

## **AC 2010-1278: INTRODUCING CRITICAL THINKING TO FRESHMAN ENGINEERING STUDENTS**

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# Introducing Critical Thinking to Freshman Engineering Students

## Abstract

In support of the University of Louisville's recent quality enhancement program (QEP) focused on critical thinking, the JB Speed School of Engineering is modifying selected core courses to include explicit discussion and/or assessment of discipline specific critical thinking. As a common course for all entering engineering students, ENGR 100 - *Introduction to Engineering* was the logical course to introduce critical thinking to engineering students and prepare them for the critical thinking demands they will experience in their future discipline specific courses and careers. This paper presents a discussion of approaches undertaken since 2008, in *Introduction to Engineering*, to introduce freshmen engineering students to critical thinking. Also presented are recent 2009 revisions to the components of the course, such as the reworking of the case studies in an effort to encourage students to demonstrate critical thinking. Explicit discussions with the students regarding the reasons for time and effort being spent on case studies and critical thinking were also added to the course. The number of critical thinking assignments was increased, expanded, and further clarified from the previous year and some assignments were also redesigned to allow for some peer reinforcement during intermediate stages. Statistical analysis of a pre and post assessment of critical thinking showed no statistical significant change in the students' critical thinking from the beginning to the end of the course. Based on written assignments and oral presentations, the instructors hypothesize that students did not grasp specific critical thinking concepts to the degree desired for the course. Possible modifications to the assessment and course are discussed in the conclusions.

## 1. Introduction

The Southern Association of Colleges and Schools (SACS) now requires all accredited schools to design and implement a quality enhancement program. In 2007, the University of Louisville adopted as its quality enhancement program (QEP) the requirement that all schools within the university, including the school of engineering, develop and implement an on-going and school wide program to "improving the critical thinking skills of undergraduate students and to more effectively prepare them to contribute to society"<sup>1</sup>. The JB Speed School of Engineering has developed its plan and made progress towards its implementation. The alignment of critical thinking improvement with ABET outcomes is also a motivating factor in the school of engineering's efforts to comply with the university's QEP. The recently introduced freshman experience course, *Introduction to Engineering*, is an important component of the plan and its implementation. As the required introductory class for incoming engineering students, the course is ideally suited to provide students with explicit critical thinking instruction. Critical thinking has been an explicit part of the instruction in *Introduction to Engineering* for three years and improvements continue to be made each year in how critical thinking instruction is made explicit. Assessment of the quality of critical thinking is also required by the schools plan and the university's QEP. The *Introduction to Engineering* courses includes explicit critical thinking assessment; but this has proved to be more difficult to implement. This paper describes improvements to the thinking instruction in *Introduction to Engineering* that have resulted from assessments from the previous years. Section two describes the school's overall critical thinking

program, how this relates to ABET outcomes, and the critical thinking goals of the *Introduction to Engineering* course. Section three describes the critical thinking instructional component of the *Introduction to Engineering* course, including changes made based on analysis of previous years implementation. Some conclusions and future directions for the ENGR 100 course are discussed in Section four.

## **2. A critical thinking agenda for the School of Engineering.**

The i2a initiative is a broad and comprehensive multi-year plan to improve the overall critical thinking abilities of students that spans general education courses, discipline specific courses, capstone projects, and community engagement<sup>1</sup>. Dr. Joe Hagerty, of the Civil Engineering Department, served on the original university task force. The result of Dr. Hagerty and other's efforts is that the Speed School of Engineering has experienced increasing support for the idea that although critical thinking is a mainstay of engineering education and is an integral part of all engineering courses, it has not been an explicit part of instruction, it has not been explicitly listed in course syllabi and that a school wide effort to improve the critical thinking of engineering students would be beneficial. Results reported by Cooney et al<sup>2</sup> show a similar disconnect between the amount of critical thinking experience engineering and technology faculty at IUPUI believed they were providing to students and the amount of critical thinking experience students perceived they were receiving. Cooney and colleagues, based on faculty anecdotes and examples of teaching and learning, concluded there was a clear disconnect between what teachers considered critical thinking and what students identified as critical thinking.

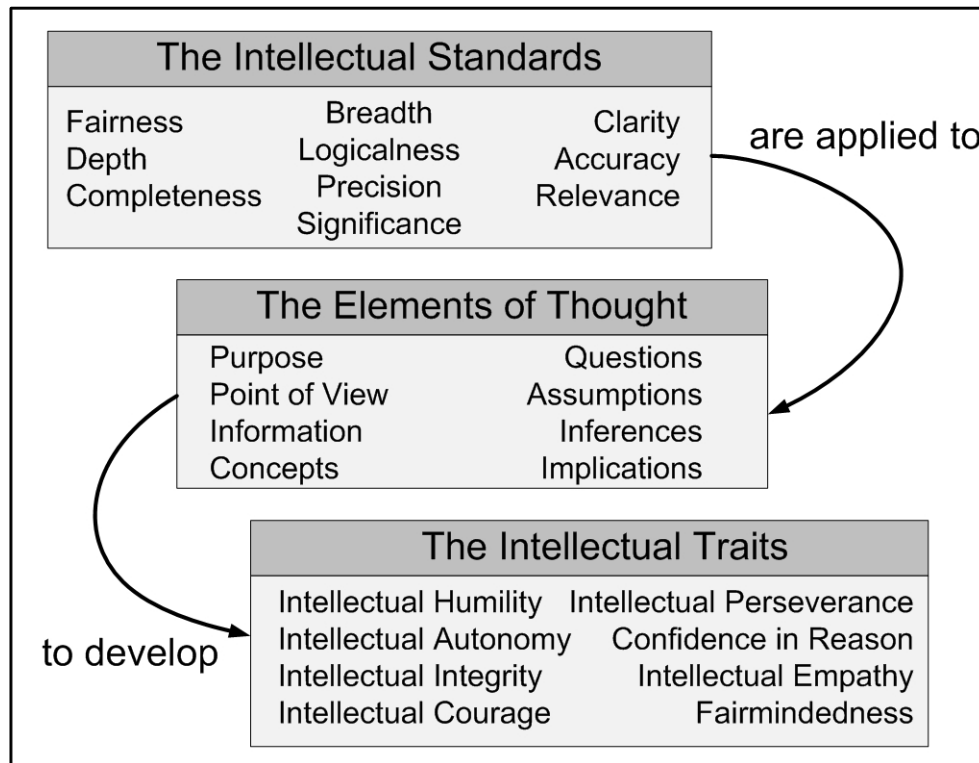
Critical thinking also supports meeting various ABET program outcomes. Specifically, developing critical thinking skills support developing the “broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context.”<sup>3</sup> Critical thinking also supports the ABET program outcome “a recognition of the need for, and ability to engage in, life-long learning”<sup>3</sup>. And finally critical thinking is an essential component of “the ability to identify, formulate, and solve engineering problems”<sup>3</sup>. Other schools have reached similar conclusions<sup>4</sup>.

### **2.1 The Paul-Elder Model of Critical Thinking**

The Paul-Elder model decomposes critical thinking into Standards, Elements, and Intellectual Traits, and imposes the following relationship on that decomposition: “the standards are applied to the elements as we learn to develop intellectual traits”. The purpose of the model is to aid in the analysis and evaluation of thought and to provide a common vocabulary for critical thinking. The model is shown in figure 2.1.

For students and instructors the model provides a common framework for defining and operationalizing critical thinking by defining eight elements of thought which capture how critical thinking examines, analyzes, and reflects on intellectual work. These eight elements lead to eight categories of questions present in critical thinking: (1) what is the purpose, (2) what is the question that is being answered, (3) what is the point of view, (4) what are the assumptions, (5) what are the implications, (6) what information is needed, (7) what inferences are being made, and (8) what is the most fundamental concept? The intellectual standards describe the

criteria used to evaluate the quality of the critical thinking and the intellectual traits are the characteristics associated with a mature critical thinker. For more information on the Paul-Elder model of critical thinking the reader is referred to The Miniature Guide to Critical Thinking Concepts & Tools, by Richard Paul and Linda Elder<sup>5</sup>. The School of Engineering is working to make this text universally available to students.



**Figure 2.1: The Paul-Elder model of critical thinking<sup>5</sup>.**

## 2.2 The role of *Introduction to Engineering* in Critical Thinking Education

While the Paul-Elder model may be widely known by critical thinking experts, it must be taught to students. It is intended that faculty adopt the language of the model when giving assignments, describing activities, and to weave it into their common vocabulary so that students begin to see that critical thinking cuts across disciplines. It is therefore important that students are explicitly taught the model as soon as possible in their educational careers. In the School of Engineering, *Introduction to Engineering* was the most logical place to begin teaching critical thinking, and to deliberately and explicitly explain the Paul-Elder model to students. Additional reasons for placing a heavy emphasis on critical thinking in *Introduction to Engineering* is our belief that:

- Critical thinking is a core engineering activity,
- Students need to learn early on to be aware of their thinking process,
- If students like to think, then they will like engineering.

*Introduction to Engineering* has several specific critical thinking goals. Students should be more conscious of critical thinking and its role in both their success as students, and in making decisions now and through-out their lives. A key goal is that students should be able to define critical thinking and should know and understand the Paul-Elder model of critical thinking.

After successfully completing the course, a student should be able to easily respond, with confidence, to the question: what is critical thinking? Also students should begin to be able to apply critical thinking standards to other's thinking as well as their own.

### **3. Critical thinking Instruction in *Introduction to Engineering***

A review by Cooney and colleagues<sup>2</sup> of recent educational literature identified two distinct themes when it came to developing critical thinking skills in engineering and technology students. Those two themes are writing for reflection and problem-based learning. Writing for reflection promotes critical thinking by having students digest given information, analyze the content and the thinking, think about their own thinking, and then articulate their thoughts and/or value judgments. Writing about open-ended problems is an approach to implementing writing for reflection, and in many cases rubrics and feedback are used to help students rewrite their reflections, pushing their cognitive function forward in response to the feedback. Another common implementation of reflective writing identified by Cooney et al. is to use writing as a tool to describe the design processes, or an aid to help think the design process through. Problem based learning is the other major critical thinking development theme seen by Cooney et al. Problem solving is central component in engineering and technology, and problem based learning is a natural progression for critical thinking instruction. The basic outline for problem based learning is:

- Students work in teams
- Teams are presented with a case study that includes an open ended problem
- Students determine the question to be answered and what information is needed
- Students gather necessary information
- As a team they discuss collected information, suggest and evaluate solutions, and present the team's conclusion.

A slightly different approach to developing critical thinking in engineering education is described by Sgro and Freeman<sup>6</sup>. They describe the use of the "Backward Design Process" or "Understanding by Design" process to cultivate higher-order thinking. The approach is a three part process, beginning with identifying the desired results, then determining what will count as evidence of that result, and finally developing the course to help students achieved the desired results. Central to this method is the idea that everything is not equally important, so in designing the course the instructor begins by asking: What is worth understanding? Answers to this question identify the "big ideas" in the course, the concepts that students should take with them. Next the instructor would ask: what would count as evidence of understanding? Answers to these questions will form the basis for the course. It is at this point that the method's strength with respect to critical thinking is seen. Evidence of understanding is much more than just recollection of facts, understanding requires, among other things, the ability to explain, interpret, and apply information and knowledge. Assessment is a significant challenge of this approach.

Writing for reflection, problem based learning, and the "Backward Design Process" all have merit when it comes to critical thinking in education, but none of them are explicit in their teaching of critical thinking, and they do not appear to define critical thinking to students or present students with a model of critical thinking. Therefore, in past years, the focus of critical

thinking instruction in *Introduction to Engineering* has been on the explicit instruction of the Paul-Elder model. The case studies, a major component of the course, have also included some implicit critical thinking instruction and activities. Based on both formal and informal assessment from previous years, and the above discussion on writing for reflection and problem based learning, some improvements to the critical thinking component of the course have been made. Section 3.1 discusses explicit critical thinking instruction, section 3.2 gives an overview of how critical thinking was implicitly woven into the case study portion of the class in previous years, and section 3.3 describes the improvements made to the class this past year.

### **3.1 Explicit Instruction and Activities**

The introductory presentation of critical thought is conducted with a class size of about 90 students in a time period of approximately 30 minutes. During this traditional lecture based instruction, students are introduced to the Paul-Elder model of critical thinking; the elements and standards of critical thought, shown in figure 2.2, are presented to the class. It is emphasized that during thinking, one needs to consider all the elements of thought and to apply the intellectual standards to the elements. As an example, it is pointed out that when thinking about something, a person needs information on the subject matter. Additionally, if they are to use this information, it must be clear to them and others who need to understand it. They also need to question if it is complete, fair, accurate and relevant to the purpose of the thinking. Then the elements and standards of thought are then shared as a potential template one can use to write, read, and assess technical (and other) documents<sup>7</sup>. The lecture is concluded with a discussion of a couple of stimulating and thought provoking questions. These are introduced as problems that should be addressed through the application of the Paul-Elder model. The students are asked to start to think about how they might approach arriving at a solution to the questions.

Following the lecture, students go to their respective breakout rooms, with about 30 students per room. During the breakout part of the class, there is a review of the Elements and Standards of Critical Thinking from the Paul-Elder model. Then students work individually on four or five problems that require some critical thinking (including the two questions that were introduced during the lecture portion of the class). Most of the problems are word problems with the solution involving setting up algebraic equations to describe the problem. Then, working in teams of four or five students an individual in the team is asked to explain their approach to the problem (method of analysis) and their solution to the rest of the team. This is followed by a group discussion to determine if other students understand and agree with the logic and math used in the solution. Students are then asked to comment on possible errors or present alternative solutions. As a conclusion, students are asked to discuss what elements of critical thought were important in solving the problem.

The breakout session concludes with the well known NASA “Lost on the Moon - Survival” problem. Each team of five students is asked to work together to reach consensus on the most important items needed for the scenario. Each individual creates their own prioritization and then shares this with their other team members. The students are encouraged to refer to the elements of critical thought (purpose, info, points of view and assumptions) as they prioritize the survival items. After discussion, students compare their individual answers with the team consensus. Finally, they compare their answers with the NASA official rankings and discuss

where they agree and disagree. Each team is asked to defend their rankings versus the NASA ranking. Each team is also asked to think about how they reached their conclusions and to re-evaluate once they see the NASA rankings.

### **3.2 Implicit Critical Thinking**

Case studies are used in the *Introduction to Engineering* course as a way for incoming students to experience and evaluate examples of various engineering activities. A major objective of the case studies is to expose students to some aspects of the modern practice of engineering, namely: teamwork, problem and data analysis, design creation, presentation and defense of a designed solution, and professional ethics. The *Introduction to Engineering* course is taken by all incoming students to the School of Engineering and the class is not separated by engineering discipline. Because of this diverse student population and potential interests, efforts are made to make the case study subjects as general as possible with detailed discipline specific technical analyses minimized. Generally, the case study work concentrates on the evaluative nature of engineering work such as identifying important variables in a problem, project assessment, and system analysis. Highly technical aspects of engineering such as detailed design, process development, and detailed analysis are avoided.

In their presentation of case study material, instructors model critical thinking to students. They use key words from the Paul-Elder model (without making explicit reference to the model) to help students fortify their understanding of critical thinking and become aware of the fundamental relationship between critical thinking and engineering. During case studies activities, students are provided an opportunity to evaluate their own thinking and determine if it incorporates the elements and standards of critical thought. For example, students are advised to review their papers to insure they contain the elements of critical thought and that all information, analysis and conclusions are presented clearly and logically and that all questions are completely answered. When presenting their own case study findings, instructors are presented with another opportunity to model their critical thinking to students. Finally, in the discussion following the instructor's presentation of his or her findings, students are encouraged to compare their critical thinking and analysis to another engineer or group of engineers. The case studies thereby reinforce the implicit critical thinking elements of the course; giving the students a chance to see and implement critical thinking as they work on the case study assignments and activities.

### **3.3 Improvements Made**

In this past year, improvements have been made in the critical thinking activities in *Introduction to Engineering*. There are two case studies in the course, one relates to a wastewater problem and the other to the collapse of a walkway at the Hyatt Regency Hotel. These case studies have undergone significant redesign with the expressed purpose to make them more effective at providing students with an opportunity to practice and develop their critical thinking skills. In addition, several new course activities have been introduced that are specifically designed to increase students' awareness of their thinking. These in-class activities are generally about one half of a class period and have the following character:

1. Require analysis and thinking (not simple math – plug and chug problem)

2. Contain a component of defending or explaining one's thinking (oral or written)
3. Involve a component of listening to others during the activity to arrive at an improved solution that incorporates multiple perspectives (individual work contributes to a team to improve solution)

### **3.3.1 Revamped Case Study 1 – Waste Water Process Development Case Study**

One improvement this year was to discuss with the students why time and effort was being spent on this particular case study. At the beginning of the case study, the important concepts and objectives of the case study were shared with the students and these concepts were associated with the specific class activities and assignments. In this way, the students were informed not only of what they were going to do, but why they were going to do each of the activities and how it pertained to an important aspect of the engineering profession. A case study overview was shared with the students. The overview summarized and connected the important concepts, learning objectives and graded assignments for the case study.

Another improvement that helped energize the students and invoke their creativity was to let them conduct their own research on potential solutions to the problem presented in this case study (open-ended problem). The problem presented in the study was a real life example of a typical open ended engineering problem, constrained by time, money and safety issues. In the past, we have supplied potential solutions to the students for them to research since the problem is somewhat complex and we did not want them to be frustrated by technical details they might not understand. The previous “led thought” type of approach generally resulted in the students reading the assigned materials with no personal engagement or thinking on their part. With a more open approach, the students seemed to take on the assignment at a more personal level and conduct research that they were interested in and had the technical ability to understand.

A third improvement was to give the students an opportunity to evaluate other student's work and have their own work evaluated by their peers. After conducting individual research for potential solutions to the case study problem, students summarized their research findings and recommendations in a paper. The individual papers were read aloud by the writers within each team (4 or 5 students on a team). As the papers were read, team members were asked to listen and evaluate the paper. This list of criteria was developed from the Paul-Elder model. After reading the papers, the team then discussed the papers, sharing thoughts not only about which solution among the team seemed to be the “best” solution but if they had enough information from the papers to reach a logically defensible conclusion on which solution they as a team could support. If more information was needed to reach a reasoned conclusion, the teams were expected to attempt to get more data or at least limit their conclusion based on existing data and reference any important missing information and assumptions in their thinking.

As part of the case study work, teams were asked to write a 1-2 page paper and to create a 10 minute presentation that conveyed to the rest of the class (about 35 students), the essence of the case study problem, approaches researched, team recommended solution and bases for the recommendation. The Critical Thinking rubric, listed in Appendix A, was discussed with the students and direction was given for them to evaluate their papers and presentations against the rubric to ensure their work incorporated evidence of high levels of critical thinking. This activity



provided students a chance to make an oral presentation and defend their teams thinking in solving this problem.

Students in the audience were encouraged to ask questions at the end of each presentation, so when they were a part of the audience, the students had an opportunity to listen to other teams' presentation and evaluate the thinking of other teams. After hearing other teams' thinking and potential solutions, the students were then challenged to reflect on their team's effort and analyze, what, if anything they would change or adjust based on hearing other information and perspectives. To complete their work on this case study, students then wrote a 1-2 page reflection paper which was assessed using the holistic rubric shown in Appendix A. For the purpose of critical thinking assessment, each paper was assigned a score of 1, 2, 3, or 4 based on the holistic rubric. Students were given a copy of the rubric as a guide.

### **3.3.2 Revamped Case Study 2**

This case study examines the actual failure of a skywalk at the Hyatt Regency Hotel in Kansas City<sup>8</sup> and was originally developed by Dr. Hagerty for use in ENGR100. This past year, Dr. Hagerty and Dr. McGinley of the Civil Engineering Department have provided invaluable help in improving this case study to better emphasize the importance of critical thinking in the engineering profession. In Case Study 2, as in Case Study 1, why time and effort were being spent on this case study was discussed with the students. An outline of class activities was provided to clarify for the students a complete picture of the nature of the work in this case study so that students clearly understood how each class activity and assignment was directly related to an important concept in practicing the engineering profession. Two major changes were introduced into the class activities related to this case study.

The first change was to educate the students in a more explicit manner about the roles and responsibilities that engineers take on in the design, fabrication and construction areas. Incoming students have almost no concept of the structure of engineering work, how it is accomplished and the importance of effective team work in engineering. In previous years with this case study, the students were asked to evaluate how this particular engineering disaster/failure occurred and who was most responsible for the failure. It was obvious from the student responses that complete and fair analysis of these questions was not possible due to their lack of information and understanding of how project work is performed. More specifically, students did not understand or were not aware of the roles and responsibility of engineers. By clarifying these roles and explicitly educating them on the role of the design, fabrication or construction engineer, it was expected that students would be able to engage in higher level critical thinking about this disaster.

This case study challenges the students' critical thinking skills by asking them to formulate an opinion and write a short paper answering the questions: "How did this failure occur?" and "Who was most responsible for this failure?" In the past, this assignment required the students to support the opinion with facts but no specific outline or structure was presented for the students to work against or compare with to make sure their work reflected sound critical thinking. This year, however, additional explicit instruction was given to the students to make sure that in creating this paper, all relevant elements of the Paul-Elder model of critical thinking

should be incorporated. It was also shared with the students that the grading of the opinion paper would be performed using the rubric in Appendix A.

The second major change in the case study was to include a mock hearing at the Professional Engineer Licensure Board. The goal of the hearing was to present and weigh the evidence regarding the Hyatt disaster and to come to a conclusion as to who was most responsible for the failure. In the hearing, students took on the roles of the various entities that had a part in the design, fabrication and construction of the Hyatt Hotel. As such, the students were challenged to create a defense argument using factual case history information that demonstrates that the entity they represent is not responsible for the disaster. In defense of their entity, the students created an opening statement for the defense, called up to three defense witnesses/experts and composed a defense closing summary statement. In addition to defense, students were allowed to cross-examine witnesses called by other defendants and prepared questions in advance. The aim of the cross-examination was for the students to identify and clarify weaknesses in the arguments and positions presented by other entities and to make sure information given was complete and accurate.

The overall purpose of this mock hearing was to engage the students in critical thinking and analysis in a fun and relevant manner. The first objective was to identify what technical error(s) occurred and then dig deeper and try to determine what system error(s) existed that allowed the technical error to go undetected. And finally, we want the students to analyze the case to determine what personal errors were made by the people involved in the case and who should be held most accountable in their opinion. The opinions are to be formulated based on complete and accurate information and logical reasoning.

#### **4. Conclusions and Future Directions**

Instructors of this course understand that students will not become excellent critical thinkers inside of a single course. However, it is possible that students become familiar with the Paul-Elder model of critical thinking and recognize its utility in helping them analyze and articulate their analysis of others thinking and their own thinking. Instructors have attempted to achieve this goal through explicit instruction of the Paul-Elder model, and through deliberate use of critical thinking language in activities and assignments.

Some increased engagement and enthusiasm, with respect to the case studies, was observed this past year. However, formal assessment of improvement in critical thinking has proved difficult. A pre assessment and post assessment were designed during the fall of 2008. These assessments have the same questions. The pre assessment was given prior to explicit instruction on the Paul-Elder model and critical thinking, the post assessment was given at the end of the course, and the assessments were not used in determining the students' grade in the course. Statistical analysis of the pre and post assessment scores showed no statistical difference between the students' performance on the pre assessment and post assessment; details are given in Appendix B. Instructors suspect that students have gained a limited understanding of the Paul-Elder model and that the pre and post assessment results are not completely reflective of what students have/have not learned. There are many possibilities that could be responsible for this outcome. One possibility is that students do not like problems where the answer is not directly obtainable

or if it involves deep thought<sup>10</sup>. Another possibility is the time allocated for the assessment was not sufficient for many students to solve the complex problems. One more obvious possibility is that students may not have given enough thought to the exercise, since it didn't affect their letter grade. There are other possibilities, but the instructors are considering revisions to the assessment. Some possible assessment revisions are increasing the number of questions, adding questions that are more specific to the Paul-Elder model, increasing the time the students are allowed, and incorporating the assessment into their course grade.

Based on written assignments and oral presentations, the instructors believe the students did not grasp the Paul-Elder model to the degree desired for the course. Possible course revisions to address this include: extending the explicit instruction of the Paul-Elder model, developing instruction to show application of the model in a deliberate fashion, evaluating the students' knowledge of the model, and creating/modifying specific assignments to allow students to apply the model. One specific modification the instructors are considering is to have students rewrite the case study reflective writing assignment based on holistic critical thinking rubric feedback, or construct the writing assignment by first explicitly answering the eight questions that come from the eight elements of thought as discussed in section 2.1.

Although assessing critical thinking and developing instruction for critical thinking and assignments to foster critical thinking has proved challenging, instructors still see value in the instruction of the Paul-Elder model. Developing critical thinking skills in students will serve students now and into their future.

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## Appendix A

University of Louisville  
JB Speed School of Engineering  
Holistic Critical Thinking Rubric

Consistently does all or most of the following:

<b>4</b>	Clearly identifies the purpose including all complexities of relevant questions. Provides accurate, complete and relevant information and evidence. Complete, fair presentation of all relevant assumptions and points of view. Clearly articulates significant, logical implications and consequences based on relevant evidence.
<b>3</b>	Clearly identifies the purpose including some complexities of relevant questions. Provides accurate, mostly complete information and some relevant evidence. Complete, fair presentation of some relevant assumptions and points of view. Clearly articulates some implications and consequences based on evidence.
<b>2</b>	Identifies the purpose including irrelevant and/or insufficient questions. Accurate but incomplete information and irrelevant evidence. Simplistic presentation that ignores relevant assumptions and points of view. Articulates insignificant or illogical implications and consequences that are not supported by evidence.
<b>1</b>	Unclear purpose that does not include questions. Inaccurate, incomplete information and irrelevant or no evidence. Incomplete presentation that ignores relevant assumptions and points of view. Fails to recognize or generates invalid implications and consequences based on irrelevant evidence.

## Appendix B Assessment of Critical Thinking

All data presented here is from the 390 students enrolled in the *Introduction to Engineering* who gave informed consent for their data to be used in research and the collection and the use of this data for this project has been reviewed by the University of Louisville's Institutional Review Board. All scores have been converted from their raw score to a percentage.

The pre and post assessment of critical thinking was given to the 390 students enrolled in the ENGR 100 course. This assessment was developed in collaboration with the University of Louisville's accreditation assessment specialist and the course instructors. There were discussions involving what aspects were desirable for the assessment. The assessment was constructed with three critical thinking related components:

1. Basic Knowledge
2. Application in Unique Situations
3. Perception Knowledge

The assessment was also developed with brevity being an important factor, due to a variety of factors. Some of the factors were limited resources, required course content, and the number of students enrolled in the course.

The pre/post assessments consist of five multiple choice questions, five Likert Scale ranking questions, and one open ended question. The following study is based on the multiple choice questions. All five multiple choice questions had four or five possible answers. Two questions pertained to the concept of critical thinking and asked the students to demonstrate their understanding of critical thinking and the Paul-Elder model. The other three were "puzzle" type questions that required the students to use critical thinking in order to solve these questions. The puzzle question answers were not obvious, but discoverable through using analytical thinking or logical reasoning.

The following mean scores are for the multiple choice section only. The mean for the pre assessment was lower than the post assessment (Table C.1), but the difference was not statistically significant ( $t=1.569$ ,  $df=227$ ,  $p=.118$ ).

**Table C.1: Mean Scores for Pre/Post Assessment**

	Mean	Std. Deviation	Std. Error Mean
Pre	51.04%	16.95296	1.19577
Post	53.23%	15.81107	1.11523

Finally, an ANOVA ( $F=0.73$ ,  $df=2$ ,  $p=.929$ ) showed that there was no statistical correlation between an improved score on the post assessment and the overall earned course letter grade.