USING WRITING IN THE SCIENCE CLASSROOM TO DEVELOP CRITICAL THINKING SKILLS

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ABSTRACT

This research was conducted to better understand how to engage students more fully in deep critical thought through writing. In an age of high stakes testing and a myriad of content, students who think critically succeed far greater than students whose thinking remains unchallenged. The study was conducted over a six month period and sought to understand if writing in the science classroom would improve depth of thought primarily displayed through lab reports. Students were also involved in co-generative dialogues with the instructor and received feedback from lab report drafts. The results of the study indicate that written assignments in the classroom, critical thinking skills, and instructor feedback on student lab reports promotes deeper levels of thought on scientific concepts. The research prompted a change in the way the instructor approached critical thinking in science curriculum and how frequently students were given written assignments, specifically in the form of lab reports.

INTRODUCTION

In today's age of high stakes testing, students are bombarded with written assessments and a breath of content they must master. Too often teachers do not have the time to cover the amount of content necessary for standardized tests. The instructor has observed within his classroom that pressures from administration, difficult home situations, and poor classroom management all impede on the learning that takes place in the classroom. Some teachers would argue that students' interest in learning has decreased with the availability of instant access to information that can lead to thoughtless knowledge. Critical thinking is essential for learners to successfully problem solve in life, fully achieve in the classroom, and competently thrive in the world. As students continually devise ways to "get by" without engaging material within the classroom, they may fail to reap the long term rewards of critical thinking.

Mastery Charter High School (MCHS), wherein the instructor conducted this research, has had a brief but successful five year history. The school seeks to educate Philadelphia students who score average or below average on state assessments. As students achieve academically, they gain the skills necessary to compete in the global economy. MCHS has successfully produced higher test scores. This accomplishment has allowed the school to branch out into the city with three new campuses (Mastery, 2007). In the fourth year of the school's existence, the U.S. Department of Education recognized MCHS as one of "15 exemplar charter schools" in the nation (Mastery, 2007). Figure 1 compares Mastery Charter's success with the surrounding Philadelphia schools (Mastery, 2007).

Figure 1.				
PSSA Test Proficiency for Mastery Charter High School				
Subject	Proficient 2005	Proficient 2006	Change	Philadelphia School System Average for 11th Graders
Math	33.8 %	37.3 %	3.5 %	23.1 %
Reading	44.2 %	46.4 %	2.2 %	30.6 %
Writing	N/A	92 %	N/A	66 %

Despite the accolades, PSSA scores are not increasing at significant intervals, as demonstrated by the change in proficiency above in Figure 1 (Mastery, 2007). Administrators considered changing several structures within the school, enhancing student motivation, and creating a deeper sense of community as a means of increasing proficiency. While these structures might help, improving classroom instruction is an essential part of the equation. The instructor seeks to engage students in deeper critical thought and teach students how to reason well instead of just regurgitating facts and knowledge. In this paper, the researcher addresses three questions: (1) Is writing an effective way a teacher can engage students in critical thinking? (2) How can a teacher improve critical thinking through writing in the science curriculum? (3) What affect do teaching critical thinking skills have on enhanced student writing?

LITERATURE REVIEW

Within the educational realm, critical thinking has been on the minds of teachers and researchers for decades. Several articles have been reviewed to provide a history of educators' concerns regarding critical thinking. Teachers have sought increased problem solving thinking for over forty years. Raths, Jonas, Rothstein, and Wassermann (as cited in Carr, 1990) note the lack of emphasis on critical thinking in the late 1960's (Collier et al., 2002). Fraker references the Nation at Risk report from 1983 and indicates deficiencies in higher level thinking skills in American students (1995). Many educators were concerned that national and state test questions placed the emphasis on rote memorization rather than thinking skills.

Thinking skills are highly valuable not only for standardized tests but also for daily life. Fraker notes that students must make decisions and judgments every day regarding information, present and future plans, and situations that require immediate action (1995). The debate still continues today, and any solution must begin with the question, "What is critical thinking?

The word 'critical' derives etymologically from two Greek roots: "kriticos" ("discerning judgment") and "criterion" ("standards") (Paul, 1996). If a person has discerning judgment based on widely held intellectual standards, he could be deemed a critical thinker. Current research indicates the importance of discernment for students in the classroom. Richard Paul noted that those who think critically "strive for clarity, precision, accuracy, relevance, depth, breadth, and logicalness" (pg. 3, 1997). *Webster's New World Dictionary* gives a definition of critical thinking as thought "characterized by careful analysis and judgment" (Webster, 2002). These character traits would be highly beneficial for any science classroom.

Paul further defines critical thinking:

> Critical thinking is that mode of thinking about any subject, content, or problem in which the thinker improves the quality of his or her thinking by skillfully analyzing, assessing, and reconstructing it. Critical thinking is self-directed, self-disciplined, self-monitored, and self-corrective thinking. It presupposes assent to rigorous standards of excellence and mindful command of their use. It entails effective communication and problem solving abilities as well as a commitment to overcome our native egocentrism and sociocentrism. (pg 1, 2004)

From Paul's definition the onus seems to lies with the student, but ultimately it is the teacher's job to instruct students how to think. Many problems prevent critical thinking in classrooms. For starters, teachers need to evaluate their reasoning process in order to improve their thinking (Paul, 1996). In many cases, "…teachers believe they are already teaching critical thinking skills, and students believe they are already learning critical skills, and both groups are resistant to change." (Scanlan, pg. 7, 2006) In addition, teachers lack the necessary skills to formulate questions that require higher-level thought. Furthermore, critical thinking is difficult to assess, and teachers do not know how to teach critical thinking skills. Teachers could benefit from learning and using appropriate strategies, and their classrooms could become an environment that would reward critical thinking. In many schools learning and thinking are two separate entities, because the teaching of critical thinking is not incorporated into the science classroom.

In 1996 Deanna Kuhn addressed the difficulty of thinking critically without being taught the proper skills: "People cannot, even when prompted, reliably exhibit basic skills of general reasoning and argumentation." (pg. 2, 2005) Therefore, teachers must guide students in the acquisition of critical thinking skills. Many researchers have offered their opinion on the best approach to develop critical thinking skills. Gelder lists some cautions when promoting the development of critical thinking skills (2005). He notes six lessons cognitive science should teach to educators: Acquiring expertise in critical thinking is hard, practice in CT skills themselves enhances skills, the transfer of skills must be practiced, some theoretical knowledge is required, diagramming arguments promotes skill, and students are prone to belief preservation (2005). Gelder also stresses that students must be actively doing the thinking themselves, or they will never improve. Similarly, in 1994 Erickson and Charness (as cited in Gelder, 2005) discover that achieving high levels of excellence in many fields of study strongly relates to the quantity of deliberate practice. Therefore, critical thinking skills must be coupled with deliberate practice in order to achieve effectiveness.

Many educators desire to implement activities that promote critical thinking. Paul notes that those who think critically:

> Typically engage in intellectual practices of the following sort: They regularly monitor, review, and assess: goals and purposes; issues and problems; information, data, or evidence; interpretations of such information, data, or evidence; quality of reasoning; basic concepts or ideas; assumptions made; implications and consequences; points of view and frames of reference. (pg. 4, 1996)

Wade (1995) provides eight guidelines critical thinkers can perform. These guidelines include asking questions and be willing to wonder, defining problems clearly, examining evidence, analyzing assumptions and biases (opinions), avoiding emotional reasoning, avoiding

oversimplification, considering alternative interpretations, and tolerating uncertainty (and failure of wrong answers). As a part of the classroom research, the instructor gave the students a survey (see Appendix A.) based on Wade's eight guidelines (1995). The instructor intended to evaluate the level of critical thinking before and after the study. The researcher will discuss the outcome of this survey later in the research findings.

The instructor used co-generative dialogues to evaluate the level of critical thinking among students. These dialogues consist of small groups of students outside of the classroom. These small groups exist to bring to the forefront unconscious teaching practices, to bring a collectively responsible voice and reflection in the classroom, and to allow students to experience an equal playing field in the teacher-student relationship. The expectations of the co-generative participants are voluntary input, equal voice, and (Martin, 2006). Furthermore, the co-generative dialogue "offers teachers and students a pathway for sharing current understandings to describe what has happened, identify problems, articulate problems in terms of contradictions, and frame options that provide new and increased choices for enacting teaching and learning" (Martin 2006). Not only do co-generative dialogues foster communication within the classroom, but also provide an excellent forum for research.

Wade, along with other researchers, argues that writing is an essential ingredient in critical thinking instruction and has important advantages over oral discussion in the development and assessment of students' critical thinking skills (1995). Wade notes that writing promotes greater self-reflection and broadens a student's perspective more so than oral expression (1995). Writing ensures the participation of every student and is a requirement for active learning. Students are able to articulate what they believe and refute the other side of an issue or concept. Writing allows students to revise unsuccessful attempts at expressing concepts. In addition, there is less risk involved with revisions. Writing allows time for careful reflection and eliminates the peer pressure of verbal responses.
Similarly to Wade's research, Oliver-Hoyo (2003) supports critical thinking through writing. She designed writing criteria to promote the use of critical thinking skills in an introductory college chemistry course (2003). The study included twenty first-semester freshmen at North Carolina State University. Written reports were used to monitor the implementation of critical thinking skills. A total of eighteen reports were evaluated with multiple drafts of each report. Oliver-Hoyo developed a rubric, which was discussed in class many times and returned to the student with numerical feedback in each category. The results from the study demonstrate an improvement in students' writing skills. The study also evidenced that the rubric provided a valuable assessment of critical thinking skills. Oliver-Hoyo states that feedback from the rubric was an important piece in her research (2003). Likewise, Paul notes that critical thinking is a repetitive process, needing constant feedback: "The feedback students receive from teachers on their ability to meet the relevant standards will be a large factor in the improvement of student reasoning" (1996).

After the instructor read many pieces of literature, he noted several critical thinking components. Researchers used co-generative dialogues to obtain necessary feedback as an evaluation tool. Gelder affirms deliberate practice within the classroom (2005). Based on the study at North Carolina State University, students wrote their own series of lab reports (Oliver-Hoyo, 2003). The lab reports the instructor assigned were revised. Students received feedback, in accordance with Paul's research (1996). The instructor used Wade's peer-reviewed rubric to evaluate each

written lab. The instructor also taught students critical thinking components and modeled how one thinks.

METHODS

The researcher conducted this study at Mastery Charter High School. With only 430 students enrolled at this public charter school, the institution is a close community of learners. Each member of the community knows the common objective: greater achievement by gaining the skills necessary in order to compete in a global economy (Mastery, 2007). Instructors and administrators provide clear expectations and maintain order through appropriate discipline.

Approximately, ninety-five percent of all students are African American, three percent Hispanic, one percent Asian, and one percent Caucasian. Seventy-five percent of all students qualify for free-reduced lunch. The urban school attracts students from all over the city. Students ride public transportation from the nearby suburbs. Businesses, banks, and tourist attractions, such as the Independence National Park, occupy the area surrounding the school.

Students are selected for admittance through a random lottery process. As a public chartered school within the Philadelphia School District, any student can attend MCHS regardless of their academic standing. The curriculum includes six to eight classes each year for four to six years, an internship in the city, and a college course. On average MCHS students score an 880 (out of 1600) on the SATs. Other requirements include a tenth grade presentation, proficiency or advanced proficiency on the Pennsylvania state standardized exam in the eleventh grade, and completion of a senior project. The students must obtain a seventy-six percent or greater to master the skills and advance to the following course (Mastery, 2007).

Approximately ninety-two percent of all students graduate from MCHS, and over seventy-nine percent of all students go on to college (two or four year higher education). Over the past three years Mastery Charter has met Adequately Yearly Progress the first and third year according to the No Child Left Behind mandate. Through data and research the school has determined that student achievement is the main educational priority. PSSA and Terra Nova scores did not provide adequate information concerning student academic deficiencies. To provide more insight, the administration created benchmark tests in math, reading, and writing. Currently, the science curriculum has no benchmark tests. Occurring every six weeks, these tests are designed to assess student achievement and gather data to guide teacher training, readjust curriculum, and improve classroom instruction. The benchmark tests have enlightened teachers by showing them where students lack understanding and where they lack professional development.

The science department consists of six teachers, four who primarily teach the majority of the science classes. Two faculty members from other departments teach the remaining courses. The science department teachers meet weekly to discuss common lesson plans. The science team usually meets monthly to discuss issues related to supplies, curriculum, or instruction. Each teacher has a voice in the community and can share concerns through the School Meeting Committee.

Each classroom contains approximately twenty-five to thirty students. The school calendar runs on block scheduling. The instructor of the study teaches eleventh and twelfth grade chemistry. The instructor chose the more mature twelfth grade class for this research. These students

express an eagerness to learn chemistry and also demonstrate motivation to learn. The class consists of twelve students – a size which promotes flexibility and eliminates many logistical concerns. Five students are male and seven are female. After the instructor had selected the class, students were informed of the nature of the study and also invited to contribute. Students volunteered to be active participants. The students proved valuable as research tools in the development of critical thinking. The researcher expected the students to learn why they choose not to think critically, to value critical thinking, and to engage in deep scientific thought.

Five out of the twelve students participated in co-generative dialogues with the instructor. The instructor-researcher did not reveal the details of the co-generative dialogues. The group consisted of both very successful and below average students. During the twenty minute discussion (typically in the mornings before school), the instructor would ask a range of questions (see Appendix C). Data collection from the co-generative group began after several initial meetings. The first four meetings allowed participants to gain familiarity with the types of questions they would later answer and to feel at ease. The following three meetings focused on questions pertaining to this research. As a means of accuracy, the instructor took notes and audio recordings throughout each session.

When investigating the most effective method for improving critical thinking, the researcher recognized the great potential of coupling critical thinking with writing. Since Oliver-Hoyo acknowledges the benefits of writing to improve critical thinking, the instructor decided to proceed with this method (2003). Students received an adapted rubric for each writing assignment (see Appendix B). Tied to Bloom's Taxonomy (1956), the rubric provided the necessary avenue for feedback. The first step in the researcher's method was assigning the students a lab report that focused on curriculum related science content. The researcher then graded the labs using the rubric mentioned above. Individual conferences followed the assessment. These instructor/student meetings lasted five to ten minutes and provided the students with the ability to see where their lab reports did not meet the specified criteria for critical thinking. Students were allowed to revise the reports for a higher grade. Not only did the instructor use the rubrics to provide feedback, he used the co-generative dialogues collect data. The co-generative dialogue sessions took place throughout the research period (see Appendix C). Similar to research conducted by LaVan and Beers (2005), students spoke freely within the sessions. Overall, the dialogues provided valuable information throughout the research and also benefited instruction within the classroom.

In addition to evaluating the written labs, the researcher concluded that writing lab reports was an insufficient means of promoting critical thinking. The instructor taught additional skills to bolster critical thinking while the students wrote the reports. These instructional instances took place three times during the research. Based upon Paul's resources (1996), the instructor gleaned information concerning which critical thinking skills to implement in the classroom. The instructor developed three lessons (see Appendix D through J). In the first lesson, the instructor asked students to define critical thinking and role play three main types of thinkers (see Appendix E). Students were able to identify aspects of critical thinking and typical questions they need to ask themselves (see Appendix G). In the second lesson, the instructor taught the students the difference between a 'fat' and 'skinny' question (see Appendix J). The students also learned the different levels of questions based on Bloom's Taxonomy (see Appendix F). The

final lesson taught the students intellectual virtues and standards. Students were then able to identify the components of deep thinking necessary within the intellectual community.

RESULTS

Five students of varying levels of academic achievement attended the co-generative dialogues. Consisting of three males and two females, the co-generative dialogue group was very cooperative and helpful. Two of the students were in the top ten percent of their class. Their science skills surpassed most of their peers. Two of the students were average, when compared to their peers. The last student not mentioned struggled significantly to grasp basic chemistry material. During the first few sessions in the fall, students discussed general topics such as enjoyable aspects of class, the amount of assigned homework, and general thoughts about critical thinking. In the spring after the five students felt comfortable around each other, the students completed a critical thinking interview (see Appendix C). This interview consisted of questions gauging the students' thoughts on critical thinking. Student 1 (S1) defines critical thinking as the time one takes "to observe all the possible outcomes." In answering the question that pertains to the components of critical thinking, students responded in the following manner:

> S2-"To observe and study."
> S1-"To have a clear mind."
> S3-"To think about prior knowledge and connections, to think outside the box."
> S1-"To brainstorm and think of all the possible outcomes. To put your hand on your chin, think of the problem, I don't know, you, like, you look at something really hard, get the information out of it and put it all into something to try and solve a problem."

When the instructor asked for some real life examples of critical thinking, students provided decisions such as deciding when one wakes up, purchasing a car or house, and thinking before one spends money. They did mention, however, that there are specific ways teachers encourage them to think critically. Student 3 responded that teachers make them stay after school to complete homework because they know students do not think critically at home.

> S2 added: "Teachers don't go on with the class because you don't know the answer, like Mr. Barry."
> S1: "Yeah my science teacher does that too."
> S1 responded shortly thereafter, "My science teacher, no names, makes me think critically; he always gives me a problem and then he gives me a different problem a little bit and then, like, he makes you work it out, like, and sometimes he doesn't really help you, like, that so that you can get it better on your own and a lot of times it is better for the student or whatever because he makes you think critically."

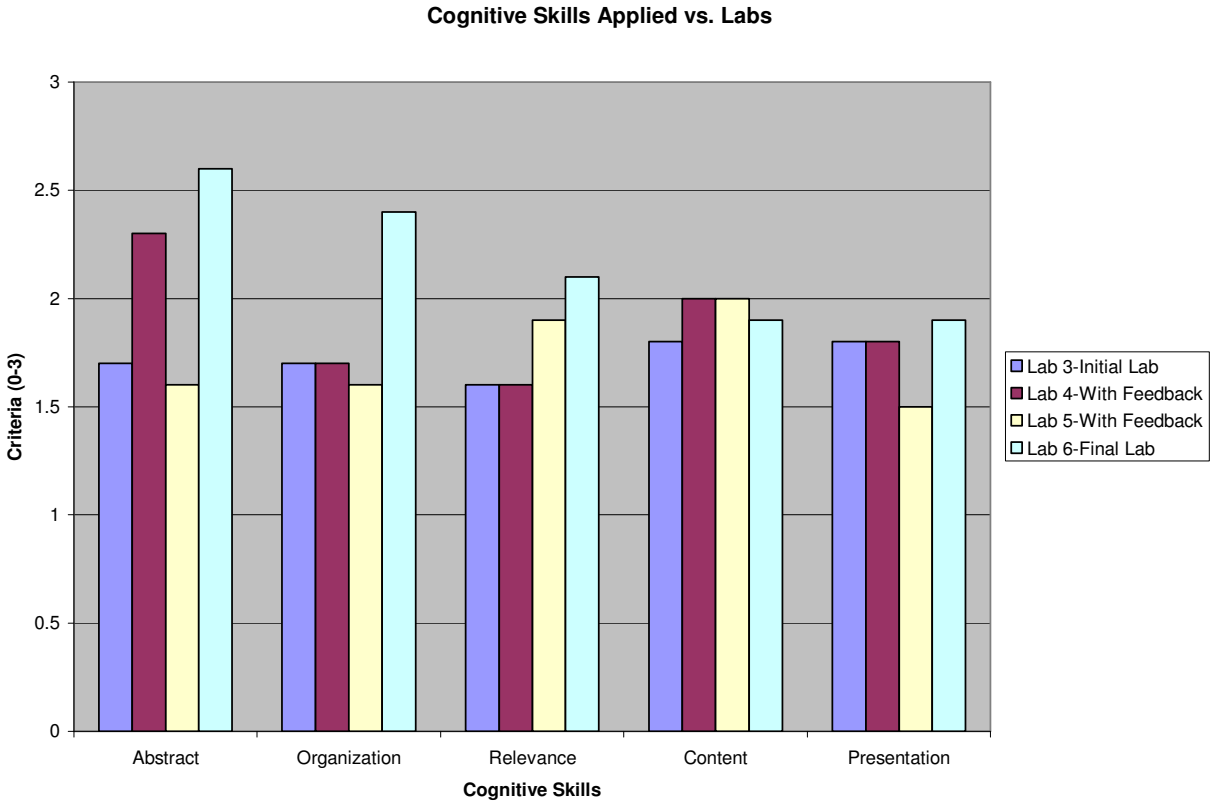
After the two month period of revising labs, receiving critical thinking training on what and how to think critically, and having discussions about critical thinking, students revisited the same questions from the critical thinking survey that the instructor gave at the beginning of the research. There was a slight but noticeable improvement in the depth of critical thought and how students approached the world around them in terms of their thinking (see Appendix D).

As students attended the co-generative dialogue sessions and revised labs to include more in-depth thought, they began to think more deeply. The average scores based on the adapted

writing rubric (see Appendix B) from Oliver-Hoyo's research (2003) showed increases in student's ability to think critically through writing lab reports (see Figure 2 below). The instructor gave three lab reports in the beginning of the year so that students could understand the teacher's expectations. After the students wrote the three initial lab reports, the instructor scored only lab three with the adapted rubric. The instructor also scored labs four and five. As stated earlier, the instructor provided feedback to the students in the form of five to ten minute conferences. The co-generative dialogues revealed that the conferences were helpful overall. One student noted that, "I get to have deeper answers on my lab report." Following the rubric, the instructor scored lab six and compared the results with labs three, four, and five. The rubric had five criteria on a scale from one to three. Relating to the major parts of a lab report, the criteria are (1) introduction, (2) organization, (3) relevance of material, (4) content, and (5) presentation. Each criterion also relates to a cognitive skill from Bloom's Taxonomy, thus linking the expectations for each lab report with the critical thinking skills taught to the students in the three sessions (see Appendix E through J).

As seen below in Figure 2, with each lab the students improved in cognitive skills. Only the "content" skill area did not see a clear overall improvement from lab three to lab six. Given the data below, n=12 students.

Figure 2



The following quotation reveals that students saw themselves as deeper writers than before the research.

Researcher-"Did you like/dislike the conferences that provided feedback? Were they helpful to give you guidance into deeper critical thought?"

S5-"I think it is helping us because it is preparing us and challenging us to do better. Like you said, most of us did good, but you want us to do better. Obviously we are getting to that point in age when a little answer or little question won't count and we need to help people understand us better."
S1-"My feedback was kinda' good from the lab because it lets you think more about your work and let you know what is going on, plus it helps you let you give a different point of view."

Researcher-"After writing up six labs over the semester, how have you seen growth in your personal writing skills as it relates to deep critical thought?"

S1-"In my conclusions and stuff I put more into it. Like overall what we do throughout the lab, anything that might have popped up that could be talked about. Instead of restating the beginning, I used to put the beginning, basically, but now I put everything."
S5-"I like putting deeper things and put what we are really talking about in the lab."
S3-"My conclusions have gotten better."
S4-"I was going to say it is stronger because now I write more, and before it was not as much."

DISCUSSION

Throughout the course of the research, the researcher realized the many advantages to writing as an essential ingredient in critical thinking instruction. Students could not "fake" their way through learning the material because the instructor read all the varying levels of thoughts on the students' assignments. Lab reports became an excellent way to have all students participate on a deeper intellectual level than through other assessments. Wade was correct in saying that writing had significant advantages over oral discussion (1995). In addition, the instructor's use of lab report revisions proved valuable just as Oliver-Hoyo's study increased critical thinking skills (2003). In this particular study students' writing improved not only in the revisions but also in the succession from lab three through lab six. This deliberate practice, as supported by the research of Erickson and Charness (as cited in Gelder) was important for students to demonstrate higher critical thinking skills (2005).

Scores on lab reports increased as a whole in conjunction with multiple approaches. First, the instructor modeled good critical thought in class and clearly defined the expectations on a well written rubric adapted from Oliver-Hoyo (2003). Modeling and defining the expectations gave students an understanding of the objective for the research. Second, after identifying the types of thinkers and components of critical thinking, students could identify the dynamics of critical thinking. Third, the lesson on Bloom's Taxonomy (1956) gave students more than one way to ask and answer a question. Co-generative dialogues indicated that teaching Bloom's Taxonomy was one of the more important critical thinking skills taught by the instructor. Finally, based on the research from Paul in 1996, feedback became a crucial piece of the research. Students indicated they truly appreciated the feedback.

Figure 2 notes the effect of research on students. This data shows that all but the content area on the rubric scores improved toward higher proficiency in cognitive thinking skills. Furthermore, students improved on guidelines Wade gives for critical thinkers to perform (see Appendix A). Within the co-generative dialogues, students told the researcher how the six month research period had affected them:

> S5-"Like, the [labs] make you think harder, and like, do even more, not just write something down…and think about what you are doing."
> S1-"I now think about stuff more than I did before. I think more deeper about things, about more possible outcomes or questions."

One of the findings from the research is worth mentioning. Higher cognitive skills did not guarantee that students would produce correct scientific content on lab reports. From the data stated above, students thought more deeply but not necessarily correctly. Students were not always accurate and logical in their scientific reasoning skills. However, students showed depth, breadth, precision, relevance, logic, and clarity in lab reports.

CONCLUSION

This research was conducted to determine how to develop critical thinking skills in the science classroom. The researcher sought deeper critical thought through the implementation of writing assignments. The instructor sought to have students better prepared for their current intellectual challenges and future schooling. Twelve seniors from MCHS participated in the six month study. Lab reports were the primary means of assessing critical thinking and a rubric evaluated various aspects of critical thinking. Co-generative dialogues provided a forum for discussion and a platform for teacher feedback.

Writing was a moderately effective way of engaging students in critical thinking. The results indicated that students improved in writing lab reports and expressing deeper levels of thought. Teaching applicable skills, allowing for deliberate practice of critical thinking, and providing feedback for students on written reports all proved valuable to the success of the research. The instructor observed a change in deep critical though the six lab reports that were written. In the future, the instructor plans to continue co-generative dialogues and writing assignments to asses critical though on scientific concepts. The instructor also plans to teach critical thinking skills to students and model the components of critical thinking.

APPENDIX A

Survey adapted from eight activities critical thinkers can perform:
Wade, Carole. (1995). Using Writing to Develop and Assess Critical Thinking. *Teaching of Psychology*. 22 (1), 24-28.

Initial and Final Survey for Chemistry Class on Critical Thinking

Directions: In light of your current level of educational experience as of today, please answer the following questions as accurately as possible using the scale provided. Circle the number that applies to you.

Never	Rarely	Sometimes	Frequently	Always
1	2	3	4	5

In science class…

1. I ask questions and am willing to wonder about the world around me.

1	2	3	4	5

2. I define problems clearly in my class assignments (homework, tests, quizzes, class work).

1	2	3	4	5

3. I carefully examine all the evidence before making an evaluation of a question.

1	2	3	4	5

4. I analyze assumptions and biases (opinions) of myself and others.

1	2	3	4	5

5. I avoid emotional reasoning when my inserting an answer to a question.

1	2	3	4	5

6. I avoid over implication of an answer.

1	2	3	4	5

7. I consider alternative interpretations to questions posed.

1	2	3	4	5

8. I tolerate the uncertainty and failure of wrong answers of myself.

1	2	3	4	5

9. I tolerate the uncertainty and failure of wrong answers of other classmates.

1	2	3	4	5

APPENDIX B

Rubric for Chemistry Writing Assignments-Mr. Barry

Trait Evaluated	Cognitive Skills Applied	Criteria for Attaining Levels of the Rubric
Abstract/Introduction	Synthesis	3. All main points of information are succinctly (briefly) presented. Keywords that accurately describe information in the answer are properly used. 2. Some points of information or keywords are missing, but all the criteria are addressed. 1. One or more criteria are absent
Organization	Analysis	3. Clear introduction, body, and conclusion are used in the written answer. Material is presented under the appropriate heading. Information is presented in reasonable amounts. There is a logical and coherent flow of information throughout the document. 2. Either one of the last two criteria not met. Contains clear introduction, body, and conclusion with relevant material in each section. 1. Requires major improvements on all criteria presented in answer.
Relevance	Knowledge and Application	3. Appropriate scientific terminology is used. The writing in the answer integrates information from class, lecture, and activities into new material. The student can provide a link between theory and applications. 2. One criterion is lacking, but efforts on the other two are shown. 1. Scientific terminology is used, but none of the other criteria is met.
Content	Comprehension	3. The student's writing conveys new information in the student's own words. Concepts are correctly understood. An appropriate depth of content is present. The writing in the answer is simple and direct. ***The student writes in the active voice rather than passive voice.*** 2. The material in the report is not well understood but effort is shown towards comprehension 1. The content is too broad. Focus is not on the scientific aspect of the topic
Presentation	Evaluation	3. The answer is well written in English and has a professional appearance: neatly written and easy to read. The presentation conforms to the required format. 2. Efforts on all criteria were made but not fully achieved. 1. One or more criteria are not met.

Rubric adapted from:

Oliver-Hoyo, M. (2003). Designing a Written Assignment to Promote the Use of Critical Thinking Skills in an Introductory Chemistry Course. *Journal of Chemistry Education.* 80, (8). 899-903.

APPENDIX C

Co-generative Dialogue #1: Critical Thinking Interview Profile

The purpose is to determine the extent to which the tools and language of critical thinking have come to play an important part in the way you go about learning, in school and in everyday life.

- What is critical thinking?
  S1-"When you take the time to observe all the possible outcomes"

- Are there any components of critical thinking?
  S2-"Observe, study"
  S1-"Having a clear mind."
  S2-"Research, information."
  S3-"…think about prior knowledge…connections, outside the box."
  S1-"…brainstorm and think of all the possible outcomes."
  S2-"…Outcomes and results."
  S1-"Put your hand on your chin, think of the problem, I don't know, you like, you look at something really hard, get the information out of it and put it all into something to try and solve a problem."
  S2-"Apply prior knowledge."

- What standards do you use when you evaluate someone's thinking?
  S1-"If somebody blurts something out they were not thinking. You need to pause before you answer a question."
  S2-"…what they are saying matches what is truthful."

- Could you give me some examples of your use of critical thinking in your life?
  S3-"You have to know when you wake up and when you wake up and why do you have to wake up at this time and how much time do you have…you have to break everything up.
  S1-"Spending money is critical thinking."
  S2-"Basketball is fast paced and you have to make quick, good decisions."
  S3-"Buying a house, car."

- To what extent have your teachers encouraged you to think critically? Explain.
  S3-"Staying after school."
  S1-"My science teacher, no names, makes me think critically, he always gives me a problem and then he gives me a different problem a little bit and then, like, he makes you work it out, like, and sometimes he doesn't really help you like that so that you can get it better on your own and a lot of times it is better for the student or whatever because he makes you think critically."
  S3-"Teachers who don't go own with the class because you don't know the answer, like Mr. Barry."
  S1-"Yeah my science teacher does that too."

Co-generative Dialogue Questions for Session #2

- When taught about what critical thinking was the other day, what were your first impressions?
  S5-"It is just not thinking. You really have to take your time… and view all options and facts to put things together."
  S1-"Everything is not as simple as it seems."

- Did you like/dislike the feedback conferences from the labs and the rubrics provided? Were they helpful to give you guidance into deeper critical thought?
  S5-"I think it is helping us because it is preparing us and challenging us to do better. Like you said, most of us did good, but you want us to do better. Obviously we are getting to that point in age when a little answer or little question won't count and we need to help people understand us better."
  S1-"My feedback was kinda good from the lab because it lets you think more about your work and let you know what is going on plus it helps you let you give a different point of view."

- How could you use 'Bloom's Taxonomy' or 'Fat/Skinny Questions' to write your lab with more critical thought?
  S1-"Like I said, you can turn a skinny question into a fat question… by using more than one simple word."
  S3-"Maybe if you read what the lab is about and pick out questions from Bloom's Taxonomy and answer them as you go along with the lab."
  S5-"You could compare and contrast the lab after you read it to compare Bloom's with how you read it."

Co-generative Dialogue Questions for Session #3

- How would you assess the change in your level of thinking (specifically in this class) over the past 8 months?
  S1-"I now think about stuff more than I did before. I think more deeper about things, about more possible outcomes or questions."
  S4-"I don't think it changed. I think it stayed the same."
  S5-"It got a little stronger, like, it had to get a little deeper, things we had to do, especially with the labs"

- What has specifically contributed to being a deeper thinking in this class?
  S3-"College, that is my biggest motivation to think hard."
  S1-"Getting out of high school and getting into the real world you have to think about things more deeply than you think about them now."
  S3-"There are no teachers on your back, so you are going to have to think harder."
  S5-"Like the (labs) make you think harder and, like, do even more, not just write something down…and think about what you are doing."

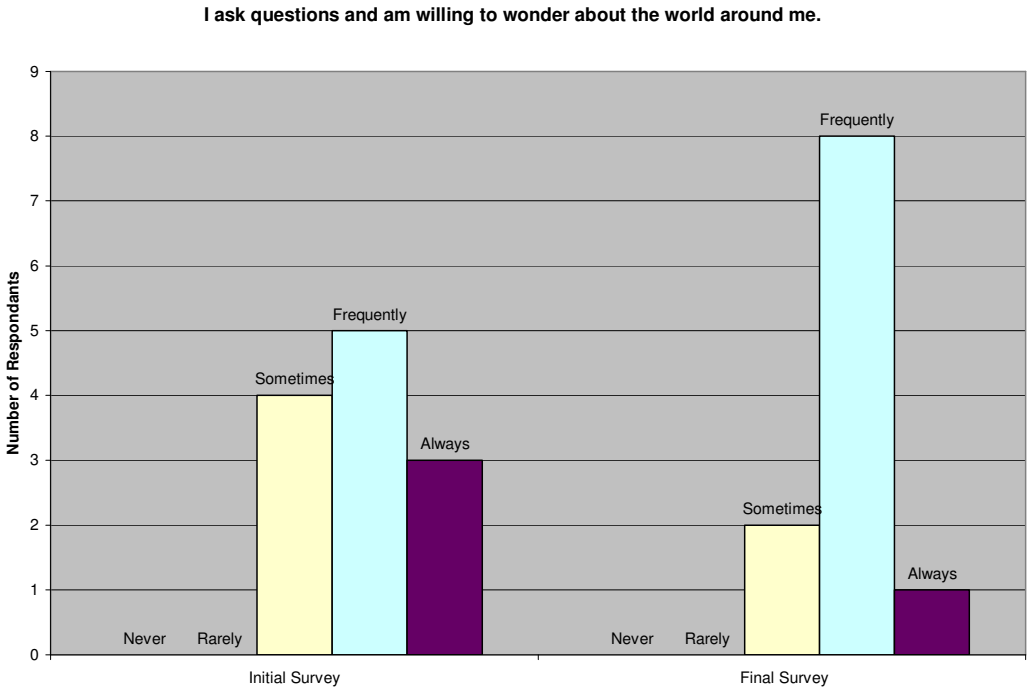
- After writing up six labs over the semester, how have you seen growth in your personal writing skills as it relates to deep critical thought?

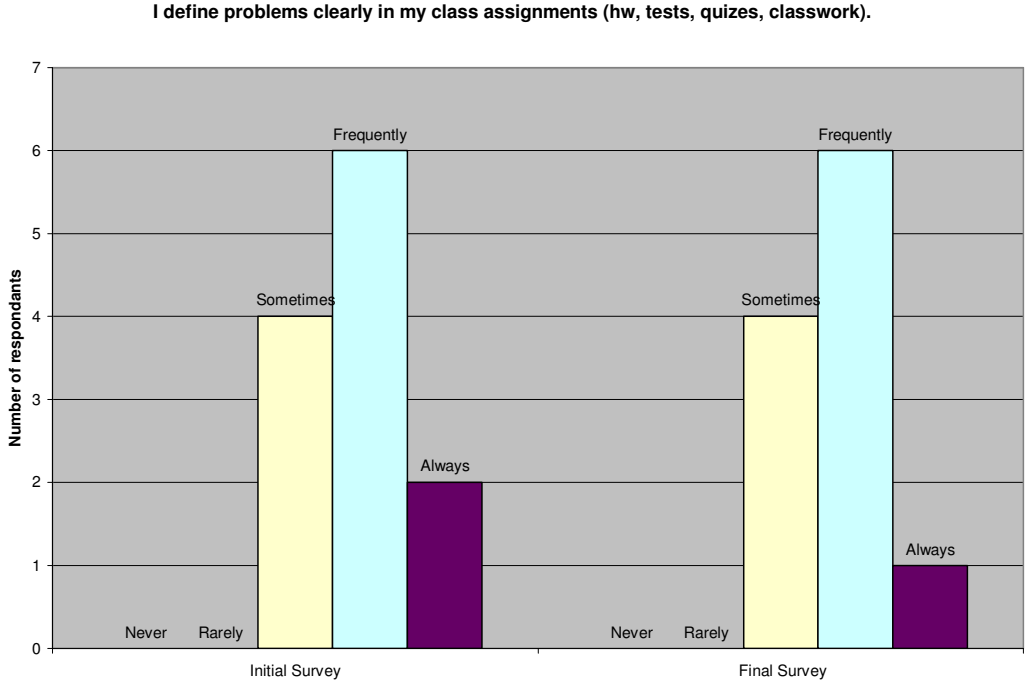
S1-"In my conclusions and stuff I put more into it. Like, overall what we do throughout the lab, anything that might have popped up that could be talked about. Instead or restating the beginning, I used to put the beginning basically but now I put everything."
S5-"I like putting deeper things and put what we are really talking about in the lab."
S3-"My conclusions have gotten better"
S4-I was going to say it is stronger because now I write more and before it was not as much."

- What parts of the lab reports have helped you with improving your writing skills?
  S3-"Conclusion, because anybody can say this happened in my lab, but the conclusion is supposed to say this happened because this happened and why that happened because this happened."
  S4-"The analysis because you can break down what you learned."
  S5-"Introduction because you want to have a good start to have a good finish [to the lab]."

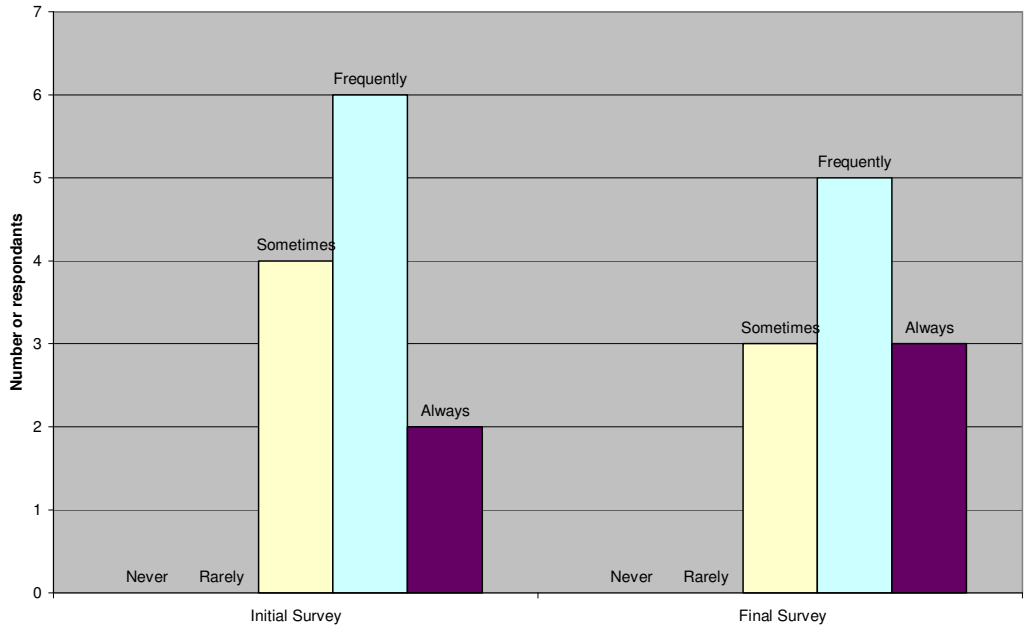
APPENDIX D

Critical thinking survey results

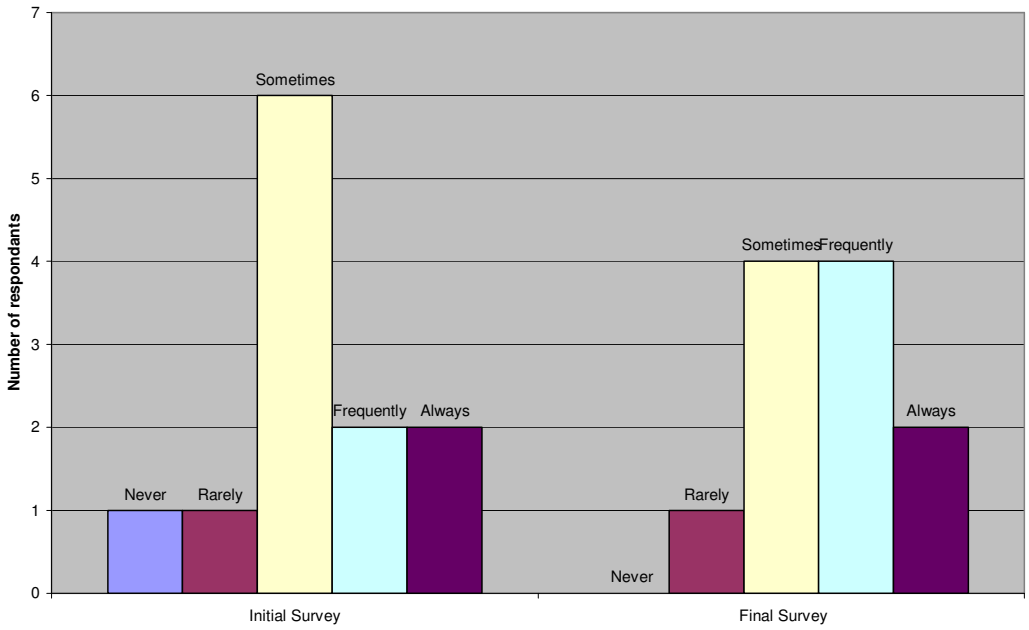




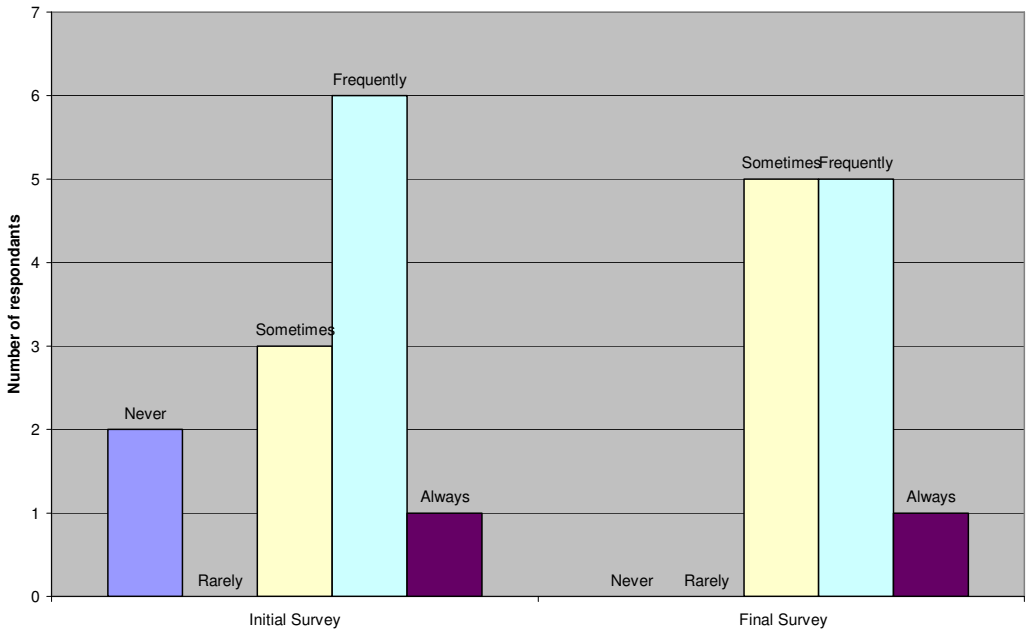
I carefully examine all the evidence before making an evaluation of a question.



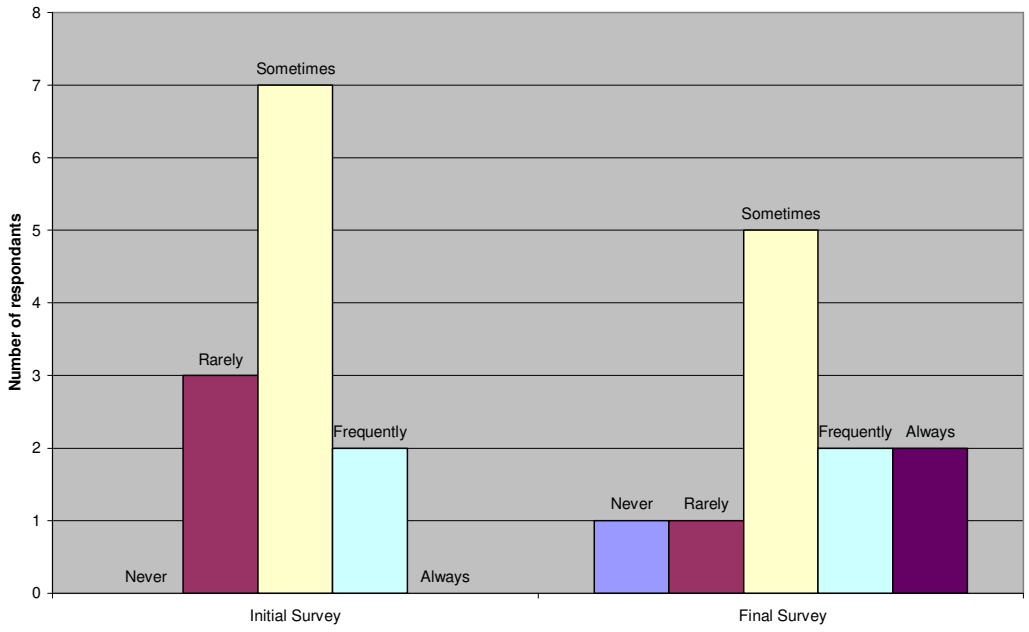
I analyze assumptions and biases (opinions) of myself and others.



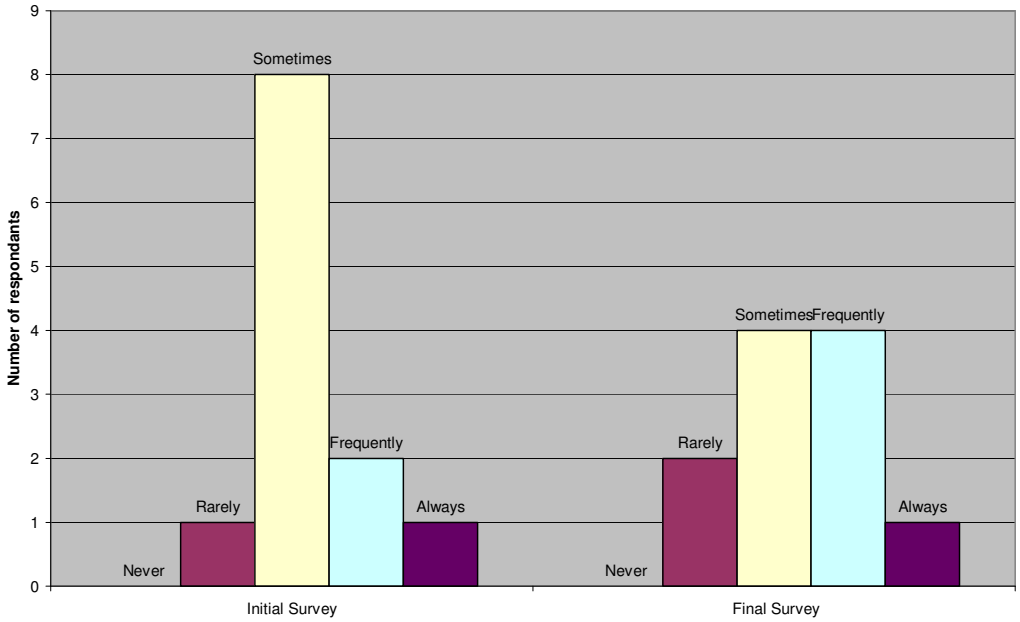
I avoid emotional reasoning when inserting an answer to a question.



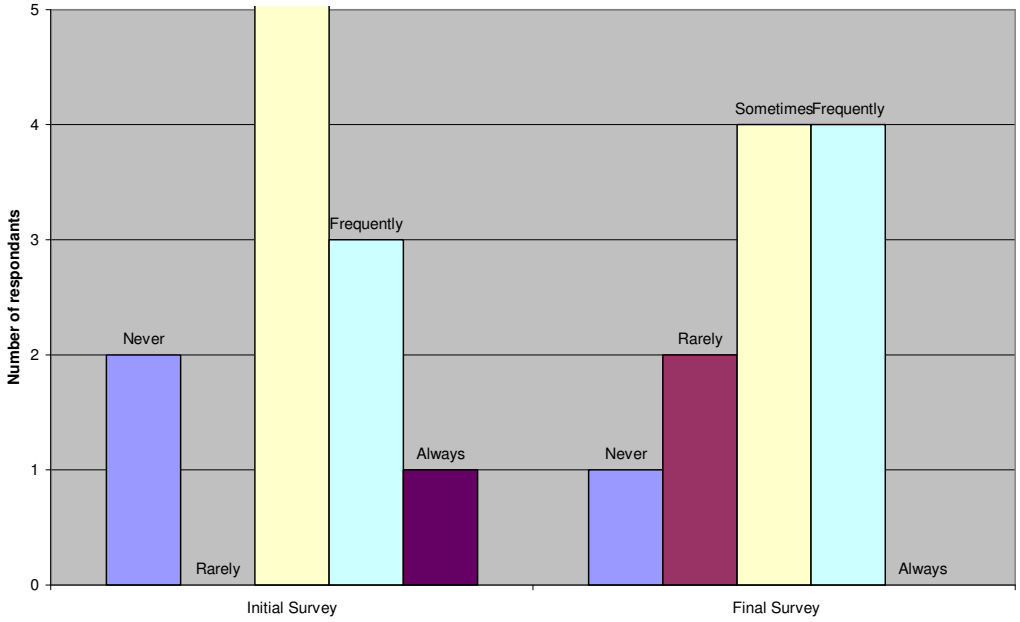
I avoid oversimplication of an answer.



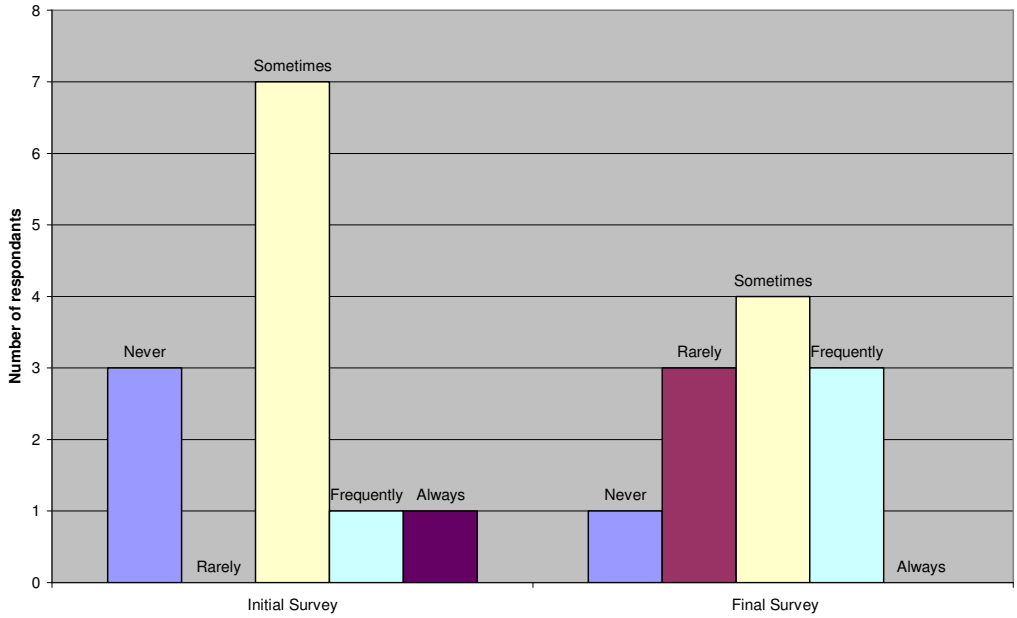
I consider alternative interpretations to questions posed.



I tolerate the uncertainty and failure of wrong answers of myself.



I tolerate the uncertainty and failure of wrong answers of other classmates.



APPENDIX E

Critical Thinking Role Play:
Naïve Nancy, Selfish Sam, and Fair-minded Fran

First meet Naive Nancy

Here is what she might say of herself (if she could clearly see how she uses thinking to deal with the world):

"I don't need to think! I understand everything without thinking. I just do whatever occurs to me to do. I believe most of what I hear. I believe most of what I see on TV. I don't see why I should question either. And I don't need to waste a lot of time trying to figure things out. Why should I, when someone will figure things out for me if I wait long enough. It's a lot easier to say "I can't!" than to do a lot of work. My parents and my teachers take care of me when I can't take care of myself. The other day I was having trouble with my math homework and started to cry, so my father did it for me. My parents give me a lot of help. It's easier that way. I do what I'm told, keep my mouth shut, and go along with whatever my friends decide. I don't like to make waves. Thinking gets you into trouble."

Next meet Selfish Sam.

Here is what he might say (if he could clearly see how he uses thinking to deal with the world):

"I think a lot! It helps me trick people and get what I want. I believe whatever I want to believe, whatever gets me what I want. I question anyone who asks me to do what I don't want to do. I figure out how to get around my parents. I figure out how to get other kids to do what I want them to do. I even figure out how to avoid thinking if I want. Sometimes I say "I can't!" when I know I could but don't want to. You can get what you want from people if you know how to manipulate them. Just the other night, I got to stay up till 11:00 by arguing with my mother about bedtime! It helps to tell people what they want to hear. Of course, sometimes what they want to hear isn't true, but that doesn't matter because you only get into trouble when you tell people what they don't want to hear. You can always trick people if you know how. Guess what, you can even trick yourself if you know how."

Next meet Fairminded Fran.

Here is what she might say (if she could clearly see how she uses thinking to deal with the world):

"I think a lot. It helps me to learn. It helps me to figure things out. I want to understand my parents and my playmates. In fact, I even want to understand myself and why I do things. Sometimes I do things that I don't understand. It's not easy trying to understand everyone and everything. Lots of people say one thing and do another. You can't always believe what people say. You can't believe a lot of what you see on TV. People often say things not because they mean them but because they want things and are trying to please you. I would like to make the world a better place. I want to make it better for everyone, not just for me and my friends.

To understand other people you have to look at things as they do. You have to understand their situation and what you would feel like if you were them. You have to put yourself in their shoes. The other night I got mad at my sister because she wanted to watch a TV program that was on at the same time my favorite show was on. I didn't want to let her until I realized that she needed to watch her program to do some homework for school. I knew then that it wouldn't be fair of me to insist on my show, since she did have to do her homework for school. It isn't easy to be fair. It's a lot easier to be selfish and just think about yourself. But if I don't think about others, why should they think about me? I want to be fair to others because I expect everyone to be fair to me."

Teacher notes:
Naive Nancy does not see much reason to think at all. She takes things as they come. She believes what she hears. She usually goes along with whatever her peers say. She intends no harm but also assumes that no one else is going to harm her. She is a ready victim for more sophisticated manipulators: adults or children. Naive Nancy will make a good student only insofar as thought is not required. She will literally, and thoughtlessly, do what she is told. She doesn't question or try to understand her own motives. She will make mistakes because she doesn't know how to listen closely and monitor what she hears for accuracy of interpretation.
Wherever mindless obedience succeeds, she will get by. What is more, much of the time her innocent "helplessness" will enable her to get others to do things for her. Rather than try to think her way through a difficulty, she is learning to say "I can't do it!" after the first or second try. She is finding out that she can usually get by without much thinking. Her innocent likeability and perpetual "incompetence" is both her strength and her (ultimate) downfall. Her only real thinking skills are in the art of being helpless, in enticing others to do her thinking for her.
Selfish Sam contrasts well with Naive Nancy. Sam values thinking. And the more he does it, the more he values it, but only in a special sense. He thinks to gain advantage, to get what he wants, to successfully put his desires above the rights and needs of others. To put it briefly, Sam is discovering the power of con-artistry. Sam is discovering that you can best get what you want by focusing clearly on your own desires, figuring out what is standing in the way of your interests, and manipulating others into acting in your interest. Selfish Sam is becoming an egocentric problem solver. He defines his problems so as to center them around getting what he wants for himself. Sometimes this means figuring out how to get out of work. But unlike Nancy, Sam is learning the power of figuring things out for himself.
He is also learning how to impress both adults and kids by what he can do. Eventually Sam will come to appreciate the power there is in groups, the advantages one gains by becoming a leader and exercising control over others. He will use his thought to win others to his side, to defeat his "enemies" (whoever he doesn't like), and extend his power and advantage over others. It isn't that he doesn't care at all about others, but rather that he cares only about those who serve him, those who are members of his group. Eventually, Sam could become an effective promoter of a vested interest, an excellent sales person, a politician, or a lawyer … any job that can "successfully" be performed without a well-developed sense of fair-mindedness.
Fair-minded Fran contrasts well with both Nancy and Sam. Like Sam, Fran is learning the power of thought. She is learning the value of figuring things out for herself. Unlike Nancy, she is not learning the art of "helplessness" because she is experiencing the pleasure and deep satisfaction that comes from successfully figuring things out for herself. She is discovering that she has a mind and can use it to solve problems, protect herself, do difficult jobs, learn complicated things, express herself well, and get along with others. But that is not all she's learning. She is also learning that other people have minds, other people have desires and needs, other people have rights, and other people have a different way of looking at things. She is learning how to enter into the thinking of others, how to see things from other people's point of view, how to learn from other people's perspective. She is beginning to notice the need to protect herself from the "Sam's" of the world. She is learning to test for herself what people say. She is learning to protect her interests without violating the rights of others.
Fran's thinking is beginning to develop a richness that Sam's will never develop (as long as he thinks selfishly), for she is learning how much one can learn from others. Eventually, Fran will gain many insights from the art of thinking within the perspective of others that she is developing. Fran's early thinking is laying the foundation for later breadth of vision. Fran's ability to think for herself in a skilled and fair-minded way will enable her to pursue any career goal that she later takes on. She will be highly valued by those who value justice and fair play. But she will also be treated with suspicion by the "true believers", by the people whose first allegiance is to a special group, to "our side". Those given to group think will come to recognize that you can't depend on Nancy to always support the "right" side (our side). She sometimes agrees with the enemy, the opposition, and the "other guys".
Foundation For Critical Thinking, Online at website: www.criticalthinking.org)

APPENDIX F

Bloom's Taxonomy Questioning

Bloom's Taxonomy provides a structured presentation of human cognition from low-level thought processes like simple recall to higher-order thinking skills like synthesis and evaluation. Bloom offers a "stair step" description of the levels of human understanding, with each new level building on previous levels. Bloom's taxonomy divides human cognition into five levels. The reading instructor can use these five levels to devise questions about reading selections that target higher-order thinking skills.

Recall questions require students to repeat or retell information. Recall involves remembering and reciting key facts, ideas, definitions, and rules. Drill and practice exercises are the most common form of recall questions.

Analysis involves separating the main ideas or components of a larger whole—that is, dividing a whole into its smaller parts. Students can then organize these smaller bits of data into "information clusters," related pieces that fit together to form the whole.

Comparison refers to noting the similarities and difference among the component parts. Comparison asks how the component parts are alike and how they are different.

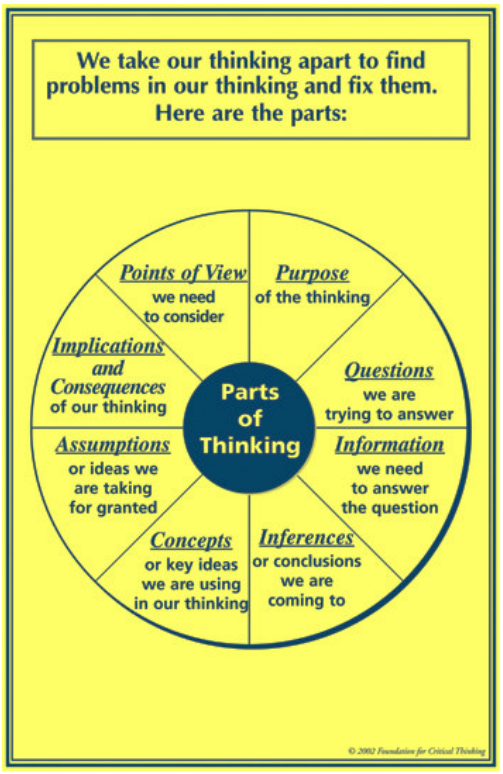
Inference means making predictions or generalizations through deductive or inductive reasoning.

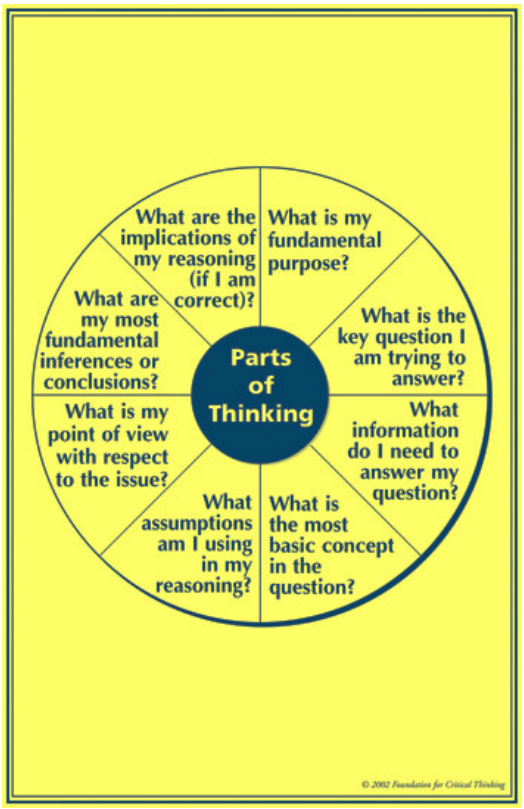
- Using deductive reasoning, students start with a general statement or principle and then explain how specific details relate to it. Deductive logic interprets supporting details through the main ideas.
- Using inductive reasoning, students investigate specific details in search of an underlying, unifying general principle. Common ideas or characteristics in the details allow students to generalize— to uncover the main idea.

Evaluation means reaching a conclusion supported by evidence. Students bring together their analyses, comparisons, and inferences to synthesize a conclusion.

Available at http://www.justreadnow.com/strategies/bloom.htm

APPENDIX G





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APPENDIX H

Universal Intellectual Standards

by Linda Elder and Richard Paul

Universal intellectual standards are standards which must be applied to thinking whenever one is interested in checking the quality of reasoning about a problem, issue, or situation. To think critically entails having command of these standards. To help students learn them, teachers should pose questions which probe student thinking, questions which hold students accountable for their thinking, questions which, through consistent use by the teacher in the classroom, become internalized by students as questions they need to ask themselves.

The ultimate goal, then, is for these questions to become infused in the thinking of students, forming part of their inner voice, which then guides them to better and better reasoning. While there are a number of universal standards, the following are the most significant:

1. **CLARITY:** Could you elaborate further on that point? Could you express that point in another way? Could you give me an illustration? Could you give me an example?
   Clarity is the gateway standard. If a statement is unclear, we cannot determine whether it is accurate or relevant. In fact, we cannot tell anything about it because we don't yet know what it is saying. For example, the question, "What can be done about the education system in America?" is unclear. In order to address the question adequately, we would need to have a clearer understanding of what the person asking the question is considering the "problem" to be. A clearer question might be "What can educators do to ensure that students learn the skills and abilities which help them function successfully on the job and in their daily decision-making?"
2. **ACCURACY:** Is that really true? How could we check that? How could we find out if that is true?
   A statement can be clear but not accurate, as in "Most dogs are over 300 pounds in weight."
3. **PRECISION:** Could you give more details? Could you be more specific?
   A statement can be both clear and accurate, but not precise, as in "Jack is overweight." (We don't know how overweight Jack is, one pound or 500 pounds.)
4. **RELEVANCE:** How is that connected to the question? How does that bear on the issue?
   A statement can be clear, accurate, and precise, but not relevant to the question at issue. For example, students often think that the amount of effort they put into a course should be used in raising their grade in a course. Often, however, the "effort" does not measure the quality of student learning, and *when this is so*, effort is irrelevant to their appropriate grade.
5. **DEPTH:** How does your answer address the complexities in the question? How are you taking into account the problems in the question? Is that dealing with the most significant factors?
   A statement can be clear, accurate, precise, and relevant, but superficial (that is, lack depth). For example, the statement "Just say No" which is often used to discourage children and teens fro using drugs, is clear, accurate, precise, and relevant. Nevertheless, it lacks depth because it treats an extremely complex issue, the pervasive problem of drug use among young people, superficially. It fails to deal with the complexities of the issue.
6. **BREADTH:** Do we need to consider another point of view? Is there another way to look at this question? What would this look like from a conservative standpoint? What would this look like from the point of view of...?
   A line of reasoning may be clear accurate, precise, relevant, and deep, but lack breadth (as in an argument from either the conservative or liberal standpoint which gets deeply into an issue, but only recognizes the insights of one side of the question.)
7. **LOGIC:** Does this really make sense? Does that follow from what you said? How does that follow? But before you implied this and now you are saying that; how can both be true?
   When we think, we bring a variety of thoughts together into some order. When the combination of thoughts are mutually supporting and make sense in combination, the thinking is "logical." When the combination is not mutually supporting, is contradictory in some sense, or does not "make sense," the combination is not logical.

Paul, R. and Elder, L. (June 1996). Foundation For Critical Thinking,
Online at website: www.criticalthinking.org

APPENDIX I

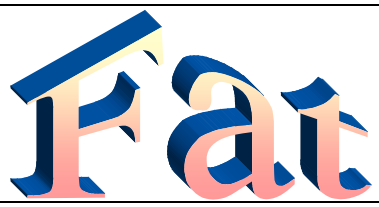
Valuable Intellectual Virtues

1. **Intellectual Humility**: Having a consciousness of the limits of one's knowledge, including a sensitivity to circumstances in which one's native egocentrism is likely to function self-deceptively; sensitivity to bias, prejudice and limitations of one's viewpoint. Intellectual humility depends on recognizing that one should not claim more than one actually knows. It does not imply spinelessness or submissiveness. It implies the lack of intellectual pretentiousness, boastfulness, or conceit, combined with insight into the logical foundations, or lack of such foundations, of one's beliefs.
2. **Intellectual Courage**: Having a consciousness of the need to face and fairly address ideas, beliefs or viewpoints toward which we have strong negative emotions and to which we have not given a serious hearing. This courage is connected with the recognition that ideas considered dangerous or absurd are sometimes rationally justified (in whole or in part) and that conclusions and beliefs inculcated in us are sometimes false or misleading. To determine for ourselves which is which, we must not passively and uncritically " accept" what we have " learned." Intellectual courage comes into play here, because inevitably we will come to see some truth in some ideas considered dangerous and absurd, and distortion or falsity in some ideas strongly held in our social group. We need courage to be true to our own thinking in such circumstances. The penalties for non-conformity can be severe.
3. **Intellectual Empathy**: Having a consciousness of the need to imaginatively put oneself in the place of others in order to genuinely understand them, which requires the consciousness of our egocentric tendency to identify truth with our immediate perceptions of long-standing thought or belief. This trait correlates with the ability to reconstruct accurately the viewpoints and reasoning of others and to reason from premises, assumptions, and ideas other than our own. This trait also correlates with the willingness to remember occasions when we were wrong in the past despite an intense conviction that we were right, and with the ability to imagine our being similarly deceived in a case-at-hand.
4. **Intellectual Integrity**: Recognition of the need to be true to one's own thinking; to be consistent in the intellectual standards one applies; to hold one's self to the same rigorous standards of evidence and proof to which one holds one's antagonists; to practice what one advocates for others; and to honestly admit discrepancies and inconsistencies in one's own thought and action.
5. **Intellectual Perseverance**: Having a consciousness of the need to use intellectual insights and truths in spite of difficulties, obstacles, and frustrations; firm adherence to rational principles despite the irrational opposition of others; a sense of the need to struggle with confusion and unsettled questions over an extended period of time to achieve deeper understanding or insight.
6. **Faith In Reason**: Confidence that, in the long run, one's own higher interests and those of humankind at large will be best served by giving the freest play to reason, by encouraging people to come to their own conclusions by developing their own rational faculties; faith that, with proper encouragement and cultivation, people can learn to think for themselves, to form rational viewpoints, draw reasonable conclusions, think coherently and logically, persuade each other by reason and become reasonable persons, despite the deep-seated obstacles in the native character of the human mind and in society as we know it.
7. **Fairmindedness**: Having a consciousness of the need to treat all viewpoints alike, without reference to one's own feelings or vested interests, or the feelings or vested interests of one's friends, community or nation; implies adherence to intellectual standards without reference to one's own advantage or the advantage of one's group.

Valuable Intellectual Virtues (June 1996). Foundation for Critical Thinking, Online at website: www.criticalthinking.org

APPENDIX J

Fat and Skinny Questions

	Skinny
Fat questions are those that require more thought than just giving a simple obvious answer or a yes/no answer. Fat questions often require expressing one' feelings and applying previous knowledge or experience in order to answer. Fat questions often trigger a lot of discussion, require time to be thought out, and may offer a variety of solutions. Samples: Can you think of a different way to test the reactivity of metals in the lab we just completed? If you could make an analogy to express why elements are stable with 8 electrons, what would it be and why?	Skinny questions are answered usually by a single right answer, a yes/no answer, or a simple gesture of yea or nay. Skinny questions do not usually initiate a lot of discussion and are generally answered by simple recall. Samples: Why Is a chlorine atom not stable with 7 valence electrons? When atoms are bonding, what is necessary for each atom to have?

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