

THE EFFECTS OF INTERGRATING ENGINEERING STRATEGIES IN THE
SCIENCE CLASSROOM ON CRITICAL THINKING SKILLS OF MY STUDENTS

by

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ABSTRACT

In this investigation I wanted to find out if implementing engineering strategies in my classes I teach would improve critical thinking skills among my students. The grades of my students ranged from the 7th grade to the 12th grade. The results of this investigation were that there was an improvement in critical thinking skills and an improvement in student involvement with their learning process.

INTRODUCTION AND BACKGROUND

Project Background

Teaching and Classroom Environment

For the past three years I have been teaching 7th grade through 12th grade science at Culdesac Joint School District # 342 (CJSD) in Culdesac, Idaho. Culdesac is a K-12 public school in a small farming community. Currently the school has a student population of 89 students. The school's ethnicity is 95% white, 4% Native American and less than 1% of other decent. English is the main and only language spoken in the homes of the students. The majority of the students that attend CJSD come from low income families. Seventy-one percent of the students that attend this school are on the free and reduced lunch program. The town is located about 20 miles out of Lewiston, Idaho and is located on the Nez Perce Indian Reservation. The town has a population of around 250 and the surrounding area has a population of 780. Most of the students that attend the school do not live in town but out of city limits.

The classes involved in this action research project were my engineering strategies class, 9th grade physical science class, 10th grade biology class and a combined 7th/8th grade life science/earth science class. There were a total of 25 students who participated in the activities but data was only collected from 19 of the students. These classes are usually taught with a direct instruction method, which is followed by guided practice and then independent practice. Further, the curriculum follows the Idaho State Science Standards.

This school is my first teaching assignment, and the five years before I took the teaching job the school had four different science teachers. My first observation was that the students lacked critical thinking skills. It seemed as if the students were accustomed to having the answers just given to them, so they struggled with having to think about a complex problem or statement. It was a challenge to get them to think about any issue or problem presented to them. These students indicated that asking “why” about a topic is not natural but instead is a skill that needs to be taught. The majority of the students would rather give up than try to find the answer to a problem by trial and error. They did not understand the scientific method and had difficulties with the metric system. Overall I noticed a gap in critical thinking skills and application of what is learned in the classroom to actual practice.

The situation I have faced at CJSD is a call to action for me, as I have a passion for the world around me and I went into science education to share that passion. I want to do whatever I can to see my students build a similar passion for the world and learning as I have. I am still learning how students learn in the classroom, but I believe that science education needs to move away from memorizing and recall of facts to a learning model that focuses on the process of how people solve problems around the world. Moving to this kind of a teaching model requires that more inquiry based learning be implemented into the classroom. I am always hearing from my students that they want more hands on activities, yet I find myself telling them that they still need the background information to understand the activities. This dialogue has led me to explore teaching methods that would put them in charge of finding the background information and putting the information to use to solve real world problems.

I truly do believe that students at CJSD are lacking critical thinking skills and need to learn these skills if they want to be successful. My observations about how my students have completed assignments, performed on tests, and completed labs in the last two years have lead me to my focus question, which is as follows: Will integrating engineering strategies into my science classrooms improve critical thinking skills among my students? The following sub-questions will also be investigated to support my main focus question. Will attitudes about science change after integrating engineering strategies in the classroom? Will my students have a better understanding about engineering after thinking like one? After all, I want them to be able to take what they have learned and apply it to real world situations. Therefore, I believe that integrating engineering strategies in the classroom will help my students gain critical thinking skills that will, in turn, increase their passion for science and an understanding of the world around them.

CONCEPTUAL FRAMEWORK

A review of the literature on the topic of engineering education and critical thinking skills can be addressed by discussing why there is a need for critical thinking skills, what critical thinking is, how critical thinking skills can be measured and why engineering activities improve critical thinking. The majority of the research deals with defining and assessing critical thinking skills. However, there is very little, if any, research on how engineering strategies in the classroom have actually improved critical thinking skills.

Developing critical thinking skills during a student's K-12 experience is important for the 21st Century. According to the Partnership for 21st century skills, students must

learn skills such as critical thinking, problem solving, communication and collaboration to succeed in today's world (American Management Association, 2010). The AMA (2010) also believes that a focus should be put on students to be creative critical thinkers that can collaborate and communicate with others to prepare themselves for the future. Students need to be taught how to think critically about the world around them. They need to be able to analyze a problem, use higher order thinking skills, and find a solution to real world problems. To do this they need to be scientifically literate. Scientific literacy means that a person can find the answers to questions that may be asked by all of us on a daily basis, identify scientific issues, engage in conversations about the validity of conclusions, be able to evaluate the quality of scientific information read in articles, evaluate arguments based on scientific arguments, and come to conclusions that are supported with evidence.

Being scientifically literate has a connection with being a critical thinker. Ninety-four percent of U.S. adults are scientifically illiterate (Shuman, et al., 2002). The U.S. National Academics issued a study in 2005 that warned America would have to improve its ability to invent new cutting edge research and new products and services to be competitive with other countries (Augustine, 2009). Studies have shown that between 50% and 85% of the growth in Gross Domestic Product during the past half century are because of the scientific and engineering achievements (Augustine, 2009, p. 26). This indicates that we need to put more of a focus in our education system in science and math. Our future lies in the skills of our students now in the K-12 system. We need more students to think critically and understand the processes of science and engineering in order to remain competitive in the 21st century.

According to a report written by the director of Career and Technical Engineering and Technology, students need to gain critical thinking skills to compete with other countries in the future (Hanson, Burton, & Guam, 2006). Integration and collaboration with core subjects strengthens technology and engineering education and the core subjects (Hanson, Burton, & Guam, 2006). Therefore, teachers need to work together to implement engineering topics in all subjects to help the students understand how all subjects are related to each other. Additionally, students need to be able to create and produce original work and ideas (Barry, 2008). Further, students need to be given real world experience that builds upon the skills they learn in school. Therefore, integrating engineering strategies into the classroom can give our students the skills they need for the future.

Finding a definition of critical thinking (CT) that spans the disciplines is a daunting task. According to Huitt (Huitt, 1993) the definition of CT has changed over the years because of different specialty fields coming to the forefront with their own definitions of critical thinking (Huitt, 1993). The following is a list of CT definitions that was presented by Huitt at the 1993 Critical Thinking Conference sponsored by Gordon College:

- "...the ability to analyze facts, generate and organize ideas, defend opinions, make comparisons, draw inferences, evaluate arguments and solve problems (Huitt (1993) as cited by Chance, 1986, p. 6)
- ...a way of reasoning that demands adequate support for one's beliefs and an unwillingness to be persuaded unless support is forthcoming (Huitt (1993) as cited by Tama, 1989, p. 64)
- ...involving analytical thinking for the purpose of evaluating what is read (Huitt (1993) as cited by Hickey, 1990, p. 175)

- ...a conscious and deliberate process which is used to interpret or evaluate information and experiences with a set of reflective attitudes and abilities that guide thoughtful beliefs and actions (Huitt (1993) as cited by Mertes,1991, p.24)
- ...active, systematic process of understanding and evaluating arguments. An argument provides an assertion about the properties of some object or the relationship between two or more objects and evidence to support or refute the assertion. Critical thinkers acknowledge that there is no single correct way to understand and evaluate arguments and that all attempts are not necessarily successful (Huitt (1993) as cited by Mayer & Goodchild, 1990, p. 4)
- ...the intellectually disciplined process of actively and skillfully conceptualizing, applying, analyzing, synthesizing, and/or evaluating information gathered from, or generated by, observation, experience, reflection, reasoning, or communication, as a guide to belief and action (Huitt (1993) as cited by Scriven & Paul, 1992)
- reasonable reflective thinking focused on deciding what to believe or do (Huitt (1993) as cited by Ennis, 1992)
- ...skillful, responsible thinking that facilitates good judgment because it (1) relies upon criteria, (2) is self-correcting, and (3) is sensitive to context (Huitt (1993) as cited by Lipman, 1995, p. 146)

Critical thinking, as all of these definitions point to, is the ability to think clearly and rationally. It also includes the ability to look back on one's behavior and thoughts and think for one's self.

Unfortunately, critical thinking can be difficult to evaluate. Bissell and Lemons (2006) identified two problems with trying to evaluate the levels of critical thinking. First there is the problem of defining CT complicated by the time spent in defining what counts as evidence of CT, which can't always be measured. (Bissell & Lemons, 2006). They decided to use Bloom's taxonomy of education objectives. They chose to use this model because it is well known and accepted. The second problem was trying to find a reliable method for assessing a student's level of critical thinking skills. There are two basic concerns in all assessment tests, test validity and reliability. The validity of a test for critical thinking has a major situational problem when questions deal with views of a situation (Norris, 1985). Each different culture can bring different views of a situation from those of other cultures, which creates a unique challenge when comparing scores with those from other cultures.

According to Norris (1985) assessment of critical thinking must take into account the context in which the thinking is being done. Tests are often used to evaluate an individual's CT skills. Norris (1985) also explains that when interpreting critical thinking tests you need to understand the background assumptions of the individual that is taking the test because knowing that information will help to determine the context in which the individual came to an answer.

The types of critical thinking assessments range from a test format to essay format. There is not one assessment that can be used to evaluate all of the different types of critical thinking skills that a person can possess. The following is a list of different types of critical thinking assessments that are currently used.

- Cornell Critical Thinking Test (CCTT): This assessment can be used with individuals from fourth grade to adults. This assessment assesses an individual's or group's critical thinking and reasoning skills. It evaluates and compares critical thinking skills development. It is a 71 multiple choice test. (Metiri Group, n.d.)
- James Madison Test of Critical Thinking (JMTCT): This assessment can be used with individuals that have a reading level above the 7th grade. This assessment assesses an individual's or group's critical thinking and reasoning skills. It evaluates and compares critical thinking skill development. This assessment is a 55 question objective test that assesses 47 different critical thinking skills. (Metiri Group, n.d.)
- The California Critical Thinking Dispositions Inventory (CCTDI): This assessment is designed for college students, high school students, and adults. This assessment is a 75 "agree or disagree" item test. This assessment measures the overall disposition toward critical thinking. (Metiri Group, n.d.)
- The Ennis-Weir Critical Thinking Essay Test: This assessment is designed for individuals in the sixth grade to adults. This is an essay test and it evaluates how an individual evaluates the argument of a paragraph and a letter as a whole. (Metiri Group, n.d.)
- Tasks in Critical Thinking: This assessment addresses three areas of critical thinking which are analysis, inquiry, and communication. This assessment uses 9 performance tasks that include several constructed response formats. Participants are not rated on their quality of writing, but on the conclusions drawn, reasoning or support given, explanation of thinking, and self-reflective behavior. (Metiri Group, n.d.)

Norris (1985) explains that critical thinking tests provide only the conclusions to thinking processes, not the processes themselves. There are many methods for assessing an individual's critical thinking skills. Therefore, based on my research into what critical thinking is, in order to accurately measure a student's true critical thinking skills teachers must use a combination of assessment methods.

To understand how engineering strategies improve CT skills one needs to understand what engineering strategies are. Engineers take what science discovers and implement it with the goal of improving the lives of people all around the world. An engineer uses a method called the Engineering Design Loop (EDL) to help guide them to find a solution to the problem they are working on. The EDL is a series of eight steps that instead of ending when you reach the last step, returns to the beginning of the process in order to modify the approach to the problem and/or solution. The College of Engineering in Boulder, Colorado uses the following Engineering Design Loop that I used in my classes. The steps are as follows:

- Identify the need and define the problem
- Research the problem
- Develop possible solutions
- Evaluate the alternatives and select the most promising solution
- Construct a prototype
- Test and evaluate the prototype
- Communicate the design
- Redesign

Using an engineering strategy like the EDL forces students to think about what they are going to do and why they are going to do it. They have to research the problem and then come up with a plan or plans that are supported by the evidence that they have researched. They use the best plan to make a prototype, and, if the prototype fails, they have to figure out how it failed and try another plan to solve their plan. They have to communicate what they did and explain how they could improve their solution. Students are responsible for communicating their results by making a presentation to the class and turning in a report to the teacher that documents their learning process. Therefore, students must use CT skills when engineering strategies are incorporated into the classroom by using the EDL.

The EDL is an engineering strategy that is a form of active learning. Michael Prince (Prince, 2004) from the Department of Chemical Engineering from Bucknell University states that active learning is any instructional method that engages students in the learning process. The evidence that supports active learning in the classroom is positive. Bonwell and Eison (Bonwell, 1991) concluded that active learning leads to better student attitudes and improvements in student's thought processes and in their written work. Students retain more of the information when active learning is used in the classroom (Prince, 2004).

The Engineering Design Loop requires students to think about their learning process and makes them think about what they are doing. Prince (2004) includes three types of learning that can be considered active learning. They are collaborative learning, cooperative learning and problem-based learning (PBL). All three of these learning methods are incorporated into the engineering strategies that are used in the classroom.

Collaborative and cooperative learning include any activity where a group of students work together for a common goal and where each individual is being assessed separately and as a group. Johnson, Johnson and Smith collected 90 years of evidence that showed that collaborative learning improves academic achievement, student attitudes, and student retention (Prince, 2004). Students using the EDL work in groups to solve a common goal but are each responsible and graded on what they have completed and on what they have done with the group. Problem based learning is a teaching method that involves the instructor giving the students a problem to solve. It usually involves students working together as opposed to individually to solve a problem. This method of teaching puts the task of learning on the group of students and or individual students. It incorporates both collaborative and cooperative learning. There is evidence that PBL improves the long term retention of knowledge compared to traditional instruction (Prince, 2004).

In conclusion, engineering strategies can improve CT skills much like a domino effect. The EDL gives the student a problem that they need to solve. They research the problem and then take what they have learned and apply it to the problem. Students then collaboratively and cooperatively solve a problem and then communicate what they have learned in writing. To be successful, a student must either develop critical thinking skills to accomplish their task, or they have to learn the skills by trial and error while working with others to solve a problem.

METHODOLOGY

The lack of critical thinking among my students led me to ask what strategy would increase my students' critical thinking skills and help them make connections between what the textbook says and how it relates to the world beyond the classroom. This initial inquiry led to my primary focus question: Will engineering strategies in the science classroom improve the level of critical thinking among my students? I also wanted to know if student attitudes about science would improve when using the engineering strategies in the classroom. In addition, I wanted to know if improvements in the attitudes about science education would result in a better understanding of what engineering is and how it applies to their life.

This study took place in my classroom at Culdesac High School. Since I teach a total of 25 students in grades 7th to 12th grade and my class sizes are small, about half of the students take more than one science class. Therefore, I chose to implement engineering strategies into four of my six classes. Classes met five days per week and the class periods were 55 minutes long. Four of my students read below a 7th grade ability level and, therefore, were not included in the report but were still involved in the activities. The academic abilities of the remainder of the students ranged from below average to above average as determined by their academic profiles provided by the school counselor. Two students chose not to take the assessments but to participate in the activities. That left me with 19 students who were the target population for my research. Table 1 shows the demographics by subject. I chose to include all students in the activities because I felt they could all benefit from the experience of engineering, in addition to obtaining a broader range of results.

Table 1
Demographics by Subject

Class Subject	Number of Students	Grade	Male	Female	Caucasian	Other Ethnicity
Life Science	12	7 th & 8 th	4	8	11	1
Physical Science	5	9 th	3	2	5	0
Engineering Strategies	6	10 th to 12 th	2	4	5	1
Biology	3	10 th	0	3	3	0

Treatment

Engineering Strategies were implemented into the classroom as hands on activities that were guided by the EDL. I used activities and lesson plans from the Teach Engineering resources for K-12 teacher's web site, which is located at the following URL: <http://www.teachengineering.com/index.php>. A list of activities from this web site can be found in Appendix A. The activities ranged from independent work to group work and were chosen from a list of engineering activities for middle school and high school students. The combination of group individual projects provided a broad base of engineering experience for all the students involved in the research. Table 2 provides a summary of the research plan and will be explained in more detail in the next section of this paper.

Table 2
Research Plan

Pre-Treatment Phase	Student Attitudes about science Survey James Madison Test for Critical Thinking test A What is Engineering Pre Survey
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Treatment Phase – Part I	Students exposed to the engineering design loop Students participate in assigned group or assigned individual engineering project one Students Present their project to classmates Students evaluate their learning process using the engineering design loop
Treatment Phase – Part II	Students Participate in group or individual engineering project two Students Present their project to classmates Students evaluate their learning process using the engineering design loop
Treatment Phase – Part III	Students choose one of the projects they have worked on in group or individual engineering project 3 Students present their project to school and the community. Students evaluate their learning process using the engineering design loop
Post- Treatment phase	Student attitude survey about science James Madison Test for Critical thinking Test B What is engineering post survey

I also used several different types of assessment tools for this project. In the pre-treatment phase, I used the James Madison Test for Critical Thinking to test my student's critical thinking skills. I gave them test A in the fall and test B during the first week of May of 2011. The students were given a science attitude survey, which can be found in Appendix B, to determine how they felt about science in January and again in May of 2011. This showed how my students' attitudes about science changed due to engineering strategies used. To measure if my students gained a better understanding of what engineering is, they also took a pre and post-test on what engineering is that can be found in Appendix C along with a rubric in Appendix D.

In the first part of the treatment, students were introduced to the Engineering Design Loop. This was done with six lessons that explained the EDL and its proper use. With each lesson the students were actively involved in class discussion and brief

individual activities that gave them practice with the concept of the EDL. I gave the students the opportunity to choose to do an independent engineering project or work with a group but they had to do the opposite for the second phase of the treatment. For the first engineering activity I assigned them a problem that they had to solve or formulate a conclusion. Every group or person had a different problem with which to work on. They were responsible for presenting their work to the class on a specific date.

During the second treatment phase students were asked to do another engineering activity. This time they were able to pick the problem that they wanted to work on, but the topic was approved by me first. They either did this as an individual or in a group but it had to be the opposite of what they chose for the first phase. They were also responsible for presenting their work to the class on a specified date. During the third treatment phase the students were asked to pick one of the two engineering projects that they worked on and improve upon it. They were responsible for communicating their results to the school and to the community at the end of the year science activity night at school.

After the completion of the project's three phases I had my students take the post engineering test, the James Madison Test for Critical Thinking test B and a Student Attitude survey on science.

Table 3 provides a brief summary of data sources that I will be using to answer my primary and secondary questions.

Table 3
Triangulation Matrix

Focus Questions	Data Source 1	Data Source 2	Data Source 3
<i>Primary Question:</i>			
1. Will engineering strategies in the classroom increase critical thinking	Pre- and Post-critical thinking test	Teacher Observations	Student Interviews

skills among my students?

Secondary Questions

- | | | | |
|--|--------------------------------------|--------------------------------------|-------------------------------|
| 2. Will student attitudes about science improve because of using engineering strategies? | Pre- and Post Surveys | Student Interviews | Teacher Observational Journal |
| 3. Will my students have a better understanding about what engineering is after implementing engineering strategies into the classroom | Pre- and Post-Engineering assessment | Student Journals, Student interviews | Teacher Observational Journal |
-

The comprehensive test of critical thinking is a 55 item objective test. It comes in two forms: form A and form B. The two forms cover the same general skills and many of the same specific skills. The test can be used on students that have a seventh grade reading level or above. It was developed in 1996 by Bill O' Meara and Dan Flage. The types of skills that it covers can be found in Appendix E. I used form A as the pre- test and form B as the post-test.

Through the Student Science Attitude Survey found in Appendix B, I wanted to find out if there was an increase in positive attitudes about science after the students were introduced to engineering strategies. I believed that there would be a positive increase in how my students feel about science in general because of the manner in which engineering is presented to students in the high school classroom. Since I used problem based learning as a strategy for teaching engineering, my students were given a problem to solve and they had to use what they knew or learned about science to solve the problem. I gave the same survey as the pre and post assessment on attitudes about science. The students took the survey online in January and again in May as a survey monkey quiz.

Using self-reflection in a science classroom as an instructional tool can be beneficial to the development of basic and advanced process skills in students. (Taylor & Rogers, 2009) I had my students write in composition books about their thoughts and feelings about the activities in class. They were responsible for writing about the following:

- What they liked and disliked?
- What they learned during the activity?
- What they would do different if they had the opportunity to redo the activity?
- How what they did relates to science?

Student interviews were done the first week of the second semester and during the first week of May. I randomly selected five students from the class list and asked them about their experience with the activities and how they perceive their actions in class on their participation in the activities.

Another part of my study dealt with my observations of students. Ediger (2007) notes that teacher observations in the science classroom are a very important part of assessment (Ediger, 2007). Teacher observations of student's performance on a task can be a very beneficial assessment in the classroom. There are many objectives in science that need to be shown but not written and some students can show you what they know even though they are unable to put it into written words. I kept a journal to write my observations regarding what and how my students were learning. I especially focused on the trials and errors they went through to find a solution to problems they faced. I believed that by doing this over the second semester I would be able to monitor student growth in how they solve problems in the classroom. My reflections reminded me of what my

students were working on and how they reacted to events in the classroom that related to their thinking process.

Included in Appendix C are pre and post- assessment questions related to engineering that my students should have been able to learn and understand after the implementation of engineering strategies into the classroom. Also, a rubric for scoring the level of understanding for the test can be found in Appendix D. The pre and post-assessments are identical. The students took the assessment online using survey monkey generated.

DATA AND ANALYSIS

The data that was collected began with the pre and post assessment of critical thinking skills to determine the intervention's impact on critical thinking skills. Student attitude surveys were used to evaluate whether attitudes among my students increased because of their experience with engineering activities in the classroom. Lastly, pre-and post-engineering questionnaire were used to determine if my students had a better understanding of what engineering is and were able to define key vocabulary that is used in engineering.

Engineering Activity Impact on Critical Thinking Skills

Data collected using the James Madison Test for Critical Thinking Skills showed an overall increase in critical thinking skills. The James Madison Test for Critical Thinking scores test takers from 0% to 100% on 46 different critical thinking skills. The critical thinking skills that were tested on the test can be found in Appendix E. The pre-

and post- test was given to (19) of my students. The average score on test A (pre-test) was 29.69 (SD = 8.265) and the average score on test B (post-test) was 37.07 (SD= 8.05).

There was a significant effect for improvement in critical thinking tests, $t(19) = 4.456 \times 10^{-5}$, $p < .001$, with 12 students receiving a higher score on test B then on test A. Figure 1 compares score comparisons from test A and Test B.

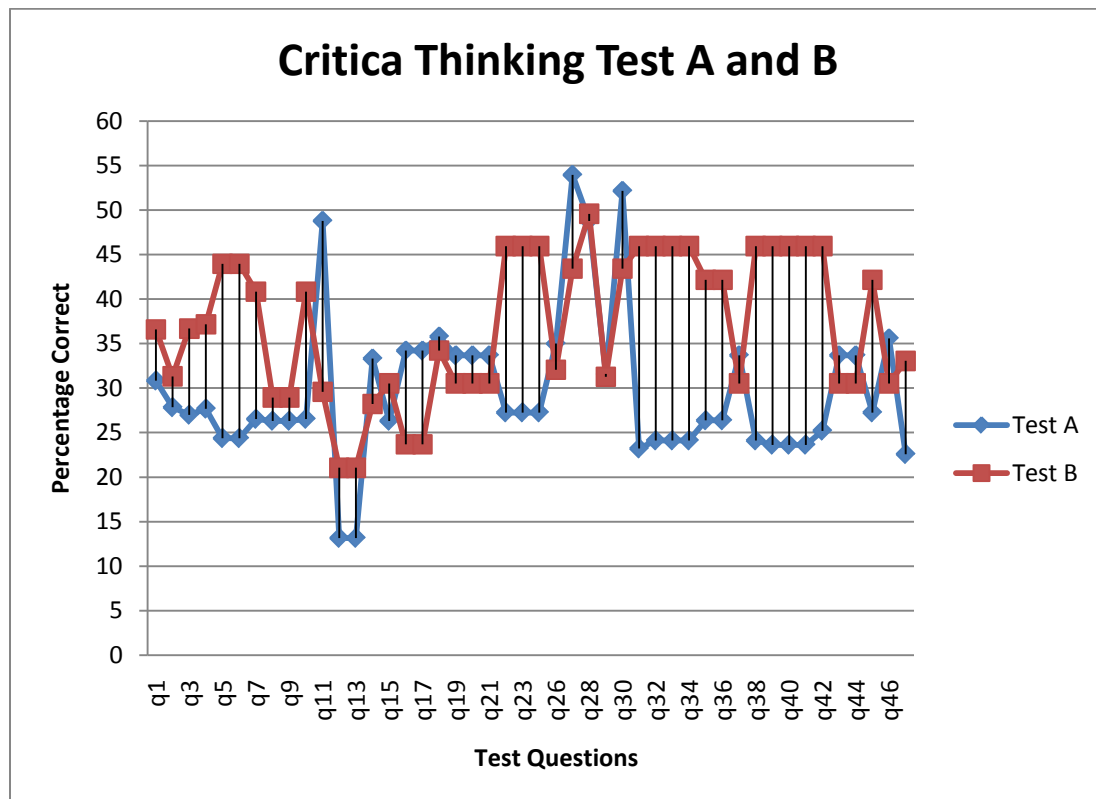


Figure 1. Line graph comparing scores from Critical Thinking test A and B (N = 19)

One student in particular struggled through the first few weeks of the treatment. He wanted me to give him specific answers to what he was looking for. At one point during the first week, he just broke down into tears. I had to sit him down and talk him through the process one on one. By the end of the treatment, he knew what he needed to do to complete his project for the science show. Here is his journal entry as his reflection “I did

not like the lack of help I got from my teacher on this project. I am not that good at science. I had to find my own help. Because of this project, I can understand how stuff works and how things around me have changed my life.” He struggled but came around to understand how what he was doing helps him to understand how science and technology have changed his life. He is now able to find evidence to support his claims. This is a critical thinking skill that he did not have before he was given the treatment.

Overall, 30 critical thinking skills on this test showed an average increase in scores among my students. Appendix D reflects the list of skills that were evaluated by question number. Eleven areas of critical thinking skills showed an increase of more than 18 points. The critical thinking skills that showed the highest improvement are:

- Distinguish arguments and explanations
- Evaluate analogical arguments and inductive generalization arguments in terms of the greater the number of similarities between the conclusion and the premises regarding the sample, the stronger the argument, except for the property in question, the greater the diversity within the sample, the stronger the argument (no biased generalization)
- Identify and avoid errors in reasoning, informal fallacies: begging the question, equivocation, post hoc, ergo propter hoc and false dilemma/ false dichotomy fallacy

The skills that were more apparent in class discussion were how the students distinguished arguments. Before implementing the engineering strategies into the classroom my students did not question what they found online for information. It was during the last treatment

phase that they started to ask if they should use sources like Wikipedia and Ask.com. They wanted to know where these sources found their information.

Engineering Activity Impact on Student Attitude Towards Science

The student attitude survey about science that is located in Appendix B was taken by the students in the fall and in the spring. Twenty four students out of twenty five students that participated in the engineering activities in my class took both the pre and post student attitude survey. The data shows that my student's attitudes about science did not change after the treatment was given to the students. However I have been teaching these same students for almost three years and you will often find most of the students taking at least two science classes from me every semester. For example: out of five points for the question "I enjoy science" the fall score was 4.04 and the spring was 3.96. There is not enough of a difference to say that they enjoy science any more than they did before.

Student interviews from before the treatment and after the treatment did change, and they all agreed that they enjoyed the hands on activities. They did not like having to conduct research to find answers to their questions, however, even though they needed to know this information to move forward with their projects. An example from a student reflection that indicates improved attitude is a high achieving student's comment. "I liked being able to work more at my own pace and to get to pick out what I wanted to work at. I liked being in charge of how much effort I put into my project because I was the only person doing this project." Student interviews gave me the opportunity to assess what my student's depth of understanding was in the engineering strategies.

I was able to observe my students' growth in the learning process. My observation during the EDL lesson was that students' understanding of the engineering concepts increased, and they truly enjoyed the lessons. I began to see complications, however, with the application of the lessons into actual practice in solving the problems. The students still embraced the mindset that the teacher should give them the answers. The students required an extra week during the first engineering activity to ensure that they were able to grasp the idea of the engineering design loop. However, during the last treatment phase, the students were able to come to class and begin working with no questions asked. At that point, if a student had a question, it was regarding a source or some aspect of their project. They were finally enjoying learning about their topics, and they wanted to know when they would begin researching another topic.

Student interviews (five pre- and five post-) and student journals showed a significant improvement in attitudes about science. All five of the students interviewed had an understanding of why engineering is important and all five enjoyed the research work that they had completed. The students that I interviewed felt that they enjoyed the activities more because they had to find the answer to their questions instead of me giving them the answer. They liked how they had to go to other teachers for help with their work. Student journals ranged in effort and depth depending on the student and the project that was being investigated. Students that became very involved in their research and projects wrote everything down in them. Others could care less and did not write anything. In the end, five students really took advantage of writing everything down in their science journals.

When I first asked my students in the student interviews if engineering has an effect on their lives, four out of five answered “no, that it did not have an effect on their lives.” After the treatment, each of the students interviewed stated that engineering has affected their lives in one way or another. They had started to use reasoning skills they hadn't noticed before implementing engineering strategies into the classroom. For example one student stated “Since I have learned about what engineering is, I have been seeing everything around me and find myself asking how was this and how was that engineered. I never thought that everything could have been engineered by someone.”

Student interviews indicated that the students were enjoying the learning process, and they admitted to enjoying the research and being in charge of their own project. They enjoyed finding ways to connect other classes to science class. Data collected from teacher observations and student journals showed that students were thinking deeper about what they were learning. When it was time for the students to pick their third project they were very energetic to pick which one of their projects they were going to improve. They knew what they had to do, and they knew what steps had to be taken to complete it. The students were energetic to begin on their work when the bell rang and worked through the whole hour.

Teacher observations of my students throughout the treatment were written note style in a science log book. Some days I had nothing to write. However, I noticed that my students were more engaged in the activities if they were somehow able to make a connection between the activity and their own experience or interests. There were several students that did not work well in groups but did wonderfully working by themselves. My observations on the first phase of the treatment showed students being frustrated that I did

not just give them the answers. I had to go over the EDL three different times with my seventh and eighth grade class before they were able to grasp the idea of it. The second phase of the treatment the students seemed to follow the EDL with almost no problems. For the most part, the students knew what they had to do and did it.

The data regarding improvement in attitudes toward science is inconclusive but what I observed in the classroom was the students taking the lead in their own learning process, which is at least a good start.

Engineering Activity Impact on Student Understanding of the Engineering Discipline

Twenty two out of twenty five of the students who participated in the engineering activities took the pre and post engineering test. The engineering posttest provides evidence that the students have a better understanding of what an engineer is and an understanding of engineering terms that are used in engineering fields. During the pre-engineering assessment, students complained while answering the questions. They did not understand what the terms meant or how engineering has affected their lives. Through the engineering activities, however, students learned that everything around them has been engineered by someone. They were amazed to learn about how engineering goes into everything from the clothes they wear to the computers they do their homework on. The rubric found in Appendix E was used to grade the pre and post engineering assessment. I ranked answers from one (“no answer”) to four (“well thought out answers”). Figure 2 shows the overall averages on the scores that were given by the students.

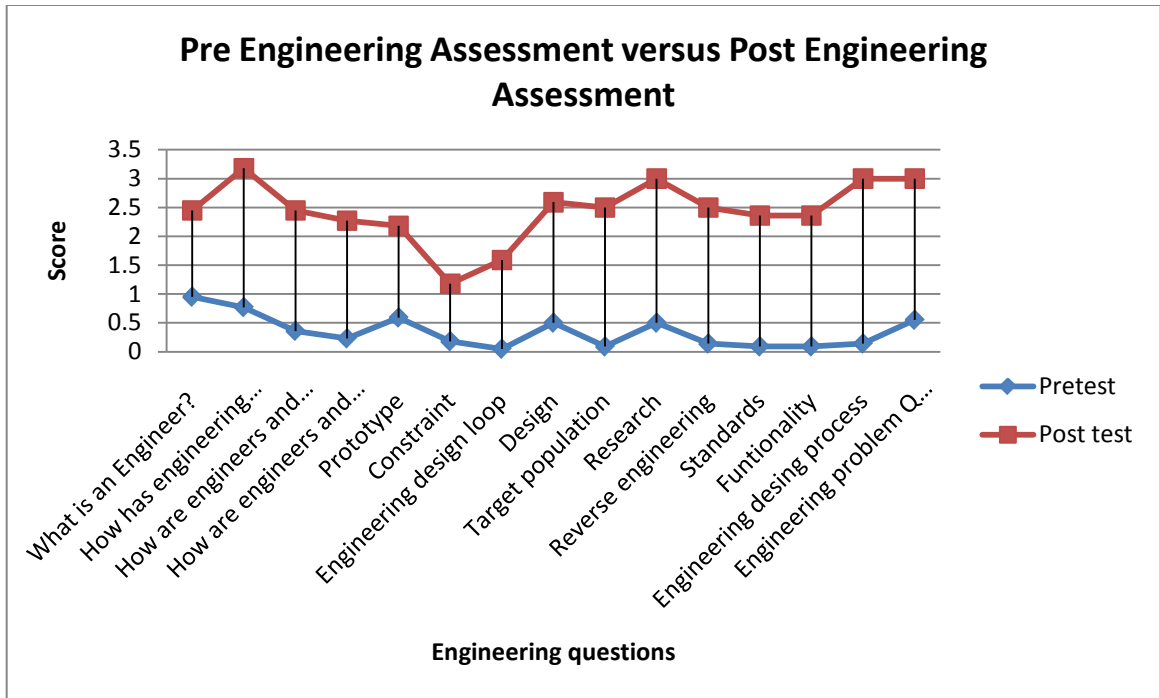


Figure 2. Line graph comparing pre and post scores for Engineering assessment (N = 22)

Student interviews and student journals showed an increase among all of the students' understanding of what engineering is and key engineering concepts. For example a total of 22 students took the pre and post assessment of engineering. On the pre assessment the average score was one when I asked what an engineer is. The most common answer received was “IDK” in the answer box. On the post assessment I had an average score of 2.5 which meant that they had the idea but were lacking complete understanding.

The answers that I received for the following question improved on the post-assessment,

“If you were given the task of constructing a device that could pick up trash from the floor and all I gave you for materials was a piece of cardboard, some tape, a ruler, and

string, how would you approach this situation to solve the task? You do not need to provide a solution but the steps you take to solve the problem need to be explained. Hint: What steps would an engineer follow?"

In the pre- assessment I was given answers like "IDK" and I would just pick up the paper". In the post assessment I was given much more complete answers, such as the following:

"Step 1: Roll up the cardboard and tape it to make a cylinder. Step 2: Break ruler into two parts. Step 3: String the two parts of the ruler together at the end. Step 4: Put the string and two part of the ruler in the cardboard so that the string is on one side of the cardboard and the two parts of the ruler is on the other. Step 5: Pull on string and it should clamp the two parts of the ruler together" or "I would put tape on the ruler and use the adhesive side of the tape to pick up trash."

Results Summary

Overall the data from this study shows an increase in critical thinking skills. The student attitude survey was less conclusive in showing student improvement in their thinking about science. However my observations showed that they actually enjoy learning about science, especially when hands on activities are involved. The engineering assessment revealed that the students did in fact gain important knowledge about what engineering is, and they were able to define key terms that engineering fields use today. While more research is necessary, these results were positive and encouraging for the use of engineering strategies in the classroom.

INTERPRETATION AND CONCLUSION

When I first developed the questions for this project I wanted to find out if engineering strategies used in the classroom would improve critical thinking skills among my students. Through the research I realized that engineering strategies used in the classroom and in the real world work setting are closely connected. Engineering strategies, like problem based learning and collaborative learning, are easy to implement in the classroom. They give the students involved a chance to use what critical thinking skills they have and to develop ones that they do not yet have. This project has taught me that much of what we do already in the classroom does work. We just need to do more projects that involve engineering strategies in the classroom and less busy book work.

I also wanted to know if the attitudes among my students about science would increase because of the implementation of engineering strategies. One factor I did not take into account when asking this question is the fact that if students already enjoy a class how they would enjoy it more. Many of my students take more than one class from me because they like how I teach and my classroom atmosphere. I have fun in the classroom and my students enjoy being in my classroom. This has taught me that if the students know and feel that the teacher enjoys what they are teaching then the students will also enjoy the class.

My last question to which I wanted to find an answer was if my students would have a better understanding about what engineering is after engineering strategies were implemented into the classroom. I wanted to know this because everything around us is engineered by someone. I was amazed to learn that at first my students really did not have a clue to what goes into the production of everything around us. As the lessons were

implemented the students themselves started to notice the complexity of the engineering that goes into all of our daily lives. I learned that our students want to know how things are made. Teaching them about engineering helped my students and myself have a better understanding of the importance of engineering in our lives.

There are some areas of this project that could be improved. Data collection could be improved. I would have liked to have more student surveys of how they felt about what they had done before and after they had completed a project. I would have liked to have a question box for the students to submit questions that they would like to know about a problem or situation with which they would like help. I would like to have the students take the critical thinking test at least four times and to have had all of my students take the engineering strategies class as a yearlong class. I would also have liked more time to collect data and complete more engineering activities with my students.

Student surveys and interview questions were never the same for any of my students. I would have liked to have a set of questions to ask my students during the student interviews that I did not change for each project. I asked individual questions that pertained to each individual and ended up with good overall results but they did not match up with what was asked to every student. For the student science journals I would like to make up a rubric and have the students put it into their science journal and make it a grade for them. It was apparent to me that the students that used the science journals correctly had a superior written portion of the project than the students that did not use the science journal as they were supposed to use it.

More training in engineering education would have improved the research. The lack of resources in the classroom and time with my students hindered the amount and

quality of data that I was able to collect. I only have five computers in my room and only one student at a time could take the critical thinking test which made it very time consuming. I believe that if every student had a computer to use while taking the test, survey and assessment would have made the results more accurate.

VALUE

This capstone project has provided me with the opportunity to develop into a better teacher. It has helped me to try new strategies in the classroom that have not only helped me grow as an individual but also helped my students grow as critical thinking. Developing and implementing this project has helped me to reflect on my teaching goals. It has helped me to find more ways to show my students the passion for life and learning that I have. As a result of this project I understand the importance of critical thinkers in my future and in my student's future. I believe now that all children can learn to think critically. They just need someone to show them how and give them the opportunity to try and use what critical thinking skills they may already have.

As a teacher, this project has benefited me in more ways than one. It has changed my view on how I want to teach. It has helped to differentiate my curriculum to fit all of my student's needs. I enjoyed seeing my students grow as individuals and as learners. I was amazed to see the students realize that they had learned something and that it made sense to them and they were able to explain the process of what they had done. Seeing my students do well in my classes gives me what I need to continue teaching. After seeing firsthand how implementing engineering strategies like the engineering loop into my classroom has worked, I want to show others how to use it in areas other than science.

Incorporating engineering strategies into my classes has given me the opportunity to share with my students how real world problems are solved. It has given me the opportunity to see my student's progress beyond what they thought they could do. My students were reluctant to step out of the learning process that they had become used to but as soon as they realized that trying a new strategy of learning is really not all that bad, they wanted more. I enjoyed seeing students that usually hate presenting in front of people; get up in front of everyone with pride because they knew that they knew what they were talking about.

As the project came to an end one of my students thanked me for not giving her the answers. She told me for once she finally felt like she really understood something. She enjoyed being in charge of her work. She said that she enjoyed thinking about the world around her in a different light. Now when she looks around she thinks about the engineering that went into everything around her.

I would enjoy a similar project again. I would like to improve on the projects that my students do, how I survey the students and what instruments I use to measure critical thinking. I would like to do a project in an at risk school setting to see if an improvement in critical thinking and willingness to learn from the students improves. Overall, I gained valuable information and critical thinking skills, while my students gained lifelong skills and memories of this project.

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APPENDICES

APPENDIX A

**LIST OF ENGINEERING ACTIVITIES USED FROM THE TEACH
ENGINEERING WEBSITE**

Titles of engineering activities used as resources in class. These and many other lesson plans can be found at this website: <http://www.teachengineering.org/>

1. Activity Design step 1: Identify the Need
2. Activity Design Step 2: Research the Problem
3. Activity Design Step 3: Brainstorm Possible Solutions
4. Design Step 4: Engineering Analysis
5. Design Step 5 Construct a Prototype
6. Design Step 6: Evaluate and manufacture a final Product.
7. Olympic Engineering
8. Shapes and Strength
9. Transportation and the Environment
10. Architects and Engineers
11. It burns
12. Save a life, clean some water
13. Power your house with water
14. Straw bridges
15. Controlling sound
16. Egg-cellent landing
17. Water desalination plant
18. Cars from the future
19. Model greenhouses
20. Am I on the Radio
21. Convertible shoes: function, fashion and design
22. Zero energy housing
23. Engineer a coin sorter

APPENDIX B
STUDENT SCIENCE ATTITUDE SURVEY

STUDENT SCIENCE ATTITUDE SURVEY

Participation in this research project is voluntary, and participation or nonparticipation will not affect grades or class standing

Directions: The statements in this survey have to do with your opinions and beliefs about science in school and the importance of science in your life. Please read each statement carefully, and circle the number that best expresses your own feelings.

Please remember that this is not a test, and there is no right or wrong answers. Please respond to every item.

1. For the following questions please answer to what extent do you agree or disagree with each of the following statements about science? (Circle one number on each line.)

	Strongly disagree	Disagree	Not sure	Agree	Strongly agree
1. I enjoy Science	1	2	3	4	5
2. Science is useful in everyday life	1	2	3	4	5
3. Scientists often don't have very good social skills	1	2	3	4	5
4. Doing science often makes me feel nervous or upset	1	2	3	4	5
5. Science challenges me to use my mind	1	2	3	4	5
6. The science that I learn now will helpful for me in the future	1	2	3	4	5
7. Scientists usually work with colleagues as part of a team	1	2	3	4	5
8. I am good at science	1	2	3	4	5
9. Advancements in science and mathematics are largely responsible for the standard of living in the United States.	1	2	3	4	5
10. I usually understand what we are doing in science class.	1	2	3	4	5
11. Knowing science really doesn't help get a job	1	2	3	4	5
12. Science is difficult for me	1	2	3	4	5
13. working as a scientist sounds lonely to me	1	2	3	4	5
14. Studying hard in science is not cool to do	1	2	3	4	5
15. Even without a strong background in science, I will probably end up with the kind of job I want	1	2	3	4	5
16. Overall, science and mathematics have caused more good than harm in our lives	1	2	3	4	5
17. I will probably take more advanced science courses available to me at this school	1	2	3	4	5

APPENDIX C
ENGINEERING PRE AND POST TEST

Name:

Directions: To the best of your ability answer the following questions and define the terms.

1. What is an Engineer?
2. How has engineering affected your life?
3. How are engineering and science related?
4. How are engineering and science different?
5. For the following terms please explain what they mean to an engineer?
 - a. Prototype
 - b. Constraint
 - c. Engineering design loop
 - d. Design
 - e. Target population
 - f. Research
 - g. Reverse engineering
 - h. Standards
 - i. Functionality
 - j. Engineering design process
6. If you were given the task of constructing a device that could pick up trash from the floor and all I gave you for materials was a piece of cardboard, some tape, a ruler, and string. How would you approach this situation to solve the task? You do not need to provide a solution but the steps you take to solve the problem need to be explained. Hint: What steps would an engineer follow?

APPENDIX D

RUBRIC FOR ENGINEERING PRE AND POST ASSESSMENT

Rubric for engineering pre/post assessment

0 points

- Did not make an attempt to answer the question

1 point

- Information limited or missing

2 points

- Lacks specific information
- Glimmer of main point development
- Beginning to define correct answer

3 points

- Correct answer is apparent but missing clarity

4 points

- Relevant and accurate detail.
- Clear and focused answer

APPENDIX E

SKILL KEY FOR JAMES MADISON TEST FOR CRITICAL THINKING

Skill Key for James Madison Test for Critical thinking

Comprehensive Test of Critical Thinking		
Questions Reflecting Skill	Skill	Description
1-55	(1)	Interpret and apply complex texts, instructions, illustrations, etc.
50-52	(02)	Recognize and clarify issues, claims, arguments, and explanations
1-2,12-15,22-32,34-52	(03)	Distinguish conclusions
12-15,22-31,33-52	(04)	Distinguish premises (reasons)
22-39	(05)	Distinguish arguments
22-39	(06)	Distinguish explanations
22-37,42-46,50-52	(07)	Distinguish assumptions (stated and unstated)
38-39	(08)	Distinguish issues
38-39	(09)	Distinguish claims (statements)
22-37,42-46,50-52	(10)	Distinguish suppositions
47-49	(11)	Distinguish unstated conclusions
40-41	(12)	Distinguish unstated premises
40-41	(13)	Distinguish implications
8-9,42-46	(14)	Recognize ambiguity and unclearness in claims, arguments, and explanations
3-7	(15)	Distinguish necessary and sufficient conditions
8-9	(16)	Describe the structure or outline of arguments and explanations (confirmation)
8-9	(17)	Describe the structure or outline of arguments and explanations (disconfirmation)
10-11,42-46,50-52	(18)	Evaluate whether an inductive argument is strong or weak
42-46	(19)	Evaluate claims and arguments in terms of consistency
42-46	(20)	Evaluate claims and arguments in terms of relevance
42-46	(21)	Evaluate claims and arguments in terms of support
10-11,22-37	(22)	Evaluate analogical arguments, and inductive generalization arguments in terms of the greater the number of similarities between the conclusion and the premises regarding the sample, the stronger the argument
10-11,22-37	(23)	Evaluate analogical arguments, and inductive generalization arguments in terms of, except for the property in question, the greater the diversity within the sample, the stronger the argument (no biased generalization)
10-11,22-37	(24)	Evaluate analogical arguments, and inductive generalization arguments in terms of the less narrow the conclusion (i.e. the wider the range of possibilities the conclusion admits), the stronger the argument
12-18,38-	(26)	Evaluate whether a deductive argument is valid or invalid (logical form)

41,47-52		
16-18	(27)	Evaluate whether a deductive argument is valid or invalid (categorical)
47-49	(28)	Evaluate whether a deductive argument is valid or invalid (truth-functional)
12-15	(29)	Evaluate whether a deductive argument is valid or invalid (semantic/definitional)
19-21	(30)	Distinguish supporting, conflicting, compatible, and equivalent claims arguments, explanations, descriptions, representations, etc.
22-37	(31)	Identify and avoid errors in reasoning, informal fallacies: begging the question
22-37	(32)	Identify and avoid errors in reasoning, informal fallacies: equivocation
22-37	(33)	Identify and avoid errors in reasoning, informal fallacies: post hoc, ergo propter hoc
22-37	(34)	Identify and avoid errors in reasoning, informal fallacies: false dilemma/false dichotomy fallacy
22-37,42-46	(35)	Identify and avoid errors in reasoning, informal fallacies: smoke screen/red herring/rationalizing
22-37,42-46	(36)	Identify and avoid errors in reasoning, informal fallacies: hasty generalization
42-46	(37)	Identify and avoid errors in reasoning, informal fallacies: appeal to ridicule/sarcasm
22-37	(38)	Identify and avoid errors in reasoning, informal fallacies: ad hominem fallacy
22-27,29-36	(39)	Identify and avoid errors in reasoning, informal fallacies: appeal to illegitimate authority
22-27,29-36	(40)	Identify and avoid errors in reasoning, informal fallacies: loaded question
22-27,29-36	(41)	Identify and avoid errors in reasoning, informal fallacies: evidence surrogate
22-26,28-36	(42)	Identify and avoid errors in reasoning, informal fallacies: stereotyping
42-46	(43)	Identify and avoid errors in reasoning, informal fallacies: appeal to consequences (favorable or unfavorable), "wishful thinking"
42-46	(44)	Identify and avoid errors in reasoning, informal fallacies: genetic fallacy
22-26,28-36,42-46	(45)	Identify and avoid errors in reasoning, informal fallacies: biased generalization
42-46	(46)	Identify and avoid errors in reasoning, informal fallacies: anecdotal evidence
53-55	(47)	Discern whether pairs of claims are consistent, contrary, contradictory, or paradoxical