement in the classroom and removed the time consuming aspect of reading journal articles in the classroom. Reading the first article took two 90-minute class periods so that the students could figure out how to do the modified CREATE method. The reading of the second article only took one 45-minute and one 90-minute class period, allowing for teachers to incorporate several articles into the classroom during the school year without having to sacrifice much of their curriculum content. The method could even become part of an inquiry curriculum since many of the articles on *Science in the Classroom* have activities that go along with them that meet the crosscutting concepts, core ideas, and science and engineering practices of the *Next Generation Science Standards*. Using these activities that go along with the articles is strongly recommended because it allows students to better understand how the authors of the articles analyzed data, established their claims, and determined next steps in their research. Also, the activities create more buy-in to the reading and make it more relevant.

For easy implementation in the classroom *Science in the Classroom*, articles were used, but there are only limited topics covered when using these articles. These articles only required slight modifications to make ready to use in the classroom, so not much time would need to be invested by the teacher to use these articles with this modified method. However, the CREATE method described by Hoskins et al. (2007) had students read three articles from the same author that showed how the research in that lab

developed overtime. Using this aspect of the CREATE method would better help students comprehend how scientific research changes and evolves overtime based on new findings within the research group and from findings from other groups. In order to incorporate this aspect of the CREATE method into the classroom teachers would need to find articles on their own in scientific journals and adapt these articles to meet their needs. Also, if the *Science in the Classroom* articles are not used there would be no supplementary activities that go along with the articles. Teachers could use data or other resources provided in the supplementary information to create their own activities.

Students developed tools for reading complex texts not only for science class but other purposes as well. Many students commented on how they appreciated being exposed to more complex scientific texts and having to interpret these texts because many students were preparing for the ACT. Since a large portion of the ACT Science section requires students to read and interpret experimental designs, graphs, and differing conclusions; students felt better prepared to do these aspects of the ACT Science section because of their prior exposure with the modified CREATE method and because of the reading comprehension tools that were used as part of the method. Students also developed a better understanding of how scientists reason and explain the data collected from experimentation, which helped them with their analyzing and explaining of their own data collected in class. This may also help students with developing their scientific reasoning skills, by seeing how scientists connect data to conclusions and explain what these conclusions mean. Many students would state at the beginning of the article that there was no way they were going to be able to understand it, and then at the end of class

discussions, these students found out that they actually had a very strong understanding of what was being presented in the article. This gave students confidence about their ability to read and understand the difficult articles.

For me personally, I developed a better understanding of how students perceive scientific research and how scientists communicated the research. I also realized during the course of this study about how to better integrate scientific reading into the classroom. Some students were disengaged from the reading because they did not see how it tied into what we were learning or the importance of the research. This helped me to realize the importance of connecting the learning to our classroom and to what is happening in the real world. For future use, I would incorporate the activities that are provided with the articles and also discuss more with the students what the importance of the research is and connect it to their own lives.

Not only did this process help me to better understand what understandings my students bring to the classroom about the scientific process, but it also helped me to develop a more methodical approach to improving my teaching. The action research process provides a scaffold to implementing new approaches in the classroom that emphasizes determining the efficacy of the changes and also helps make the process of change in the classroom less daunting. Before going through my action research project the changes I made in my classroom were often done without a plan and I did not try to determine if these changes were actually improving the learning of my students. Now having gone through this process once I will feel comfortable making systematic improvements in my class and being able to collect different forms of data to determine

what impact these changes made. This process also exposed me to educational research literature that can be used to help guide changes that I enact in my classroom. Using the various educational literature articles can provide a solid pedagogical framework or even practical suggestions on implementing best practices in the classroom.

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APPENDICES

APPENDIX A
INSTITUTIONAL REVIEW BOARD STATEMENT



INSTITUTIONAL REVIEW BOARD
For the Protection of Human Subjects
FWA 0000165

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 c/o Microbiology & Immunology
 Montana State University
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 Telephone: 406-994-6783
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MEMORANDUM

TO: Lily Apedaile and John Graves
FROM: Mark Quinn *Mark Quinn CJ*
DATE: November 29, 2016
SUBJECT: "Using Adapted Primary Literature Articles to Help Students Better Understand the Scientific Process"
 [LA112916-EX]

The above research, described in your submission of November 29, 2016, 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:

- (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.
- (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
SCIENCE IN THE CLASSROOM ARTICLES

Adapted from *Science in the Classroom*
Mechanisms of reef coral resistance to future climate change. Palumbi *et al.*

Introduction

Reef-building corals have experienced global declines resulting from bleaching events sparked by pulses of warm-water exposure (1–4). However, corals in naturally warm environments can have high resistance to bleaching temperatures and can survive heat exposure that would bleach conspecifics in cooler microclimates (5, 6). Similarly, recent discovery of populations of heat-resistant corals show that physiological or evolutionary mechanisms of environmental accommodation exist (7, 8). Such populations are ideal test sites for research into the mechanisms of coral response to climate change. Corals in adjacent backreef pools in the U.S. National Park of American Samoa on Ofu Island experience strong differences in temperature (9,10). In the highly variable (HV) pool, temperatures often exceed the local critical bleaching temperature of 30°C, reaching 35°C during strong noontime low tides (6). By contrast, the moderately variable (MV) pool rarely experiences temperatures above 32°C. Corals in the HV Pool have higher growth rates (9, 10), higher survivorship, and higher symbiont photosynthetic efficiency during experimental heat stress than conspecifics from the MV pool (6). These pools provide a powerful system to test the speed and extent of coral acclimatization and adaptation to warm-water conditions in the context of future climate change.

Methods

To test corals in their native habitats for physiological resistance to heat stress, we collected branches of the tabletop coral *Acropora hyacinthus* [cryptic species E (11)] and exposed them to experimental bleaching conditions. *A. hyacinthus* is a cosmopolitan species that constitutes a large percentage of hard coral cover on Pacific reefs and shows high levels of bleaching and mortality during large-scale bleaching events (4). We chose *A. hyacinthus* for this study because it is a dominant reef-builder and is especially sensitive to environmental stress, making its relative ability to acclimate or adapt extremely important to the future of coral reef ecosystems as climate change proceeds. We subjected branches of corals to a prescribed ramp in water temperature of 29° to 34°C for 3 hours, followed by an incubation for 3 hours at 34°C. These conditions mimic the natural increase in temperature observed in the HV pool during a tidal cycle.

To test for acclimatization, we transplanted coral colonies of *A. hyacinthus* reciprocally from their native locations in the HV and MV pools to three transplant sites within each pool. We transplanted 6 colonies from the HV pool and 12 from the MV pool. After 12, 19, and 27 months, we tested transplanted colonies for thermal resistance. For 11 separate colonies, 22 of 23 paired bleaching experiments show that corals acquired at least part of the heat sensitivity of the pool they were transplanted into.

Results

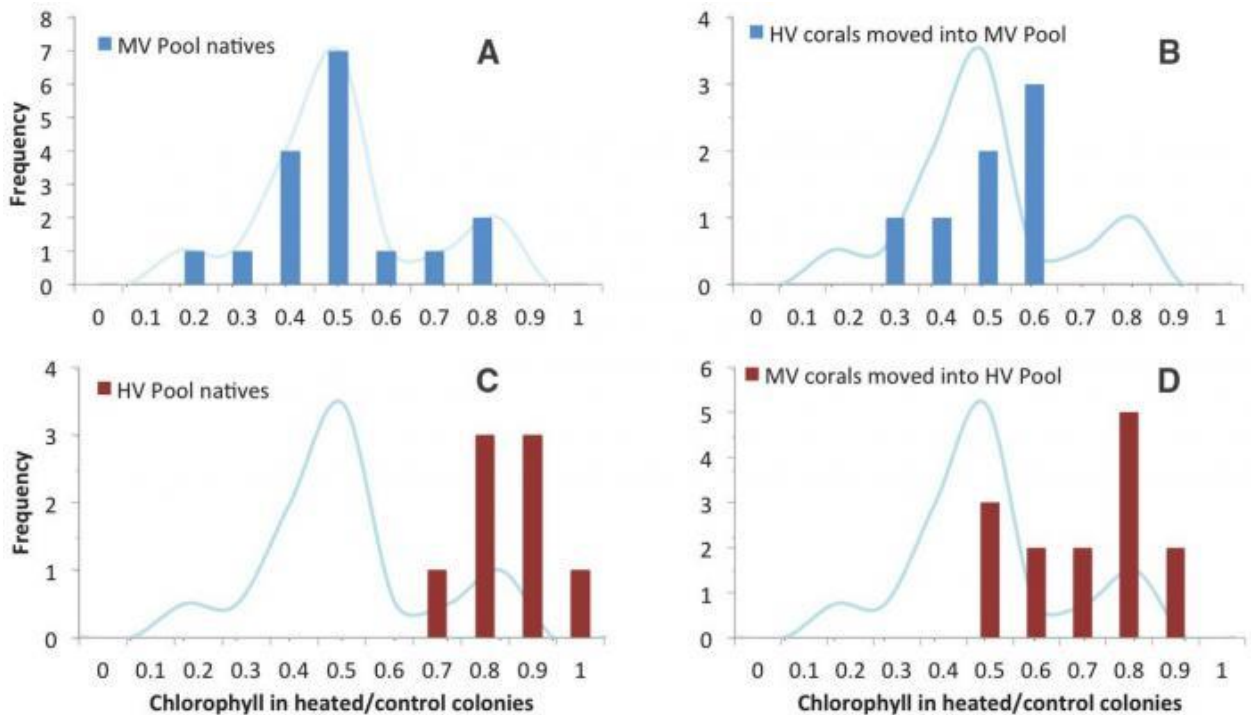


Fig. 1. Chlorophyll retention in coral colonies exposed to experimental heat stress compared with nonstressed controls. Upper panels show results from corals native to the moderately variable (MV) pool (A) and from corals moved into the MV pool (B). The lower panels are from corals native to the highly variable (HV) pool (C) and from corals moved into the HV pool (D). The smoothed curve reflects the distribution in (A) and is included in other panels for reference.

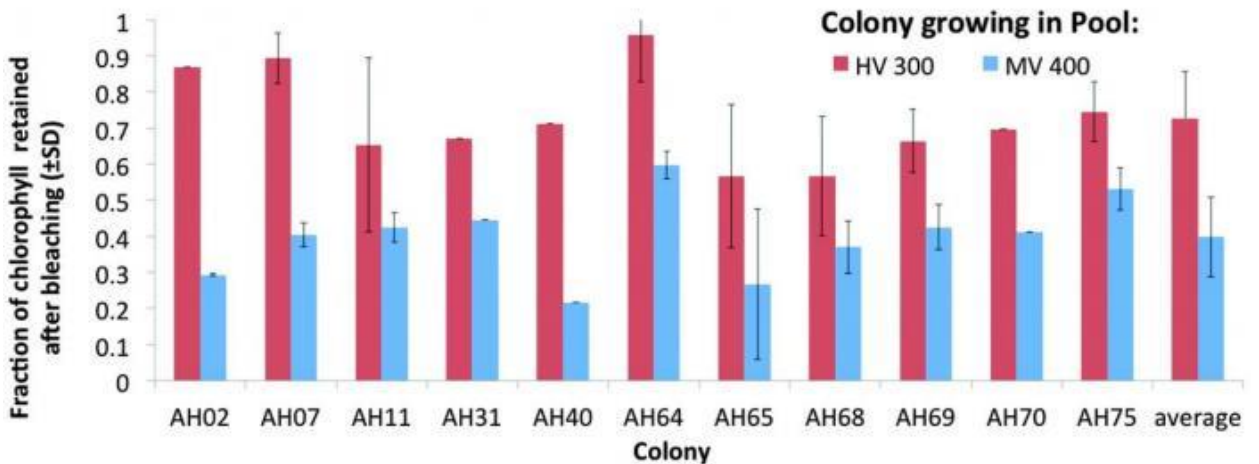


Fig. 2. Response of corals to reciprocal transplantation. The degree of bleaching experienced by a coral colony is measured by the ratio of chlorophyll that remains in experimentally heat-stressed colonies ($N = 2$ to 4 replicates per colony) compared to non-heat-stressed controls. Data are from 11 transplants into both the MV pool (blue) and HV pool (red). Error bars are SDs for colonies that were stressed-tested on two to three separate dates each.

Discussion

Experiments on fragments of tagged and monitored colonies showed that individuals native to the HV pool exhibit higher resistance to thermal stress, measured by retention of chlorophyll derived from photosynthetic symbionts, than corals from the MV pool (Fig. 1). The average retention of chlorophyll a after experimental heat stress was 80% in HV pool corals (Fig. 1C) but only 45% in MV pool corals (Fig. 1A, *t* test, $P < 0.00001$) compared with controls. The experiments showed higher chlorophyll a retention during heat stress in colonies transplanted to the HV pool than in the same colony transplanted to the MV pool ($P < 0.0001$, paired *t* test, Fig. 2). Bleaching resistance did not vary with the time of transplant or season ($P > 0.80$).

These experiments showed that some corals are capable of broad acclimatization to microclimate and developed enhanced resistance to bleaching without changing symbionts. We can place this capacity for acclimatization in an evolutionary context by comparing the natural phenotypic difference that we find between pools with the shift due to acclimatization after transplantation. Phenotypic change in evolutionary biology is often measured by the intensity parameter *I*, which is defined as the change in mean phenotype before versus after natural selection, divided by the standard deviation (SD) (19). In our case, we applied this concept to the spatial differences between pools instead of to temporal differences. The average phenotypic change from corals native to the HV pool versus the MV pool was 0.35 with a SD of 0.14 (compare Fig. 1, A and C). Thus, the phenotypic shift between pools was 2.5 SDs.

Here, *I* measures the difference in phenotype between coral populations subjected to different environments and is affected by phenotypic change caused by the fixed effects between the microclimates (denoted I_f), as well as by the acclimatization of individuals (denoted I_a), $I = I_f + I_a$. In this case, fixed effects include evolutionary adaptation, shifts in symbiont type, developmental changes, and epigenetics. Our transplant experiment allowed us to measure I_a as the average change in mean phenotype among acclimating individuals (0.214) divided by the SD (0.137), resulting in $I_a = 1.56$ (Fig. 1, A versus B and C versus D). This in turn allowed us to estimate I_f to be 0.94 SD units ($= I - I_a$).

These estimates indicated that these corals did acclimate to higher temperatures. The change in phenotype due to acclimatization (1.56 SD units) was similar to, but higher than, the change that we estimated is caused by fixed effects between pools (0.94 SD units).

Conclusion

The possibility that corals can acclimate to local differences has been suggested for decades: Conspecific corals at different latitudes show bleaching temperatures 1° to 2°C above local mean summer maximum sea-surface temperature (20, 21), despite substantial differences in mean summer maximum temperatures. However, the mechanism generating this pattern has not been rigorously tested. Early analyses of the threat to corals from climate change (1, 2) emphasized the potential for coral acclimatization or local adaptation to alter predictions of climate change effects. New models show that coral adaptation over a 40-year time frame could substantially change predictions for coral reef demise (22). But because future adaptation over many generations has been considered too slow for long-lived species such as corals, the role of individual acclimatization in coral environmental tolerance has been central to the debate on the future of reefs. The corals in our experiment achieved a larger bleaching phenotype shift ($I_a = 1.56$) due to acclimatization within 15 to 24 months than the shift due to fixed effects between habitats, a substantial acceleration in the rate of local matching of coral phenotype to thermal environment. Our results show that acclimatization

can allow corals to acquire substantial high-temperature resistance more quickly than strong natural selection would produce.

We do not yet know how many coral species can acclimate or evolve. Several dozen coral species live and grow in the overheated backreef pools of Ofu (23), but whether all individual colonies have equal acclimatization ability, or if there is an upper thermal limit to acclimatization or adaptation (24), remain unknown. It is also probable that multiple stressors—from acidification and heat, for example—can reduce the ability of corals to respond (25). Thus, acclimatization alone cannot be expected to completely overcome the threat to corals from widespread bleaching events, especially if the onset of high-temperature stress is abrupt and sustained. In this regard, the tempo and severity of heat anomalies will be critical for effective coral acclimatization.

Persistence of populations through climate change demands biogeographic shifts of species (26–28), evolutionary adaptation of populations (29), or local acclimatization of individuals (2). For long-lived, sessile foundation species that create ecosystem habitat such as forest trees or reef-building corals, range shifts and evolution are predicted to be slow (2, 30). Consequently, the rate and scope of acclimatization in these species to future environmental conditions is central to understanding the impact of climate change. For the fast-growing, shallow-water species that we studied, acclimatory and adaptive responses allowed them to inhabit reef areas with water temperatures far above their expected tolerances. How well other corals can similarly respond, and what the limits of these responses are, will determine how well current models accurately predict the future demise of coral reefs.

Adapted from *Science in the Classroom*
Sewer pipes party: sulfate is not invited

Authors: Ilje Pikaar Keshab R. Sharma Shihu Hu Wolfgang Gernjak Jürg Keller Zhiguo Yuan

Introduction

Urban sewer networks collect and transport domestic and industrial wastewaters through underground pipelines to wastewater treatment plants for pollutant removal before environmental discharge. They protect our urban society against sewage-borne diseases, unhygienic conditions, and noxious odors and so allow us to live in ever larger and more densely populated cities. Today's underground sewer infrastructure is the result of an enormous investment over the last 100+ years with, for example, an estimated asset value of one trillion dollars in the USA (1). This equates to ~7% of its current gross domestic product. However, these assets are under serious threat with an estimated annual asset loss of around \$14 billion in the United States alone (1). Sulfide-induced concrete corrosion is recognized as a main cause of sewer deterioration in most cases (2).

Under the anaerobic conditions common in sewage, sulfate is reduced to hydrogen sulfide by sulfate-reducing bacteria (3). The emission of hydrogen sulfide in gravity sewer sections, sewage pumping stations, and inlet structures of wastewater treatment plants induces sulfide oxidation to form corrosive sulfuric acid on concrete surfaces exposed to air (4, 5). The presence of sulfate in wastewater and its conversion to sulfide in anaerobic sewers are generally considered unavoidable, and water utilities around the world have been focusing on the removal of sulfide after its formation (3, 5-7), incurring mitigation costs comparable to the value of asset losses (3).

Sulfate in sewage can originate from three potential sources, namely, sulfate in source water used for drinking water production, sulfate added as the counter ions of aluminum or iron salts used as coagulants in the water treatment processes, and human and/or industrial wastes discharged. Coagulation plays an important role in drinking water treatment (8, 9). It removes (colloidal) solids and natural organic matter (NOM), which can compromise disinfection and act as precursors for disinfection by-products. Sulfate- and chloride-based aluminum (Al) or iron (Fe) salts are most commonly used.

To reveal the relative contribution of each of the three sources, we conducted an extensive measurement campaign over 2 years (January 2009 to December 2010), during which we monitored sulfate levels in raw source water, drinking water, and sewage in a suburban area in South East Queensland, Australia (10), where aluminum sulfate is used as coagulant in the drinking water production. Sulfate concentrations in the source water supplying a water treatment plant,

produced water from the plant, and sewage from a sewage pumping station collecting freshly discharged sewage from ~2900 households supplied by the plant were analyzed weekly. We subsequently conducted an extensive industry survey in Australia, comparing sulfate data in drinking water with and without sulfate addition during water treatment.

As much as 52% of the sulfate present in the sewage of the monitored area is contributed by the addition of aluminum sulfate as coagulant in the drinking water production, with a net contribution of 9.2 mg S/liter ([Fig. 1](#) and fig. S1). This result is supported by the national industry survey (table S1). Among the 77 plants surveyed, 51 plants provided sulfate data in both the source and produced waters. The sulfate levels in the source and product waters are comparable in the 17 plants that do not use sulfate-containing coagulants ([Fig. 2](#)). In the remaining 34 plants, where sulfate-based coagulants are added, the average sulfate concentration in the produced drinking water is approximately four times that in the source water ([Fig. 2](#)). The average sulfate addition in the 34 plants is 10.1 mg S/liter, comparable to the 9.2 mg S/liter increase measured in our sampling campaign ([Fig. 1](#)). These results reveal the substantial contribution of sulfate-based coagulants to sulfate levels in drinking water. The dosing rates (1.9 to 20.3 mg S/liter) are in agreement with the practice in other countries (table S2) and are also consistent with the theoretical demand. The coagulant dosing rate is typically determined by the NOM concentration in the source water, with a theoretical dosing ratio of 1.0 mg Al/mg C ([11](#)). The NOM levels in source waters typically range between ~3 and 15 mg C/liter ([12-14](#)), which would lead to a sulfate addition of 5 to 27 mg S/liter.

Forty-three out of the 77 plants surveyed (56%) use aluminum sulfate as the coagulant, which confirmed its widespread application. This result is consistent with reports from other countries such as the United States, China, India, and the United Kingdom (table S2). There is evidence that sewers are more seriously corroded in cities and regions with higher sulfate concentrations in drinking water (fig. S2). To assess the impact that sulfate-based coagulants can have on sewer corrosion, we performed extensive simulation studies using a virtual sewer network with average characteristics ([10](#), [15](#)).

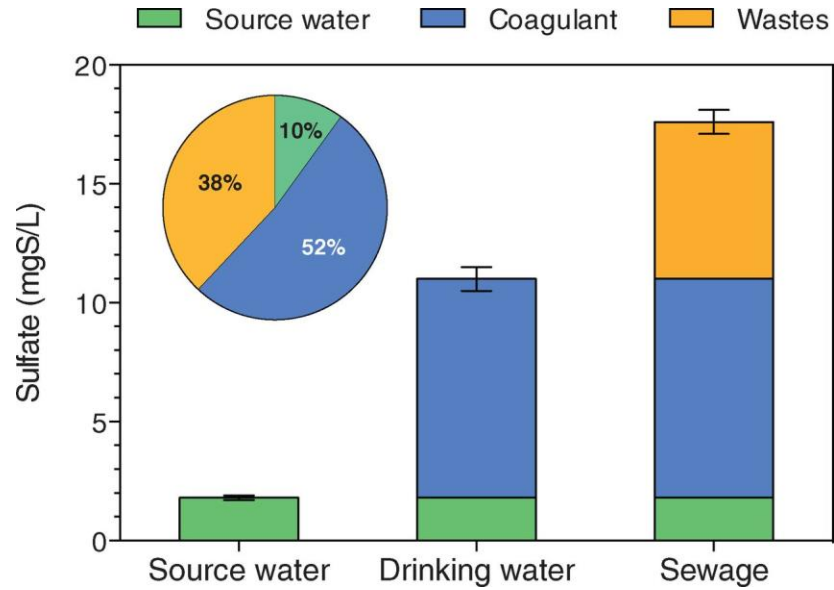


Fig. 1. Sulfate concentrations in source water, drinking water, and sewage in the sampled suburban area in 2009-2010. The sample sizes for the source water, drinking water, and sewage are 101, 104, and 92, respectively. Presented data are means \pm SEM. The inset shows the relative contributions of the three sources.

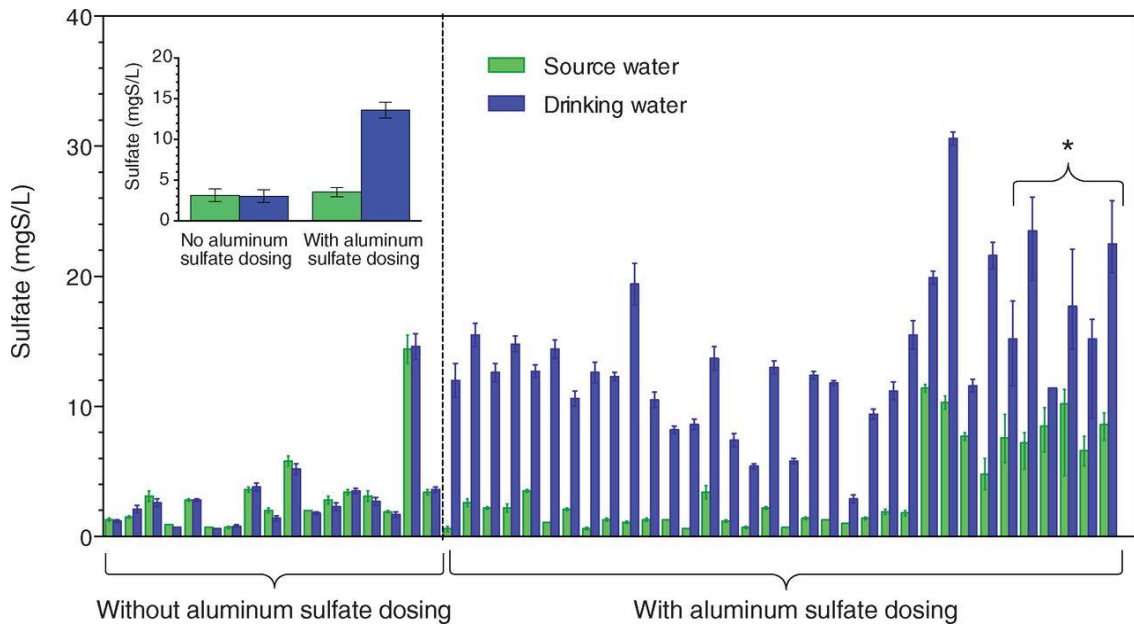


Fig. 2. Sulfate concentrations in source water and drinking water. (Inset) Average sulfate concentrations in source and drinking waters with and without aluminum sulfate addition in the treatment process. Presented data are means \pm SEM, except for those under the asterisk (*), which show the mean, maximum,

and minimum values. In the cases marked by the asterisk, data were provided in the form of mean, maximum, and minimum values.

Methods

A measurement campaign was conducted over a two-year period (Jan 2009 – Dec 2010) to measure sulfate levels in the source and drinking water at a local drinking water treatment plant (DWTP) that uses aluminum sulfate as the coagulant. Sulfate in the source water (n=101) and drinking water (n=104) were measured in a local NATA accredited analytical laboratory. In the same measurement campaign, inorganic sulfur species including sulfate, thiosulfate, sulfite and sulfide in the sewage in a local catchment area receiving drinking water from the above DWTP were also measured (n=92). The sewer network in this catchment collects sewage from approximately 2900 households through short gravity pipes. Fresh sewage samples were collected from a local wet well on an almost weekly basis and immediately filtered using a 0.22 μ m syringe filter (Millipore, USA) and preserved in a Sulfide Antioxidant Buffer (SAOB) solution prior to analysis. Sulfide, sulfite, thiosulfate and sulfate concentrations were measured with Ion Chromatography (IC), using the Dionex 2010i system. A detailed description of the preservation method and analytical procedure is provided in Keller-Lehmann et al. (27).

To enable a robust and equitable comparison between the different simulation cases, we implemented chemical dosing in the model (16). Through the addition of ferric chloride, a commonly used chemical for corrosion mitigation (7), the dissolved sulfide concentration was maintained at low levels (mostly below 0.5 mg S/liter) in all cases. With the addition of sulfate at 5 to 15 mg S/liter in the drinking treatment, the predicted costs for sulfide mitigation in sewers increased by ~30 to 50% compared with the case without sulfate addition (Fig. 3). We performed 72 additional simulation runs with the source water sulfate concentration, hydraulic retention time, rising main fraction, and sewage temperature systematically varied within their typical ranges (10).

Results

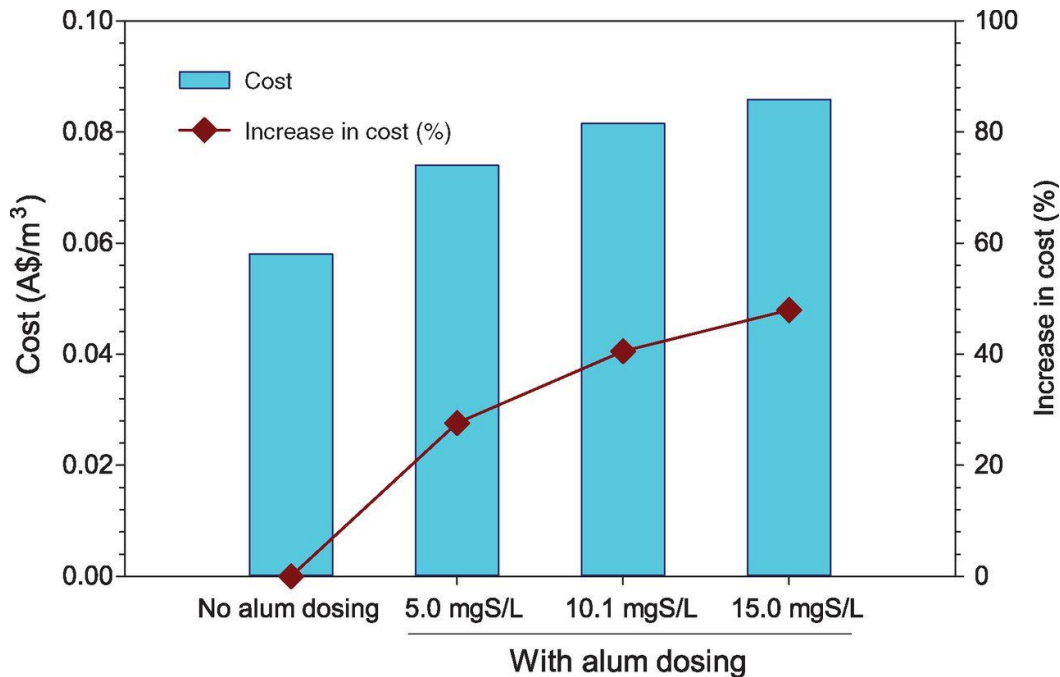


Fig. 3.

Predicted impact of the use of sulfate-based coagulants in drinking water treatment on sewer corrosion mitigation for average sewer and sewage conditions. The relative sulfide mitigation cost increases were calculated by using the case without sulfate addition as the reference.

Discussion

The results reveal that substantial cost savings can be achieved by avoiding the use of sulfate-based coagulants in all cases except when the source water already contains a high level of sulfate (e.g., >10 mg S/liter) (fig. S4A). Sulfate concentration in source waters is dependent on geological conditions and varies substantially between regions. It varies between ~1 and 14 mg S/liter with a mean value of 3.4 mg S/liter and a median value of 2.2 mg S/liter in the surveyed Australian cities (Fig. 2). Wide concentration ranges have also been reported for other parts of the world from <1 to >300 mg S/liter, with typical values of 5 to 7 mg S/liter (17, 18). These results imply that the majority of source waters have a sulfate concentration that is below the threshold values (10 to 15 mg S/liter) revealed by our simulation studies.

Our results highlight the benefits that could be attained by replacing sulfate-based coagulants with alternative, non-sulfate-based coagulants. Ferric chloride and polyaluminum chloride (PAC) are similarly effective coagulants and readily available and are indeed already used by some water utilities worldwide (19). The changeover costs are generally very low compared with the downstream saving potential, which may help water utilities, who are facing large, and still escalating, expenditures for the protection and rehabilitation of sewer assets (20, 21).

Conclusion

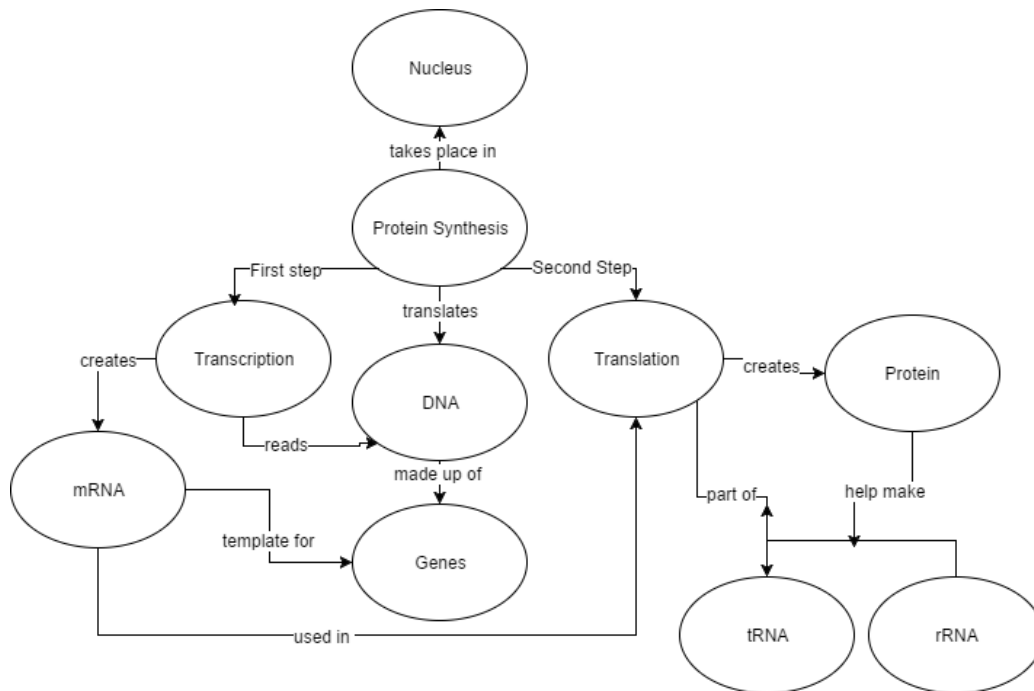
In cases where source waters contain high levels of sulfate (e.g., > 10 to 15 mg S/liter), proactive sulfate removal could be considered. Nanofiltration or reverse osmosis, for example, typically removes 95% to >99% of sulfate but is associated with high capital and operational costs. Simulation results show, however, that substantial savings can be achieved in corrosion management by removing sulfate from source water (fig. S5), which could largely offset the cost for membrane filtration. For example, the addition of a nanofiltration step in a French water treatment plant resulted in an increase of only €0.045/m³ in its operational costs (22). The filtration process also removes NOM, which would generate additional benefits such as the reduction of disinfection by-products, micropollutants, and microbial hazards, all of which are key considerations for public health protection (23, 24). Similar benefits can be achieved by the use of "climate-independent" water sources, such as desalination or potable water reuse that typically incorporate similar membrane filtration processes. However, such advanced treatment methods are more energy- and cost-intensive compared with conventional drinking water treatment (25). Their potential application should be carefully assessed from a health, economic, and environmental perspective.

Many water utilities will need to upgrade both their water supply and wastewater service infrastructure over the next 10 to 15 years, which will require enormous capital investments (21, 23, 26). Our findings show that there are critically important connections between these two seemingly independent systems. Although integrated urban water management and total water-cycle planning are firmly anchored in many policies developed by various levels of governments, in reality, individual subsystems—such as drinking water production and sewer and/or wastewater management—are often considered separately and optimized to generate locally maximized benefits (or least cost) without taking into account the existing connections across the water cycle. Our results show that such a disconnected management strategy can generate negative impacts in other parts of the urban water infrastructure. Although the technical challenges of reducing sulfate in sewage seem simple, institutional barriers may prevent a shift toward a whole-of-water-cycle optimization strategy. Given the increasing complexity and interdependence of the urban water systems, including recent trends in local water reuse, water-sensitive urban design, and low-impact development, the development and consistent application of novel, system-wide integration tools are essential to an overall optimization strategy. Such advances will be crucial to encourage the water industry to fully embrace integrated urban water management processes and to reap the benefits of this valuable concept.

APPENDIX C
ANALYSIS TEMPLATE

Consider: Read the Introduction section, while reading circle any key terms or ideas, then answer the following questions

In this section you will create a concept map that shows the information in the Introduction section of the paper. The purpose of a concept map is to show the key terms, ideas, and how these are all connected for a certain topic. The concept map starts with a central idea and then has other sub-topics that branch off from the central idea. Connections between ideas are shown by using arrows to connect the ideas, and linking words are written over the arrows to explain how the two ideas are connected to each other. Below is an example of a concept map.



1. To start your concept map identify the central idea (purpose of the study):
 2. List the circled key terms, methods, and ideas introduced in the Introduction
 3. On a separate sheet of paper draw a bubble in the middle of page and write in central idea from step 1, then draw bubbles and write in all terms from step 2.
 4. Now start drawing arrows between bubbles that are connected to each other. Make sure to write above the arrows (2-3 words) that explain how the different ideas are connected.
- Read: Read the Methods and Results section and answer the following questions.

Describe the information being conveyed in Figure 1 in your own words:

Describe the information being conveyed Figure 2 in your own words:

Describe the experimental method that matches up with Figure 1:

Describe the experimental method that matches up with Figure 2:

Create a diagram that shows the experimental method used for Figure 1:

Create a diagram that shows the experimental method used for Figure 2:

Elucidate a hypothesis

What do you think is the hypothesis for the first experimental method (Figure 1)?

What do you think is the hypothesis for the second experimental method (Figure 2)?

What is the control for the first experimental method?

What is the control for the second experimental method?

Analyze Part I: Use the Results section to answer the following questions

What is the label for the x-axis in Figure 1?
How were the values for this axis determined?

What is the label for the y-axis in Figure 1?
How were the values for this axis determined?

What main points can be drawn from Figure 1?

How do these main points relate to the hypothesis for the first experimental method?

What is the label for the x-axis in Figure 2?
How were the values for this axis determined?

What is the label for the y-axis in Figure 2?
How were the values for this axis determined?

What main points can be drawn from Figure 2?

How do these main points relate to the hypothesis for the second experimental method?

Based on the results what conclusions can you draw?

Analyze Part II: Read the Discussion section, while reading underline conclusions that the author makes, and then answer the following questions.

What conclusions did the authors make (summarize what the authors stated in the article)?

How do your conclusions compare to the conclusions of the author(s)?

What questions or concerns do you have?

Think of the Next Experiment. Read the Conclusion section and underline any important points you think the author makes in this section.

Based on the conclusions from the Discussion section and the important points from the Conclusion sections think of what would you do as the next experiment?

Why did you decide on this as the next experiment?

Extend.

Based on everything you have learned from reading this paper create another concept map for all of the information presented in the paper.

APPENDIX D

VIEWS ABOUT SCIENTIFIC INQUIRY SURVEY

Views about Scientific Inquiry

Student ID #: _____

Class: _____

Date: _____

The following questions are asking for your views related to science and scientific investigations. There are no right or wrong answers. Participating in this survey is completely voluntary.

Please answer each of the following questions. You can use all the space provided to answer a question and continue on the back of the pages if necessary.

1. A person interested in birds looked at hundreds of different types of birds who eat different types of food. He noticed that birds who eat similar types of food, tended to have similar shaped beaks. For example, birds that eat hard-shelled nuts have short, strong beaks, and birds that eat insects have long, slim beaks. He wondered if the shape of a bird's beak was related to the type of food the bird eats and he began to collect data to answer that question. He concluded that there is a relationship between beak shape and the type of food birds eat.
 - a. Do you consider this person's investigation to be scientific? Please explain why or why not.
 - b. Do you consider this person's investigation to be an experiment? Please explain why or why not.
 - c. Do you think that scientific investigations can follow more than one method?

If no, please explain why there is only one way to conduct a scientific investigation.

If yes, please describe two investigations that follow different methods, and explain how the methods differ and how they can still be considered scientific.

2. Two students are asked if scientific investigations must always begin with a scientific question. One of the students says "yes" while the other says "no". Whom do you agree with and why?

Minutes of light each day	Plant growth-height (cm per week)
0	25
5	20
10	15
15	5
20	10
25	0

3. (a) If several scientists ask the **same question** and follow the **same procedures** to collect data, will they necessarily come to the **same conclusions**? Explain why or why not.
 (b) If several scientists ask the **same question** and follow **different procedures** to collect data, will they necessarily come to the same conclusions? Explain why or why not.

4. Please explain if “data” and “evidence” are different from one another.

5. Two teams of scientists were walking to their lab one day and they saw a car pulled over with a flat tire. They all wondered, “Are certain brands of tires more likely to get a flat?”

Team A went back to the lab and tested various tires’ performance on one type of road surface.

Team B went back to the lab and tested one tire brand on three types of road surfaces.

Explain why one team’s procedure is better than the other one.

6. The data table below shows the relationship between plant growth in a week and the number of minutes of light received each day.

Given this data, explain which one of the following conclusions you agree with and why.

Please circle one:

- a) Plants grow taller with **more** sunlight.
- b) Plants grow taller with **less** sunlight.
- c) The growth of plants is **unrelated** to sunlight.

Please explain your choice of a, b, or c below:

7. The fossilized bones of a dinosaur have been found by a group of scientists. Two different arrangements for the skeleton are developed as shown below.

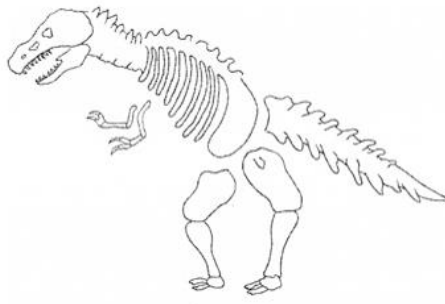


Figure 1

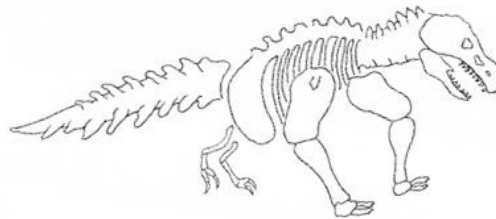


Figure 2

- a. Describe at least two reasons why you think most of the scientists agree that the animal in *figure 1* had the best sorting and positioning of the bones?
- b. Thinking about your answer to the question above, what types of information do scientists use to explain their conclusions?

APPENDIX E

OPEN-RESPONSE ARTICLE QUESTIONS SURVEY

APPENDIX F
CLASSROOM TEST OF SCIENTIFIC REASONING

**CLASSROOM
TEST OF
SCIENTIFIC
REASONING**

Multiple Choice Version

Directions to Students:

This is a test of your ability to apply aspects of scientific and mathematical reasoning to analyze a situation to make a prediction or solve a problem. Make a dark mark on the answer sheet for the best answer for each item. If you do not fully understand what is being asked in an item, please ask the test administrator for clarification. Answering these questions is completely voluntary.

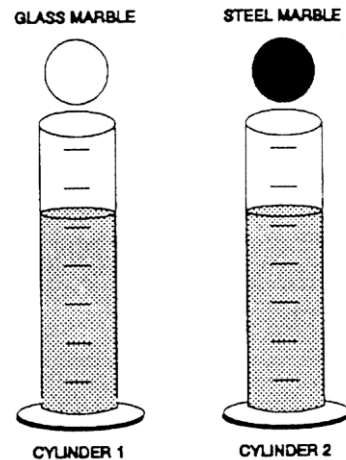
**DO NOT OPEN THIS BOOKLET UNTIL YOU ARE TOLD TO
DO SO**

1. Suppose you are given two clay balls of equal size and shape. The two clay balls also weigh the same. One ball is flattened into a pancake-shaped piece. *Which of these statements is correct?*
- The pancake-shaped piece weighs more than the ball
 - The two pieces still weigh the same
 - The ball weighs more than the pancake-shaped piece
2. *because*
- the flattened piece covers a larger area.
 - the ball pushes down more on one spot.
 - when something is flattened it loses weight.
 - clay has not been added or taken away.
 - when something is flattened it gains weight.

3. To the right are drawings of two cylinders filled to the same level with water. The cylinders are identical in size and shape.

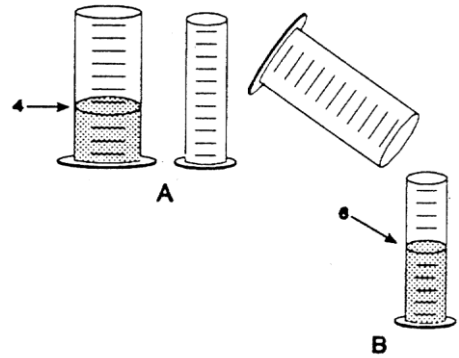
Also shown at the right are two marbles, one glass and one steel. The marbles are the same size but the steel one is much heavier than the glass one.

When the glass marble is put into Cylinder 1 it sinks to the bottom and the water level rises to the 6th mark. *If we put the steel marble into Cylinder 2, the water will rise*



- to the same level as it did in Cylinder 1
 - to a higher level than it did in Cylinder 1
 - to a lower level than it did in Cylinder 1
4. *because*
- the steel marble will sink faster.
 - the marbles are made of different materials.
 - the steel marble is heavier than the glass marble.
 - the glass marble creates less pressure.
 - the marbles are the same size.

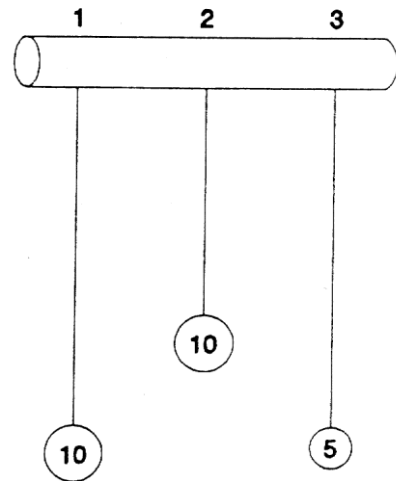
5. To the right are drawings of a wide and a narrow cylinder. The cylinders have equally spaced marks on them. Water is poured into the wide cylinder up to the 4th mark (see A). This water rises to the 6th mark when poured into the narrow cylinder (see B).



Both cylinders are emptied (not shown) and water is poured into the wide cylinder up to the 6th mark. *How high would this water rise if it were poured into the empty narrow cylinder?*

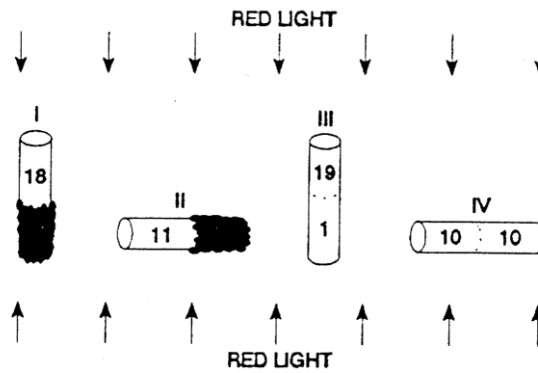
- a. to about 8
 b. to about 9
 c. to about 10
 d. to about 12
 e. none of these answers is correct
6. *because*
 a. the answer can not be determined with the information given.
 b. it went up 2 more before, so it will go up 2 more again.
 c. it goes up 3 in the narrow for every 2 in the wide.
 d. the second cylinder is narrower.
 e. one must actually pour the water and observe to find out.
7. Water is now poured into the narrow cylinder (described in Item 5 above) up to the 11th mark. *How high would this water rise if it were poured into the empty wide cylinder?*
 a. to $7 \frac{1}{2}$
 b. to 9
 c. to 8
 d. to $7 \frac{1}{3}$
 e. none of these answers is correct
8. *because*
 a. the ratios must stay the same.
 b. one must actually pour the water and observe to find out.
 c. the answer can not be determined with the information given.
 d. it was 2 less before so it will be 2 less again.
 e. you subtract 2 from the wide for every 3 from the narrow.

9. At the right are drawings of three strings hanging from a bar. The three strings have metal weights attached to their ends. String 1 and String 3 are the same length. String 2 is shorter. A 10 unit weight is attached to the end of String 1. A 10 unit weight is also attached to the end of String 2. A 5 unit weight is attached to the end of String 3. The strings (and attached weights) can be swung back and forth and the time it takes to make a swing can be timed.



- Suppose you want to find out whether the length of the string has an effect on the time it takes to swing back and forth. *Which strings would you use to find out?*
- only one string
 - all three strings
 - 2 and 3
 - 1 and 3
 - 1 and 2
10. *because*
- you must use the longest strings.
 - you must compare strings with both light and heavy weights.
 - only the lengths differ.
 - to make all possible comparisons.
 - the weights differ.

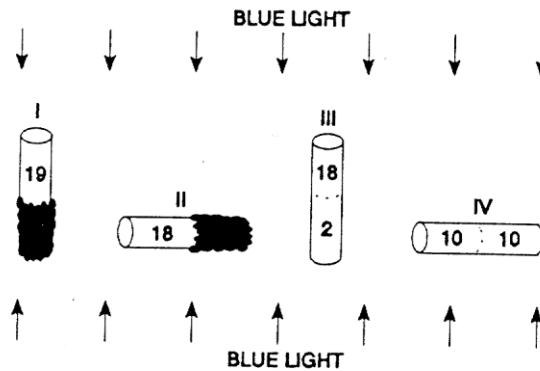
11. Twenty fruit flies are placed in each of four glass tubes. The tubes are sealed. Tubes I and II are partially covered with black paper; Tubes III and IV are not covered. The tubes are placed as shown. Then they are exposed to red light for five minutes. The number of flies in the uncovered part of each tube is shown in the drawing.



This experiment shows that flies respond to (respond means move to or away from):

- red light but not gravity
 - gravity but not red light
 - both red light and gravity
 - neither red light nor gravity
12. *because*
- most flies are in the upper end of Tube III but spread about evenly in Tube II.
 - most flies did not go to the bottom of Tubes I and III.
 - the flies need light to see and must fly against gravity.
 - the majority of flies are in the upper ends and in the lighted ends of the tubes.
 - some flies are in both ends of each tube.

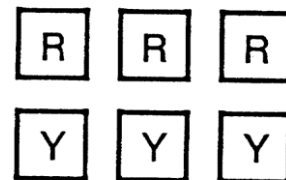
13. In a second experiment, a different kind of fly and blue light was used. The results are shown in the drawing.



These data show that these flies respond to (respond means move to or away from):

- blue light but not gravity
 - gravity but not blue light
 - both blue light and gravity
 - neither blue light nor gravity
14. *because*
- some flies are in both ends of each tube.
 - the flies need light to see and must fly against gravity.
 - the flies are spread about evenly in Tube IV and in the upper end of Tube III.
 - most flies are in the lighted end of Tube II but do not go down in Tubes I and III.
 - most flies are in the upper end of Tube I and the lighted end of Tube II.

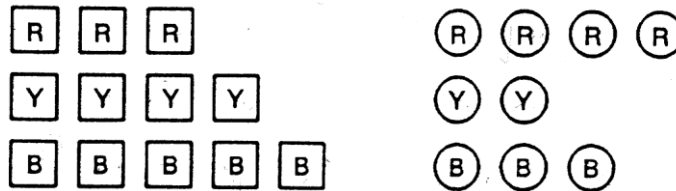
15. Six square pieces of wood are put into a cloth bag and mixed about. The six pieces are identical in size and shape; however, three pieces are red and three are yellow. Suppose someone reaches into the bag (without looking) and pulls out one piece. *What are the chances that the piece is red?*



- 1 chance out of 6
- 1 chance out of 3
- 1 chance out of 2
- 1 chance out of 1
- cannot be determined

16. *because*
- 3 out of 6 pieces are red.
 - there is no way to tell which piece will be picked.
 - only 1 piece of the 6 in the bag is picked.
 - all 6 pieces are identical in size and shape.
 - only 1 red piece can be picked out of the 3 red pieces.

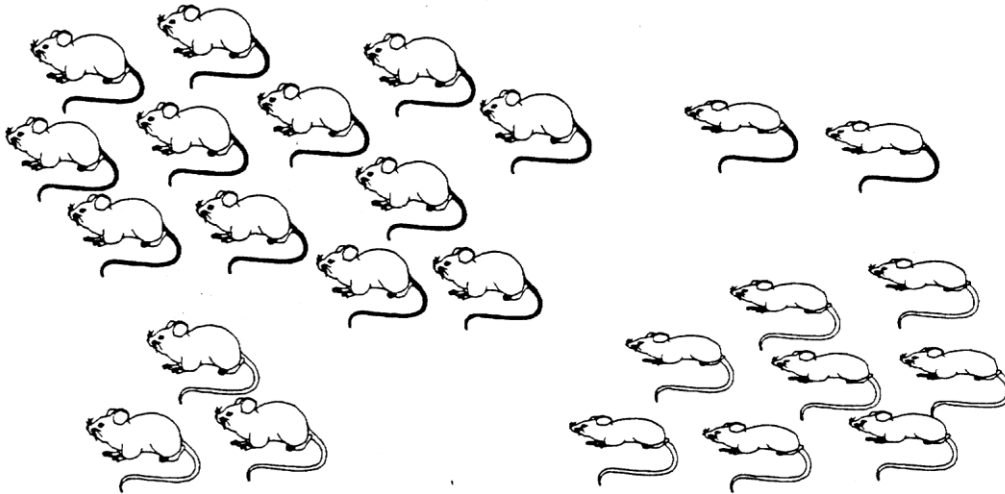
17. Three red square pieces of wood, four yellow square pieces, and five blue square pieces are put into a cloth bag. Four red round pieces, two yellow round pieces, and three blue round pieces are also put into the bag. All the pieces are then mixed about. Suppose someone reaches into the bag (without looking and without feeling for a particular shape piece) and pulls out one piece.



What are the chances that the piece is a red round or blue round piece?

- cannot be determined
 - 1 chance out of 3
 - 1 chance out of 21
 - 15 chances out of 21
 - 1 chance out of 2
18. *because*
- 1 of the 2 shapes is round.
 - 15 of the 21 pieces are red or blue.
 - there is no way to tell which piece will be picked.
 - only 1 of the 21 pieces is picked out of the bag.
 - 1 of every 3 pieces is a red or blue round piece.

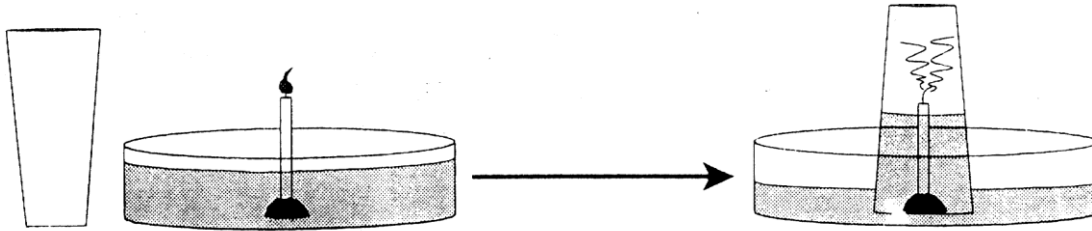
19. Farmer Brown was observing the mice that live in his field. He discovered that all of them were either fat or thin. Also, all of them had either black tails or white tails. This made him wonder if there might be a link between the size of the mice and the color of their tails. So he captured all of the mice in one part of his field and observed them. Below are the mice that he captured.



Do you think there is a link between the size of the mice and the color of their tails?

- a. appears to be a link
 - b. appears not to be a link
 - c. cannot make a reasonable guess
20. *because*
- a. there are some of each kind of mouse.
 - b. there may be a genetic link between mouse size and tail color.
 - c. there were not enough mice captured.
 - d. most of the fat mice have black tails while most of the thin mice have white tails.
 - e. as the mice grew fatter, their tails became darker.

21. The figure below at the left shows a drinking glass and a burning birthday candle stuck in a small piece of clay standing in a pan of water. When the glass is turned upside down, put over the candle, and placed in the water, the candle quickly goes out and water rushes up into the glass (as shown at the right).



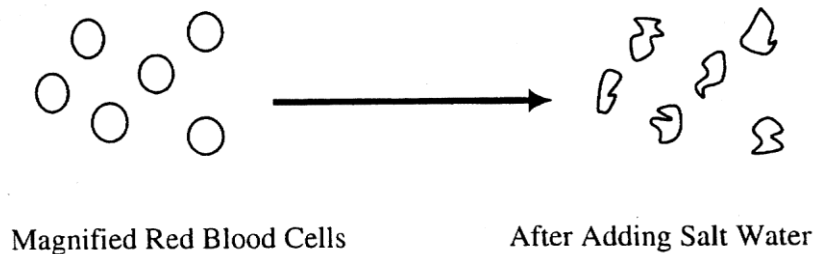
This observation raises an interesting question: Why does the water rush up into the glass?

Here is a possible explanation. The flame converts oxygen into carbon dioxide. Because oxygen does not dissolve rapidly into water but carbon dioxide does, the newly formed carbon dioxide dissolves rapidly into the water, lowering the air pressure inside the glass.

Suppose you have the materials mentioned above plus some matches and some dry ice (dry ice is frozen carbon dioxide). *Using some or all of the materials, how could you test this possible explanation?*

- a. Saturate the water with carbon dioxide and redo the experiment, noting the amount of water rise.
 - b. The water rises because oxygen is consumed, so redo the experiment in exactly the same way to show water rise due to oxygen loss.
 - c. Conduct a controlled experiment, varying only the number of candles to see if that makes a difference.
 - d. Suction is responsible for the water rise, so put a balloon over the top of an open-ended cylinder and place the cylinder over the burning candle.
 - e. Redo the experiment, but make sure it is controlled by holding all independent variables constant; then measure the amount of water rise.
22. What result of your test (mentioned in #21 above) would show that your explanation is probably wrong?
- a. The water rises the same as it did before.
 - b. The water rises less than it did before.
 - c. The balloon expands out.
 - d. The balloon is sucked in.

23. A student put a drop of blood on a microscope slide and then looked at the blood under a microscope. As you can see in the diagram below, the magnified red blood cells look like little round balls. After adding a few drops of salt water to the drop of blood, the student noticed that the cells appeared to become smaller.



This observation raises an interesting question: Why do the red blood cells appear smaller?

Here are two possible explanations: I. Salt ions (Na^+ and Cl^-) push on the cell membranes and make the cells appear smaller. II. Water molecules are attracted to the salt ions so the water molecules move out of the cells and leave the cells smaller.

To test these explanations, the student used some salt water, a very accurate weighing device, and some water-filled plastic bags, and assumed the plastic behaves just like red-blood-cell membranes. The experiment involved carefully weighing a water-filled bag, placing it in a salt solution for ten minutes and then reweighing the bag.

What result of the experiment would best show that explanation I is probably wrong?

- the bag loses weight
- the bag weighs the same
- the bag appears smaller

24. *What result of the experiment would best show that explanation II is probably wrong?*

- the bag loses weight
- the bag weighs the same
- the bag appears smaller