STUDENT CRITICAL THINKING ON SCIENTIFIC MISINFORMATION

Andrew Parliment
Colorado State University
Fall 2014
ABSTRACT

This mixed methods action research study assessed student responses in two different lessons in which students were unknowingly presented with scientific misinformation in order to test their critical thinking in a scientific context. It was delivered to a general chemistry class at Fossil Ridge High School in Fort Collins, Colorado. During the first lesson, students worked in small groups and one student recorded the thoughts of each group member while they read a one page article on a water powered car. This was followed by a survey and a full class discussion. After this lesson, students were debriefed about being misled with this lesson, and they were presented with a list of things to consider when critiquing a scientific article. Weeks later, during the second lesson, students responded individually to a video about solar roadways. These individual responses were compared to responses from the first lesson to assess whether class performance improved. Of the 20 students in the study, 40% questioned the first lesson, the water powered car, and 10% outright rejected it. During the second lesson, 60% of students questioned the solar roadways proposal and 15% outright rejected it. These 50% increases were not found to be statistically significant according to the Z test, however.
SECTION I

Introduction

Background

Critical thinking is the process of applying one’s own reasoning to a subject to produce questions and evaluate validity (Bailin et al., 2010). Critical thinking might take the form of asking higher level questions about a lesson or analyzing a source’s validity in a history classroom (LaPoint-O’Brien, 2013). In a science classroom, it might take the form of reasoning through a scientific procedure or considering the validity of an argument (Gokehale, 1995). Studies have shown that collaborative learning (Gokehale, 1995) and self-reflection (Choy and Oo, 2012) are effective ways of teaching critical thinking. The Informal Reasoning Fallacy Instrument (IRFI) and the California Critical Thinking Dispositions (CCTDI) are both instruments designed to assess critical thinking with regards to logical fallacies (Ramasamy, 2011).

Rationale

Critical thinking is a major focus of standards in all science classrooms (Vieira et al., 2011). The true sign of critical thinking is the ability to independently identify poor reasoning when it is presented. Critical thinking, however, is not something that can simply be taught through direct instruction or simply insisting that students practice it. In addition, it is not something that can be taught separate from the subject in which the critical thinking is to be used (Bailin et al., 2010). Students should instead be put in situations that encourage them to apply their critical thinking skills to the content, and show them the importance of these skills. In addition, collaborative learning is one of many ways a classroom environment can better support critical thinking (Gokehale, 1995). Critical thinking is of extreme relevance to modern education,
and there has been something of an international arms race amongst industrialized nations in recent years with the intention of producing more scientists and engineers (Vieira et al., 2011).

**Purpose and Hypothesis**

The purpose of this study is to test a potential collaborative lesson to encourage critical thinking. The intention is that the scaffolding of guiding students through critical thinking will encourage students to exercise their own reasoning when considering scientific arguments. The research question for this study is “Can critical thought be promoted through guided instruction and group inquiry?” This study will be one of mixed methods, with information about whether or not students identified the misinformation presented to them being the quantitative set of data, and the process and experience they describe their group having gone through being the qualitative portion.

To answer this question, students will first be exposed to faulty scientific research and asked to discuss their thoughts. They will discuss in groups, and each group will write a report of the contributions from each group member. This first session will end with a debriefing that explains that the premise of the scientific article provided was inaccurate, a description of the problems in the article, and a description of the thought process critical thinkers engage in. Weeks later, students will be exposed to similar misinformation, and again asked to respond to it. The intention is that the guidance they received during the first lesson will give them context for how to think critically in this second lesson, and in the future when they are presented with claims. The hypothesis is therefore that students will be more critical of the second set of scientific misinformation after the first lesson in critical thinking and the misdirection that came with it.
What are the advantages of critical thinking?

Critical thinking: Conceptual Clarification and Its Importance in Science Education (Vieira et al., 2011) is a compilation of research that discusses the role critical thinking plays on an international scale, the need for critical thinking when teaching scientific literacy, and possible methods for teaching critical thinking. Its purpose is to add relevance to the focus on critical thinking in the classroom, and provide tools teachers can use to implement these goals. To support their claims, Vieira, Tenreiro-Vieira and Martins (2011) reference a wide range of research on critical thinking and its role in education.

Vieira et al. (2011) begin by spelling out the importance of critical thinking in education. They establish that improving the quality of critical thought in the classroom has been an international arms race in education due to nations competing to have the schools that produce the best scientists and innovators. They go on to describe the reasons for this emphasis. For example, scientific literacy is more than simple science facts; it requires critical thinking skills in order to apply that knowledge and reason like a scientist. This information will help establish relevance to students as to why critical thinking is important and needs to be learned.

After establishing the relevance of critical thinking, they go into some strategies for promoting it. Discussions, personal position essays, and analyzing journal articles are all given as examples of ways to encourage and build critical thinking in the science classroom.
How can critical thinking be taught?

Collaborative Learning Enhances Critical Thinking (Gokhale, 1995) was a quantitative study on how collaborative learning affects critical thinking. The purpose of this study was to examine how group work versus individual work affects performance on both critical thinking skills and drill-and-response skills. The effect that the group or individual learning exercise had on these skills was assessed with pretests and posttests. The instrument used to collect data was the tests, designed by Gokhale (1995), which contained assessments on DC circuits that contained questions on components of the circuit (drill-and-response skills) as well as the layout and interpretation of circuits (critical thinking skills). All students were given the same 50 minute lecture on circuits, and were then randomly sent to different rooms, one in which students worked on their inquiry worksheet in groups, and the other where they did so individually. The performance of students was then used to analyze how their performance was affected by the activity.

Gokhale (1995) begins by citing modern research into the links between collaborative learning and critical thinking. This research concludes that collaboration, especially in small groups, enhances critical thinking skills.

Gokhale’s (1995) research goes on to establish that collaborative studying raised results on the critical thinking portion of the post-test, more so than it did on the drill-and-practice section of the test. This further supports the notion that students should work in groups for a critical thinking activity.

Action Research: The Development of Critical Thinking Skills (LaPoint-Obrien, 2013) tests a ticket out the door activity in which students in a ninth grade history course end the class.
writing a minute essay in which they describe three facts, ideas, concepts or thoughts from the lesson and posed one insightful question. It is a mixed methods action research study that uses the student responses and grades of student essays as its data. Students were asked to analyze the lesson for three of its most important insights, and to question the content of their class. These essays were scored by a consistent rubric over the course of the study. LaPoint-O’Brien (2013) asserts that teaching through rote memorization alone discourages critical thought on the material.

LaPoint-O’Brien’s (2013) results were very positive. After the first day of implementation of the activity, students asked if they could discuss the activity with their peers after submitting it in order to better improve their understanding. The scores on the essays fluctuated throughout the study, but showed overall improvement by the end of the 3rd week, with a 40% increase in the students receiving a score between 3.00 and 3.99, a 26% decrease in scores between 2.00 and 2.99 and a 13% decrease in scores between 1.00 and 1.99 in the third week compared to the second week. The number of students who received perfect scores remained consistent between these two weeks at one student.

LaPoint-O’Brien’s (2013) study outlines an important method for assessing critical thinking: assessing the questions asked by students about the material. Since the goal of education in critical thinking is to encourage the questioning of information, it stands to reason that any evaluation of critical thinking must assess the questions asked by students.

Enhancing Critical Thinking Skills Among Authoritarian Students (Henderson Hurley and Hurley, 2013) begins by defining an authoritarian personality type based on the work of Altemeyer (2006) and Stone, Lederer, and Christie (1993). An authoritarian is defined as an
individual who prefers the established order, follows official dictates, and is hostile to those perceived as a threat to the norm. They argue that this opposition to challenging authority inhibits critical thinking. This report is a literature survey that seeks to apply modern research on critical thinking to lessons best suited for the authoritarian personality type.

Henderson-Hurley and Hurley (2013) propose that authoritarian students need to be pushed from their comfort zone and challenged with new ideas. They use an example of a criminal justice class in which 95% of students reported on a survey that prison’s primary function was to deter crime and incapacitate criminals. In order to encourage critical thinking, students were given an assignment to argue the case of the opposing viewpoint that the primary purpose of prison is to rehabilitate prisoners. In an anonymous discussion board after the completion of the assignment, half of the students reported that their views had changed as a result of the assignment, and one third reported that they saw serious problems with the prison system. The reevaluation of their beliefs shows that critical thinking was encouraged in this classroom.

Henderson-Hurley and Hurley (2013) provide an example of one personality type that learns critical thinking in a way that differs from other students. Teaching and encouraging critical thinking will be a different experience for each student based on their personality and their willingness to challenge their own ideas and those of their society. It is vital as an instructor to realize that some students will require a different approach in order to encourage their critical thinking.

The Impact of Preparing Agriculture Faculty to Influence Student Critical Thinking Disposition (Burbach, Matkin and Quinn, 2001) is a quantitative study in which teachers were
trained on how to encourage critical thinking. The University of Florida-Engagement, Maturity, and Innovativeness Assessment (UF-EMI) was used to assess critical thinking in these three areas of students in the classrooms of teachers who had received such training.

Burback, Matkin and Quinn (2001) observed seven of the fourteen classes showing improvement in all three areas, and only two courses showed no significant improvement in any of these areas. Although a control class is not available for comparison, these results show that an instructor can increase scores on critical thinking assessments.

This success in encouraging critical thinking supports the claim that teaching critical thinking is a worthwhile goal in a classroom. Furthermore, given that the results vary from classroom to classroom (Burback, Matkin and Quinn, 2001), it is clear that there are certain pedagogical techniques and/or classroom environments that foster critical thinking better than others.

Reflective Thinking and Teaching Practices: A Precursor for Incorporating Critical Thinking into the Classroom? (Choy and Oo, 2012) is a quantitative study that uses a survey given to 60 instructors in higher education as its data to determine the level of reflection in higher education instructors. Choy and Oo (2012) claim that reflection is vital for both students and teachers to encourage critical thinking in the classroom.

The 33 question survey asked instructors questions regarding how often they thought about how they might change lessons in the future, how they react to feedback, and whether they consider why they teach the way they do. The results showed that the instructors surveyed were most concerned with their content knowledge when it came to their teaching, with little self-reflection of how they were presenting this information. Even fewer respondents reported using
student feedback to modify their lessons. This also indicates that self-reflection was not a process that these instructors involved their students in.

According to Choy and Oo (2012), self-reflection is a vital component of critical thinking, and it is important to model this behavior for students. This survey delineates areas in which instructors can improve their ability to self-reflect, encouraging students to reflect on their own learning and the information they are provided.

Common Misconceptions of Critical Thinking (Bailin et al., 1999) serves as a compilation of research on misconceptions about critical thinking. Its purpose is to clarify these misconceptions to ensure that teachers are not using them in their lesson plans. In support of their claims, Bailin, S., Case, R., Coombs, J. R., & Daniels, L. B. (1999) provide references to research in the critical thinking to support what they consider to be the truth with regards to these misconceptions.

Bailin et al. (1999) make the case that critical thinking is often misunderstood by the general public, and that this may affect the way it is understood in the classroom. For instance, they point to compelling research and sound reasoning that critical thinking cannot be taught exclusively as a general skill but must be learned and practiced in the specific context of a subject area. The critical thinking skills learned in one subject area are not immediately generalizable to other subject areas. They support this claim with an assertion from Nickerson, Perkins and Smith (1985) that transfer of critical thinking between subject areas is itself a learned skill, and it should not be expected that practicing critical thinking in one area will improve it in another. This spells out the scope of the kind of critical thinking that can be taught in the science classroom; students should be taught content specific critical thinking and transfer
should be encouraged, but students should not be expected to be all purpose critical thinkers after demonstrating critical thinking in one specific setting.

Furthermore, they make the case that critical thinking should not be presented as something that is discrete that can be learned divorced from the content. This claim is supported by Beyer (1987) in his book Practical Strategies for the Teaching of Thinking. If critical thinking is indeed often specific to the context it is learned in, attempting to teach critical thinking outside of content is useless.

It is also fallacious, as Beyer (1987) points out, to think of critical thinking as a single procedure. It is tempting to offer a check list for how a student should critically analyze something, but if you do they begin to perform your critical thinking and cease to do their own. Students should be introduced to solid critical questions, but only for the intention of helping them to ask their own questions.

Outlining these examples of how critical thinking should not be taught provides some useful warnings for the design of a critical thinking lesson. It is clear that students cannot be given an outline of how to think critically, and that a general “brain teaser” will not teach them critical thinking skills that they can readily generalize to other subjects.

**How can critical thinking be measured?**

An Analysis of Informal Reasoning Fallacy and Critical Thinking Dispositions among Malaysian Undergraduates (Ramasamy, 2011) is an experiment that uses both the Informal Reasoning Fallacy Instrument (IRFI) and the California Critical Thinking Dispositions (CCTDI) to assess the critical thinking of Malaysian Undergraduate students. These tests distinguish between a number of logical fallacies and scores students on their ability to avoid them. An *ad*
hominem is a fallacy in which the person giving the argument is attacked rather than the argument itself. A slippery slope fallacy is one in which someone claims that one event leads to another, when there is in truth no logical connection. A hasty generalization assumes that statistical trends imply a rule about a certain population. A post hoc ergo propter hoc, also known as the false cause, asserts a causal connection between two things where none actually exists. This is often the result of the person making the fallacy assuming that a correlation implies causation. A false analogy is one in which someone assumes that because two things share certain qualities, they must also share the quality of interest.

The findings between these two instruments were fairly consistent. They showed that 15 to 16.4% fell victim to the ad hominem fallacy, 8 to 10.6% fell victim to the slippery slope fallacy, 6.9 to 11.6% fell victim to the hasty generalization, 16.5 to 18% fell victim to the post hoc ergo propter hoc, and 15.3 to 19.4% fell victim to the false analogy.

Although this study examines a very different population, it provides an insight into how critical thinking can be measured. Although they are more formal means of assessment than are appropriate for this study, the IRFI and the CCTDI provide a valuable insight into the nature of instruments used to assess critical thinking.

Summary

Critical thinking in the sciences is best taught through collaborative learning (Gokehale, 1995) and self-reflection (Choy and Oo, 2012). Critical thinking is typically context specific, and should not be seen as a general skill that can be taught with exercises that are divorced from content (Bailin et al., 2010). In order to assess critical thinking, we must assess the logical fallacies and inconsistencies to which a student falls victim (Ramasamy, 2011).
SECTION III
Methodology

Context and Setting

Fossil Ridge is a large and well-funded high school surrounded by affluent neighborhoods on the southern end of Fort Collins, Colorado. The horse shoe shaped building sits in a relatively undeveloped area. The building itself is highly eco-conscious in its design, with all classrooms having external windows for natural lighting. It is a part of the Poudre School District, which serves Fort Collins, Laporte and surrounding areas.

The student body at Fossil Ridge is 86% white, 7% Hispanic or Latino, 3% of two or more races, 2% Asian, 1% American Indian or Alaskan native and 1% black. 11% of students at Fossil Ridge are eligible for a free or reduced price lunch program (greatschools.org). As a whole, students in the Poudre School District are 74.31% white, 17.93% Hispanic or Latino, 3.15% of two or more races, 3.06% Asian, 0.53% American Indian or Alaskan native and 1.37% black. 30.79% of Poudre School District students are eligible for free or reduced lunch (psdschools.org). Both Fossil Ridge and the Poudre School District are generally less diverse than the state of Colorado as a whole, of which the student population is 56% white, 32% Hispanic or Latino, 3% of two or more races, 3% Asian, 1% American Indian or Alaskan native and 5% black. 41% of Colorado students are eligible for free or reduced lunch (greatschools.org).

Fossil Ridge has a very involved parent community that helps organize and chaperone a variety of school related events from school dances to athletic and academic competitions. Fossil Ridge has a very involved integrated services department. General education students are very
Respectful of the integrated services staff and students, and I have often seen general education students helping differently abled students between classes.

Fossil Ridge operates on the Multi-Tiered System of Supports (MTSS), which monitors student discipline issues and failing grades across classes and intervenes when necessary. Students are given special accommodations as needed for 504 learning plans and individualized learning plans (IEPs).

Joe Anastasia’s general chemistry class is an inquiry-based environment in which questioning is encouraged. His demeanor is often strict, but he makes a point of making jokes and having fun with students. The class consists of fifteen boys, three of whom are Hispanic/Latino, and eleven girls, one of whom is Asian. This class is the appropriate setting for action research in critical thinking because one of the goals of a general chemistry classroom is for students to be scientifically literate voters and consumers. The ability to critically analyze misinformation will help students achieve this goal.

**Participants**

Of the twenty six students in the class, all participated. However, one group of four did not turn in their group response sheet for the first activity, and two did not turn in their individual response sheets for the second activity. Since the activity compares improvement between the two sessions, these six students were left out of the final results. This brings the number of male Hispanic/Latino students to two.
The study was conducted in two lessons. The first lesson, delivered by the researcher on November 18, 2014 divided students into their normal work groups and gave them an article on water powered cars to discuss (Appendix A) which is an abridged version of an article from the website collective-evolution.com (Arjun Walia, 2013). After reading the article, students discussed it in groups and one student recorded the thoughts of each group member. These were then collected and students took a survey on their previous knowledge on the subject (Appendix B). The class was then opened to a full class discussion on the article. To avoid creating misconceptions and to encourage future critical thinking, the discussion was followed by the delineation of a list of problems with the idea of a water powered car. This list was also projected onto the Smartboard (Appendix C). The lesson concluded with a description and short discussion of a variety of strategies to evaluate a scientific article. These strategies were also projected onto the Smartboard (Appendix C).

The second lesson was delivered by Mr. Anastasia on December the 4th. The lag time and change of instructors was a way to address concern that students might have been prompted to be more critical if they realized that this lesson was a follow-up to the study. In this lesson, the first four minutes of the Youtube video for the solar roadways proposal was shown, students are asked to individually write a brief reflection on what they thought, and are asked to state whether they had heard of solar roadways before. There was then a full class discussion and a similar debriefing on the scientific issues with the project (Appendix D). Small group discussions were not necessary, as the intention was to evaluate critical thinking skills during this lesson, rather than teaching them. With the end of the semester approaching, I was asked to keep this lesson brief, so a survey was not given. It was not deemed necessary to include a survey to examine
prior knowledge for this lesson, as the issues with the solar roadways project required a broad and fairly basic knowledge level.

These two pieces of scientific misinformation were chosen primarily due to the fact that the researcher felt that 10th grade science students would have the scientific knowledge to criticize either, and that each required about the same level of scientific scrutiny to debunk. In addition, the topic of the scientific misinformation, alternative energy, is kept consistent to control for any disposition students might have to be more or less critical of information on this topic. They were also chosen for the fact that both are not widely known to be hoaxes, which would bias student responses.

On December 9th, the researcher asked for a show of hands as a response to two questions concerning possible sources or error in the action research. These questions concerned the possibility of students realizing that the second lesson was indeed a follow-up to the first and noticing videos with titles such as “Solar Roadways: Busted!” in the Youtube side bar before we started the video. Either of these realizations on the part of the students would have certainly biased their views of the information presented to them.

Responses from each group/individual, as well as an assessment of whether each student accepted, questioned or rejected the idea of a water powered car were the data sources for this study. The evaluation of the essays serves as quantitative data to evaluate critical thinking objectively and the text of the responses themselves are quoted as qualitative data to assess the reasoning of the students. This mixed methods strategy is ideal because the two sets of data evaluate the lesson in different ways. The quantitative data shows whether there is improvement seen between the two lessons and whether this improvement can be attributed to more than
simple chance. The qualitative data, on the other hand, provides an insight into the way in which students think critically about misinformation.

The primary means of data collection are the records of the student discussions for the first lesson, the written reports for the second lesson and the questionnaires that they filled out for the first lesson. The data from this action research study will be a means of evaluating a lesson in identifying scientific misinformation as a means of improving a student’s scientific critical thinking skills.

**Data Source**

The data collection instruments are the discussion topic for the first lesson, the survey for the first lesson, and the writing prompt for the second lesson.

The discussion topic for the first lesson is “What do you think about this article?” leading questions were not used, as the intention was to see if students would raise questions about the article organically.

The survey asked students to rate their confidence on a number of subjects with one of the five answers very confident, confident, neutral/mixed, unconfident or very unconfident. These subjects would have been useful in debunking the notion of a water powered car. They were also asked three questions about their interest in science, critical thinking and their open mindedness with choices of strongly agree, agree, neutral/mixed, disagree or strongly disagree. These questions allow for the comparison of student assessment of critical thinking and scientific knowledge to their performance, as well as the ability to evaluate whether self-reported open minded students are more or less critical of scientific misinformation. The survey concludes by asking if students had heard of water powered cars before (Appendix B). This allows for
comparisons of students who had heard of water powered cars to students who had not to see if students had been prompted to be critical of the article by their previous knowledge. It also allows for comparison of how common exposure is for water powered cars versus solar roadways.

The writing prompt for the second lesson consisted of two questions. “Had you heard of solar roadways before, and if so, what were your thoughts?” and “After seeing this video, what are your thoughts?” Again, the first question allows for a way of comparing those who had heard of solar roadways before to those who had not, and for comparison of how common exposure is for the topics of each of the two lessons. The second question again takes a neutral approach to the topic in order to assess whether students would question the video on their own.

The final follow-up questions concerning possible sources of error asked for a show of hands to the questions “Did you realize that this lesson was a follow-up to my first action research lesson on the water powered car?” and “Did you notice the side bar links to videos critical of the solar roadways project in the Youtube sidebar?”

**Researcher’s Role**

The researcher gives the first lesson for the study. During data collection, the researcher’s role is minimal to prevent any influence on how critical the students are of the water powered car article. The discussion question was written in such a way as to produce as little influence on the students’ thought processes as possible. The researcher then leads a full class discussion, still remaining neutral on the subject. After data collection, the researcher assumes the role of an instructor: listing scientific issues in the article, presenting through direct instruction a procedure
for how to analyze scientific information and leading a group inquiry discussion on how and when to use this method.

In order to keep students from being biased by a realization that this was a follow-up to the water powered car lesson, Mr. Anastasia gave the second lesson. The intention was to make the lesson seem like Mr. Anastasia had simply decided to show them a video on a new innovation. To prevent this bias, the researcher was not involved until the students had finished their responses. Again, a full class discussion followed the student responses. After data collection, the researcher once again presented the scientific problems inherent in the information given and facilitated a brief discussion about how students appeared to be more critical during the full class discussion and how questioning scientific information is appropriate in all settings.

Validity, Reliability, and Credibility

The compilation of research done by Vieira, Tenreiro-Vieira and Martins (2011) states that critical thinking skills are largely context specifics. That is to say, critical thinking skills developed in the sciences cannot immediately be transferred to social studies. This supports the methods of the proposed lesson, which aims to teach critical thinking by giving students practice in thinking critically about a scientific article, rather than attempting to build some general critical thinking skill.

According to the research of Gokhale (1995), collaborative learning improves the learning of critical thinking skills. The collaborative aspect of this assignment was inspired by Gokhale’s research. Both LaPoint-Obrien (2013) and Choy and Oo (2012) assert that reflection is vital in order to improve critical thinking. By recording the thoughts of each individual in the
group, each group member must reflect on what thoughts they wish to have recorded for themselves.

Ramasamy (2011) supports the notion that critical thinking should be assessed by an evaluation of the students’ ability to point out logical fallacies and inconsistencies. Although the formal list of logical fallacies are not used, reasonable criticism of scientific writing relies on logical critique.

The compilation of this research has resulted in the design of a study that incorporates content specific critical thinking, cooperative learning and self-reflection into its lesson planning. The method of evaluation is based on the logical process students undergo when critiquing the article.

Ethical Issues

The potential ethical issues with this study were the fact that both lessons initially mislead students, the information presented to them is not scientifically valid, and that any comparative groups of students might result in some students receiving a less effective lesson. Misleading and misinforming students are unacceptable in a science classroom and, as a result, these ethical issues needed to be eliminated.

The misdirection in the study was necessary in order to assess critical thinking. If students were told outright that the information was invalid, assessments of their critical thinking afterwards would be useless and the lesson would likely be unsuccessful at teaching critical thinking. As a result of this possible ethical issue, the researcher’s beliefs on the subject are never stated. It would be unethical for the researcher to lie about the material and tell students
that it is something they believe in and endorse, so the material is presented simply as a
discussion point.

Regardless of the manner in which this misinformation is presented, it is still likely that
the fact that this material is being presented to the class will lead to the spread of misinformation.
In order to prevent this, each lesson ends in a detailed listing of the scientific misinformation in
the article, and a discussion follows to assess that students understand that the information is not
scientifically valid.

Had control groups been used, a positive control would consist of students being
encouraged to critique the article, while the negative control would consist of students not being
debriefed and given the lesson on critical thinking between the first and second lesson. The
positive control would have resulted in students being given a lesson that would likely been less
valuable long term. This is unfair to students in the positive control group. Students in the
negative control would have been given misinformation for the several weeks between the two
lessons. When finally debriefed after all data collection, it is possible that students might have
spread this misinformation, and might resist refutations of it.

These possible ethical concerns resulted in a methodology that eliminated all of them.
The results of this experiment have the potential to benefit scientific instruction in the
researcher’s classroom and perhaps beyond, but these results cannot come at the costs of the
education and wellbeing of the students involved.
Procedure and Timeline

Provided below are the dates and approximate delivery times of all lessons and data collection for the action research.

November 18th

8:00 – Read articles in groups and discuss

8:10 – Take survey

8:15 – Group discussion

8:20 – Debrief and continue discussion

8:30 – Return to regular lesson

December 4th

8:00 – Introduce and show video

8:05 – Individual response time

8:10 – Debrief and discuss

8:20 – Return to regular lesson

December 9th

8:00 – Show of hands for questions relating to sources of error

8:05 – Students ask questions about the methods and goals of the research

8:10 – Return to regular lesson
Limitations

As noted earlier, it was suspected that some students may have been aware that the second lesson was another evaluation of critical thinking, and would thus have been prompted to think more critically. Showing a video with little context is uncharacteristic in Mr. Anastasia’s classroom. In addition, the video side bar contained links to videos critical of solar roadways, such as “Solar Roadways: Busted!” In order to correct for this error, students were asked to report whether they were aware of either the videos or the possibility that they were being assessed for their critical thinking so that the results, excluding these students, could be examined to observe whether they were significantly different.

Another possible limitation is that the second lesson students were not in groups. Students might be more or less likely to show critical thinking while in groups. Although consistency across trials is ideal, this was the best way to individually assess the critical thinking skills they learned in the first lesson. In addition, keeping students separate resulted in a shorter lesson that was less intrusive into the classroom. Furthermore, students might approach videos and articles with different levels of critical thinking, and the time in the semester may have impacted how engaged and critical they were in either lesson.

Fossil Ridge has an uncharacteristically white and upper-class student base, and it is unknown whether similar studies in more diverse classrooms, or classrooms of a different culture, would find similar results. Care should be taken when applying the findings of this study to other schools.
Quantitative Results

For the initial lesson, eight of the twenty students raised critical questions about the water powered car article, and two outright rejected the notion, or 40% and 10%, respectively. This data is compared to the data from the second lesson in table 2. Seven (or about 37%) of these students had heard of the water powered car previously. Two of the students who had heard of water powered cars questioned the article, but none of them rejected it. This results in about 29% of students who had heard of the water powered car questioning it and 0% of them rejecting it. For the purpose of this study, students who rejected the article are also counted as having questioned it.

On the survey, responses were assigned numerical values with one being very unconfident or strongly disagree, two being unconfident/disagree, three being neutral/mixed, four being confident/agree and five being very confident/strongly agree. The average response was between neutral and confident for background knowledge of conservation of energy, combustion, and electrolysis with the first two being closer to confident and electrolysis leaning closer to neutral. Students reported an average understanding of hydrogen fuel cells that was between neutral and unconfident. The average survey responses for each were 3.7, 3.67, 3.15 and 2.6 respectively. On average, students rated themselves as agreeing that they apply their own knowledge and think critically about new information rather than accepting it at face value (a numerical score of 4), being just above neutral about the question of whether they seek out news on science and technology (a numerical score of 3.15) and on average reported just above agreeing with the statement that they are open minded (a numerical score of 4.15).
Table 1

<table>
<thead>
<tr>
<th></th>
<th>Very Confident /Strongly Agree</th>
<th>Confident / Agree</th>
<th>Neutral</th>
<th>Unconfident / Disagree</th>
<th>Very Unconfident / Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conservation of Mass</td>
<td>4</td>
<td>7</td>
<td>8</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Combustions</td>
<td>3</td>
<td>8</td>
<td>8</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Electrolysis</td>
<td>2</td>
<td>5</td>
<td>7</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>Hydrogen fuel cells</td>
<td>0</td>
<td>4</td>
<td>6</td>
<td>8</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 1 shows the responses to the survey given after the first lesson. Students generally gave themselves very favorable ratings, and seemed hesitant to answer very unconfident/strongly disagree. Given the fact that electrolysis and hydrogen fuel cells are topics well beyond the scope of their science classes so far, it is likely that students are over reporting their confidence.

Of the three students that reported having at least some confidence in three of the four subjects, none were critical of the article. Of the five students who strongly agreed with the statement that they think critically and apply their own knowledge when considering new information, one questioned the article, and this student also rejected it. This student represented 20% of the students who agreed with the statement on critical thinking. This student was a white female, and will be referred to as R when discussing her responses. Of the seven students who agreed to the statement that they seek out news on science and technology, R being the only student to strongly agree, one (R) rejected the article and two others questioned it. Thus, about 42% of students who described themselves as seeking out scientific news questioned the article and about 14% rejected it. Of the eight students who strongly agreed with the statement that they were open minded, one rejected the article and two others questioned it. This second student to reject the article was also a Caucasian female who I will refer to as B when discussing
her responses. About 38% of self-reported open minded students were critical of the article and about 13% rejected the article. Of the five students who were neutral to the statement that they were open minded (no student disagreed with this statement) only R rejected and was critical of the article, making 20% of these non-open minded students critical of the article and rejecting of it.

For the second lesson, twelve students were critical of the solar roadways proposal and three rejected it, resulting in 60% questioning and 15% rejecting. Although both R and B raised questions about the video, neither fully rejected it. Of the five students who strongly agreed with the statement on critical thinking on the survey given during the first lesson, all questioned the video and one (20%) rejected the claims of the video entirely. This data is compared to the data from the initial lesson in table 2. This rejecting student is a Caucasian male, and will be referred to as L. Of the seven students who agreed with the statement that they sought out news on science and technology, five questioned the video and one rejected it. This other rejecting student is a Caucasian male, and will be referred to as G. Of the eight students who considered themselves open minded, five questioned and one (L) rejected the video. This resulted in about 63% of self-reported open minded students questioning and about 13% rejecting. Of the five students who responded as neutral to the statement on open-mindedness, four questioned the video and 1 (G) rejected it. This resulted in 80% of self-reported non-open minded students questioning and 20% rejecting. The third student who rejected the video is a Caucasian male from New Zealand who will be referred to as S. He self-reported that he agrees with the statement on critical thinking, he is neutral on the statement on science and technology news, and he agrees on the statement that he is open minded. None of the three boys who rejected the solar roadways video rejected or even questioned the water powered car article. S had heard of and
was critical of solar roadways before seeing the video, but the other two had not previously heard of solar roadways.

Table 2 shows the number of students who accepted, questioned or rejected the two sources of scientific misinformation. The first lesson discussed the water powered car and the second discussed the solar roadways project. These results showed a 50% increase in both questioning and rejection of the misinformation.

When asked about the possible sources of error, two of the students reported that they had figured out that this lesson was a follow-up the water powered car lesson, one of whom also noticed the videos in the side bar that were critical of the solar roadways proposal. A third student also noticed these videos. Of these three students, two questioned the video and one did not. None of them rejected it. The removal of the students who were biased would cause little change, with about 59% questioning the video and about 18% rejecting it. The most dramatic effect from this change would be to raise the percentage of students who reject the video by lowering the total (none of the biased students rejected the video) in a way that would be misleading and make the results between the two lessons less comparable. For this reason, this change was not made.
Between the two studies, both questioning the misinformation and rejecting it saw a 50% increase, with questioning going from eight to twelve students and rejecting going from two to three students. However, a Z test of the data revealed a roughly 10.3% probability that the increase in questioning is due to chance and a roughly 31.6% chance that the increase in rejection is due to chance. It is also worth noting that the Z test is considered unreliable with less than five positive responses, which is the case for the data on the rates of rejection. At the standard alpha value of 5%, this study cannot conclude that the lesson had a statistically significant impact on either questioning or rejecting scientific misinformation.

Qualitative Results

During the first lesson, R rejected the article, pointing to the unscientific nature of article, and stating “I’d like to know where the article came from.” She also notes that the technology involved is not new, and questions why we would not be using water as a fuel source if what the article describes is possible. B, who was in a different group from R, stated “I don’t think it’s more powerful than gas.” in reference to the claim that it produces two and a half times the energy output of gasoline. During the full class discussion, both girls raised these concerns. Of the students who questioned this article, the most common concerns were the claim that water had two and a half times the energy output of gasoline and that the article is six years old and we still don’t see water fueled cars on the road.

During the second lesson, G rejected the video stating “I think it sounds like the perfect solution, but that’s its problem, there must be some reason that these are not being fully researched.” L rejected the idea due to the massive costs that would be involved in even partial implementation of this technology. S rejected the video stating “I doubt it can fit every scenario
in our world. Rain?” S was the only student who brought up the issue of rain, which could potentially damage the solar panels and make the road surface difficult to stop on. It is unclear whether S is referring to one of these ideas, both, or some unrelated issue that he sees with the technology. The most common questions raised by students were the cause, implementation and the notion that this technology is somehow too good to be true.

Findings

The qualitative data of this study provided a valuable insight into the way students criticize scientific writing, the criticisms that are most apparent to them, and their willingness to reject a scientific proposal. The most common criticisms for both lessons were more based in practicality than science. For example, questioning why the water powered car had not yet been implemented or discussing the immense cost and difficulty of implementation of the solar roadways project.

The quantitative data was ultimately inconclusive based on the Z test, but it provided some valid insights. The increase in questioning in the second lesson is suggestive of a possible trend and repeating similar experiments with larger sample sizes or across more lessons might show a clear and statistically significant trend.
Conclusions

Due to the small sampling size, no conclusions can be drawn about the effectiveness of the first lesson, or trends between the different categories of students (critical thinker, open minded, non-open minded and seeking of scientific news). However, the comparisons of the categories of students all seemed to show trends that were not consistent between lessons, and often close to the average values for all students. This could suggest that there is no correlation between how students report their abilities and how they perform. In addition, the non-statistically significant upward trend in questioning and rejecting the misinformation may warrant further study.

Section V

Conclusions and Recommendations

Dissemination Plan

Before dissemination of this action research on a large scale, further study with a larger sample size is needed. It might, however, be valuable to collaborate with a science department to have further research done on the subject.

When more information has been gathered, however, this research would be appropriate for academic publication. The long term intent would be to disseminate this information to as many science teachers as possible (and any other teachers and laypersons that may find it useful or interesting). The first step would be submitting the research to an academic journal, and then
attempting to promote the research to a wider audience through opinions pieces on blogs, magazines and/or newspapers, both on the local, national and international level.

In addition to publication, this research will be disseminated on a more direct level by collaboration between colleagues and administrators. Should I wish to implement critical thinking lessons in the future, it is important to collaborate with my colleagues so that they can produce similar lessons if they so desire, and to collaborate with my administrators and heads of department to ensure that these lessons align with the agenda of the school and the department.

Dissemination of this information, after further research has been conducted, is important due to the lack of research into how to teach critical thinking. There exists a great deal of information on the value of critical thinking (Vieira et al., 2011), and misconceptions about critical thinking (Bailin et al., 2010), however, studies concerning critical thinking were often highly contextualized, and did not deal specifically with scientific misinformation.

**Action Plan**

In order to verify the trends witnessed in this study, it is necessary to reproduce the research on a larger scale. It would be beneficial to have a similar experiment run in all science classes consisting of more than two lessons. Data could then be compared across class and grade level, and progress could be tracked from lesson to lesson. This would provide significant data into the efficacy of this kind of critical thinking lesson in a science classroom.

After a discussion with cooperating teachers, it was decided that due to the inconclusive nature of the data, the need for a broader, long term study and the tight schedule of both general chemistry and Earth System Science, regular critical thinking lessons would not be implemented. In future classrooms, however, an ongoing series of lessons that present students with either true
scientific information or scientific misinformation will be used in a long term study to test the effects of such lessons on critical thinking. This recurring approach, in which students are sometimes exposed to true information and sometimes false information, will better reflect the way that this method would be used in the classroom.
Running Head: STUDENT CRITICAL THINKING ON SCIENTIFIC MISINFORMATION

References


JAPANESE COMPANY UNVEILS WATER POWERED CAR

A Japanese company called Genepax unveiled their water powered car in 2008 in Osaka, Japan. It doesn’t matter if it’s tap, bottled, or lake water, any type of water can make this car run. An energy generator splits the water molecules to produce hydrogen and this is used to power the car. They use a membrane electrode assembly (MEA) to split the Hydrogen from the Oxygen through a chemical reaction. The cell needs only water and air, eliminating the need for a hydrogen reformer and high pressure hydrogen tank.

The reality of this device has been verified by patent offices all over the world. To search a Japanese patent, you have to go through the Industrial Property Digital Library (IPDL). This organization makes patents available to the intellectual property department of the Japan Patent Office. The IDPL provides over 60 million documents and their relevant information as published since the end of the 19th century. The fact that these are even published for patent pending says a lot.

USING WATER AS FUEL

Water makes the perfect fuel source. It’s comprised of two hydrogen atoms and one atom of oxygen. When the water molecule is separated into its two component atoms and oxidized as fuel, the result is equivalent to an energy output that is two and one half times more powerful than gasoline. The byproduct of the combustion is water vapour, totally pollution free, returning water back into the atmosphere. The process used is known as electrolysis, which is a method of separating elements by pushing an electric current through a compound. Various techniques for water splitting have been issued in water splitting patents all over the world. You can click here to look at a few from the United States.

Not too long ago, researchers at Virginia Tech extracted hydrogen energy from water. They discovered that the energy stored in xylene splits water molecules as well, yielding high purity hydrogen. You can read more about that here. There are multiple examples of creating hydrogen by splitting the water molecule (2).

Source


Note: This is a clipping from a longer article, abridged for the purpose of this lesson.
Survey

Name: __________________________

Your name will be used only to connect you with the comments from your group discussion, and will not end up in my final report for my research. This information will not be shown to Mr. Anastasia or anyone else.

Survey

For each topic, mark the box for how confident you feel with your knowledge on this topic.

<table>
<thead>
<tr>
<th></th>
<th>Very Confident</th>
<th>Confident</th>
<th>Neutral/Mixed</th>
<th>Unconfident</th>
<th>Very Unconfident</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conservation of Energy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Combustion</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electrolysis</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrogen fuel Cells</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

For each statement, mark how strongly you feel this statement describes you.

<table>
<thead>
<tr>
<th></th>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Neutral/Mixed</th>
<th>Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>I apply my own knowledge to information presented to me and think critically about it, rather than accepting it at face value.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I seek out news on science and technology.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I am open minded.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Had you heard of a water fueled car before reading this article?
Appendix C

Closure Activity: Water Powered Car Debriefing and Lesson in Critical Thinking

Problems with this article

- Combusting hydrogen gas is the reaction $2\text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2\text{O}$, which does release energy. Electrolysis, converting water to hydrogen and oxygen gas, $2\text{H}_2\text{O} \rightarrow 2\text{H}_2 + \text{O}_2$, is the reverse reaction, and therefore requires an input of energy. Water is not the fuel source in this case, the energy used to perform the electrolysis is.
- Hydrogen fuel cells may be a useful means of storing energy, but it is pointless to perform the electrolysis in the car itself, because you will still need the energy source to perform the electrolysis.

Strategies for thinking critically about an article

- What do you know about the topic already?
- Does this new information align with what you already know about the topic?
- Has the author made a case based on evidence and sound reasoning, or does it simply appeal to an authority figure?
- If you are not convinced by the case being made, research the claims. Does your research add credibility to the claims, or cast doubt on them?
- Don’t give someone making a significant claim the “benefit of the doubt”. If their reasoning is valid they will have the tools to defend it. Someone making a claim has the burden of proving it, the responsibility does not lie on others to disprove it.
Appendix D

Closure: Solar Roadways Debriefing

- Prohibitively expensive. If powering the entire country with solar panels was cost effective, we would likely already be doing it. Glass is also much more expensive than asphalt. Covering all US roads in tempered class would cost nearly 10 times the US federal budget.

- Does not take into account wear and tear of large vehicles stopping or long term durability.

- Heat to melt snow higher than heat to keep panel “just above freezing point”. The energy required to melt ice is about equal to the amount of energy to heat the same amount of water from 0°C to 70°C.

- Glass grinds down over time, becoming weaker, more opaque, and more slick.

- Very difficult to get clear glass from recycled glass.

- Storing and distributing power is difficult.

- LEDs would not be visible during the day.

- Roads need a way to let water run off of them and be porous enough to let water drain through them. Water would get between panels, potentially damaging circuitry or freezing.

- Tiles tend to crack, buckle and work their way loose (like sidewalk tiles).

- Light pollution would cause problems for star gazers and astronomers.

- Easier to just install solar canopies.

- The inventers have proposed that parking lots should be the first places to implement solar roads. Parking lots are typically most full during the brightest parts of the day, thus making many of the solar panels useless.