AC 2009-1736: EXPLICIT TEACHING OF CRITICAL THINKING IN "INTRODUCTION TO ENGINEERING"

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Explicit Teaching of Critical Thinking in ENGR 100 - "Introduction to Engineering"

Abstract

In evaluating how the School of Engineering will meet the requirements of a recently launched, University wide, quality enhancement program (QEP), engineering faculty were questioned about the role of critical thinking in their teaching and in the profession of engineering. There was unanimous agreement that critical thinking is an important requirement to be successful in most engineering courses. However, there was general agreement that critical thinking was not an explicit component in course lectures, syllabi, or objectives. The assumption was that students understood critical thinking and its role in the practice of engineering. Subsequent interviews with incoming engineering students found a limited understanding of critical thinking. In an effort to help students become better critical thinkers and appreciate the importance of its practice throughout their education and careers, critical thinking and engineering reasoning are now explicit parts of the engineering school's recently introduced, "Introduction to Engineering" (ENGR 100) course.

To maintain consistency with the University's overall QEP, the Paul-Elder model of critical thinking is used to define and operationalize critical thinking. Critical thinking is now both an explicit and implicit component of the "Introduction to Engineering" course. One class meeting is dedicated entirely to the topic of critical thinking, and is organized around the Paul-Elder model. Following this presentation, students are given some critical thinking exercises. The course also includes a number of case studies where students explore engineering as an activity in greater detail. Using the language of the Paul-Elder model, the critical thinking or engineering reasoning in these case studies is made explicit to students during case study discussions. Students also participate in the analysis of the case studies, through team based exercises and assignments. These assignments include implicit critical thinking components. The critical thinking portion of the assignment helps reinforce the importance of engineering reasoning to the students. By making critical thinking an explicit outcome of the course, students will be better prepared to strengthen and enrich their critical thinking skills in future (upper level) courses.

To measure the outcome of the explicit critical thinking instruction in the course, students are given a pre-assessment and a post-assessment of their understanding of critical thinking and their ability to think critically. The pre-assessment occurs before any class meetings that are dedicated to the Paul-Elder Model and critical thinking. The post-assessment follows a critical thinking homework assignment and some case study discussions, allowing students time to improve and grow in their critical thought processes. It is expected that after introducing the model to the students and making the language and process clear to them, their post-assessment will show an improvement in their critical thinking. In the future, as students progress through the engineering program, periodic critical thinking assessments as part of the QEP will be done to track the impact of "Introduction to Engineering" on future critical thinking behavior.

1. Introduction

As part of the University of Louisville's effort to maintain quality teaching and learning and prepare students to meet the challenges they will face throughout their lives, a quality enhancement plan (QEP) was adopted in 2007. The QEP will also serve to fulfill part of the accreditation requirements made by SACS. The focus of the QEP is "on improving the critical thinking skills of undergraduate students and to more effectively prepare them to contribute to society" (QEP final report page 4). Implementation of the plan, called Ideas to Action (i2a), is a University wide, multi-year, ongoing effort to strengthen and improve how critical thinking skills are cultivated in undergraduate students. Each unit within the University is developing an implementation plan that includes a mix of course modifications, a culminating experience and targeted, critical thinking specific, assessment. The J.B. Speed School of Engineering is currently developing and implementing its i2a plan. One component of the implementation is to make critical thinking an explicit component and measured outcome of the Introduction to Engineering (ENGR-100) course which is required for all incoming freshman engineering students. Section 2 gives some background information on critical thinking, particularly in the education field and specifically engineering education. Section 3 takes a thorough look at the purpose, goals and implementation of the "Introduction to Engineering" (ENGR 100) course. Section 3 includes some samples from the critical thinking lectures as well as some assignment examples. Section 4 discusses the results from this past year's (2008) critical thinking pre and post assessments. Conclusions and the future direction for the ENGR 100 course are discussed in Section 5.

2. Critical Thinking

The term "critical thinking" is one with which most people are familiar, but is difficult to easily define, as shown in[1] where 89% of teachers interviewed claimed critical thinking to be an important education objective, but only 19% were able to give a clear explanation of critical thinking. One of the classic definitions of critical thinking comes from Robert Ennis: "Critical thinking is reasonable, reflective thinking that is focused on deciding what to believe or do"[2]. This definition does a good job of briefly capturing three key elements of critical thinking: reason, reflection, and judgment (or as Ennis puts it so well – "deciding what to do or believe"). The element of reason in critical thinking indicates that critical thinking must be logical and reasonable, not idiosyncratic and arbitrary. But as the definition indicates there is much more to critical thinking than just being logical, it is also reflective. Critical thinking is thinking about thinking, it is metacognitive. The combination of reflection and reason leads to the final element, belief (and or action). Critical thinking develops conclusions by reasoning out answers to questions and reflecting on the reasoning; the end result being belief, and in many cases action, based on those conclusions.

A slightly different definition of critical thinking is given by Michael Scriven and Richard Paul: "critical thinking is the intellectually disciplined process of actively and skillfully conceptualizing, applying, analyzing, synthesizing, and/or evaluating information gathered from, or generated by, observation, experience, reflection, reasoning, or communication, as a guide to

belief or action"[3]. An insight of this definition that is beneficial for educators is the phrase "intellectually disciplined process" which emphasizes that critical thinking is a formal process that students should learn about, acquire and develop as part of their formal education.

The complexity of defining critical thinking presents several challenges to both practitioners of critical thinking, and those who might wish to teach critical thinking: (1) the difficulty for different individuals (instructors), in different disciplines, to describe and discuss critical thinking and have a third party (students) readily correlate and consolidate those discussions, (2) clearly stating expectations about what constitutes good critical thinking, (3) objectively assessing the quality of someone's (student) critical thinking (as opposed to "I know it when I see it").

A model of critical thinking, by providing a common vocabulary and conceptual constructs can help address these challenges. The Paul-Elder model of critical thinking[4] is the model adopted by the University of Louisville for the i2a initiative. The model was chosen because it has a formal structure and is a discipline neutral model. There are other models, but describing them is beyond the scope of this paper.

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 aide in the analysis and evaluation of thought and to provide a common vocabulary for critical thinking. The model is shown in figure 2.1.

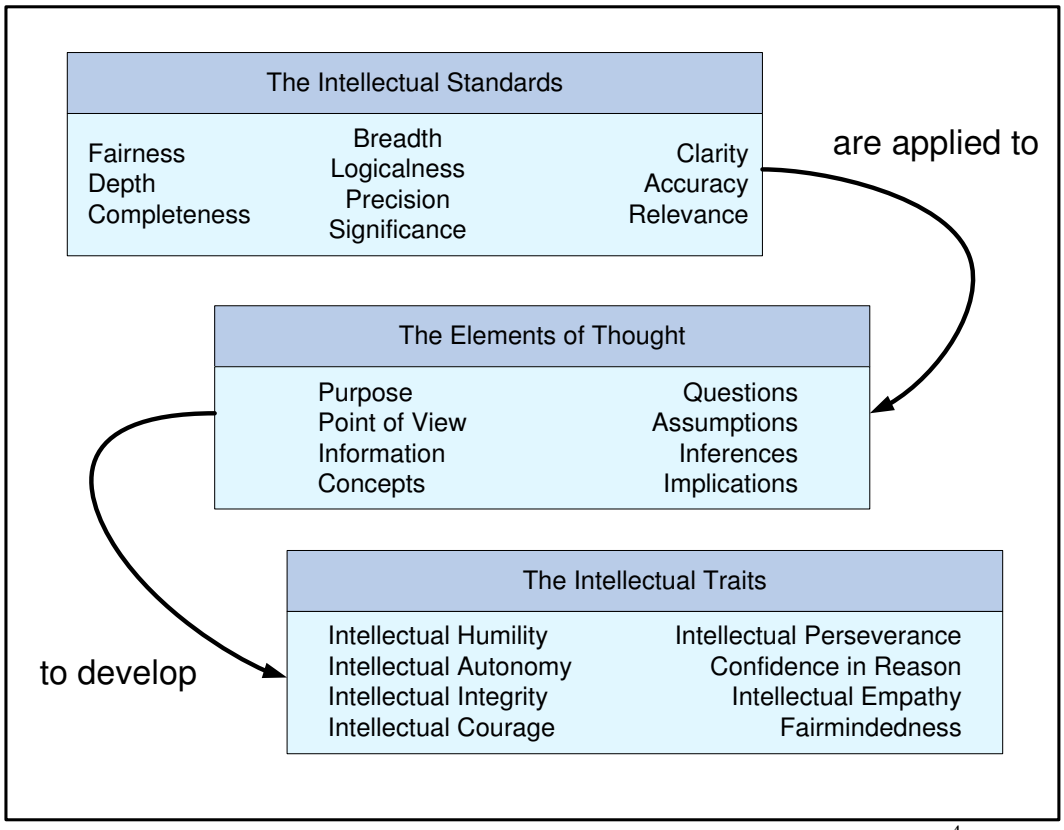

Figure 2.1 The Paul-Elder model of critical thinking, adapted from[4].

For students and instructors the model operationalizes 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 point of view, (3) what are the assumptions, (4) what are the implications, (5) what information is needed, (6) what inferences are being made, (7) what is the most fundamental concept, and (8) what is the question that is being answered? 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.

2.2 Critical Thinking in Engineering Education

The ability to think critically is an important skill for practicing engineers and critical thinking is in line with ABET's standards. Specifically, critical thinking skills indicate that engineering students have "the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and social context." Critical thinking also supports the ABET outcome "a recognition of the need for, and ability to engage in, life-long learning". And finally the ABET outcome "the ability to identify, formulate, and solve engineering problems" required critical thinking skills. The questions we must ask as engineering educators is then:

- How are we teaching/developing critical thinking in our students?
- Are students aware they are learning critical thinking skills?
- Are they aware that they are supposed to be developing critical thinking skills?

Faculty emphasis on critical thinking was investigated in a study by Richard Paul. The study included 38 public colleges and 28 private colleges and included both education faculty and subject matter faculty. In the study 140 faculty were given both closed-ended and open-ended questions. 89% of the respondents claimed that critical thinking was a primary objective their instruction, but only 9% were clearly teaching for critical thinking on a typical day in class[1]. 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 was reported by Cooney et al[5]. Cooney and colleagues, based on faculty anecdotes and example of teaching and learning, concluded there was a clear disconnect between what teachers considered critical thinking and what students identified as critical thinking.

In preparing and developing the J.B. Speed School of Engineering's i2a plan, the engineering faculty members were questioned about the role of critical thinking in their teaching and in the profession of engineering. Responses were similar to those described above: critical thinking is an important component of engineering courses and the engineering profession, but it is not an explicit component in many courses' lectures and syllabi. It seemed that faculty typically assumed that students knew and understood critical thinking. However, interviews with incoming freshman engineering students found a limited understanding of critical thinking.

A review by Cooney and colleagues[5] 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 a 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[6]. They describe the use of the "Backward Design Process" or Understanding by Design process to cultivate higher-order thinking. The approach is a three step 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 achieve 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? It is at this point that the method's strength with respect to critical thinking can be seen. Evidence of understanding is much more that just recollection of facts, understanding requires, among other things, the ability to explain, interpret, and apply information and knowledge. Finally, the instructor asks what learning experiences and teaching approaches will promote understanding, answers to these questions will form the basis for the course.

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.

3. Introduction to Engineering (ENGR 100) with Critical Thinking

The "Introduction to Engineering" course, ENGR 100, was introduced into the J.B. Speed School of Engineering's curriculum beginning in the 2006-2007 academic year. It is a two hour course required for all freshman engineering students. The goals of the course are many and varied. In part the course serves as an orientation course for freshman, orienting them to college life, assisting with the transition from high school to college and making sure they are aware of all of the campus resources. In its capacity as an introductory course for incoming engineering students, the course exposes students to all of the engineering disciplines taught at Speed School. It also increases their understanding of what engineers do, familiarizes them with engineering design, ethics, professionalism, and some select software they will use in their engineering coursework.

The course was redesigned in 2007, at the same time the Speed School was developing its i2a plan. It was decided at that time, the course design should include an emphasis on the students' development of critical thinking skills. The fundamental premise being that with better critical thinking skills, the students will be more prepared to tackle the adjustment to college life and college work. Additionally, in order for students to become truly aware of the engineering profession, they must understand, recognize and be able to implement critical thinking. Critical problem analysis and critical thought are at the core of engineering activities. Critical thinking is incorporated through four ways: 1) through an explicit lecture on critical thinking, using the Paul-Elder model as guide to defining and understanding critical thinking, 2) through critical thinking breakout session which follows the critical thinking lecture, 3) a specific critical thinking assignment, and 4) through case study discussions where the course leader draws attention to critical thinking (or lack of) done by engineers in specific cases.

In the fall of 2008, a pre and post general critical thinking assessment was added to the course. The goal of this activity was to gauge the impact, if any, of the critical thinking emphasis in the course. This is not considered part of the instruction of critical thinking, but will serve as a tool

to evaluate the state of incoming freshmen's critical thinking skills and measure how well the explicit and implicit critical thinking instruction is working.

3.1 Lecture/Presentation portion of Critical Thinking

The introductory presentation of critical thought is conducted with a class size of about 90 students in a time period of approximately 30 minutes. The outline for the introductory lecture is below:

- Introduce the concept of critical thinking
- Formal definition of critical thinking (Paul-Elder Model)
- Discussion of Critical Thought (in terms of the model)
- Application of critical thinking to assessing and/or writing an Engineering Document
- Bloom's Taxonomy : Levels of thought
- An example using Bloom's Taxonomy
- Some motivating current or relevant challenge problems.

The lecture begins with a general discussion of how people think and how they reach conclusions in their thinking. This is followed with the definition, shown below, of critical thinking that has been adopted at the university. The definition is parsed and discussed, concentrating on the idea that critical thought involves thinking about information in a well defined, logical manner so that actionable and justified conclusions are reached.

> "Critical thinking is the intellectually disciplined process of actively and skillfully conceptualizing, applying, analyzing, synthesizing, and/or evaluating information gathered from, or generated by, observation, experience, reflection, reasoning, or communication, as a guide to belief and action."--Ideas to Action, UL

Students are introduced to the Paul-Elder model of critical thinking, and the elements and standards of critical thought, shown in figure 2.1, are presented to the class. It is emphasized that during thinking, one needs to include all elements of thought and needs to apply the intellectual standards to each element to be sure it is sufficient to be used as a part of one's thinking process. 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 our 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[7]. The following slide (Figure 3.1) is used to frame this discussion.

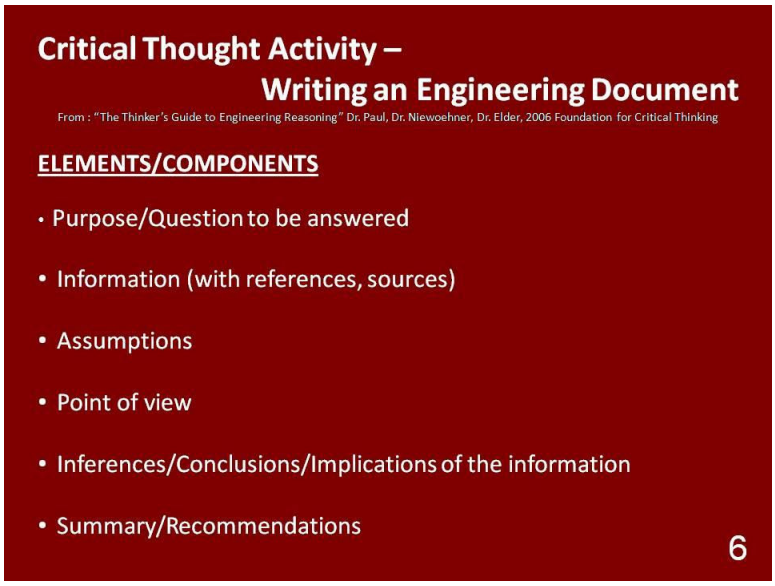

Figure 3.1: Critical Thinking Discussion Prompt from Lecture Presentation

To encourage students to develop a well-rounded understanding of the human thought process, a brief introduction to Bloom's Levels of Thought is juxtaposed with the Paul-Elder model at this point. A benefit of this approach is the ease with which Bloom's model can be exemplified. A concrete example involving various levels of engineering analysis and thought is presented to students. The mechanical engineering example, used this past year, is shown in Figure 3.2.

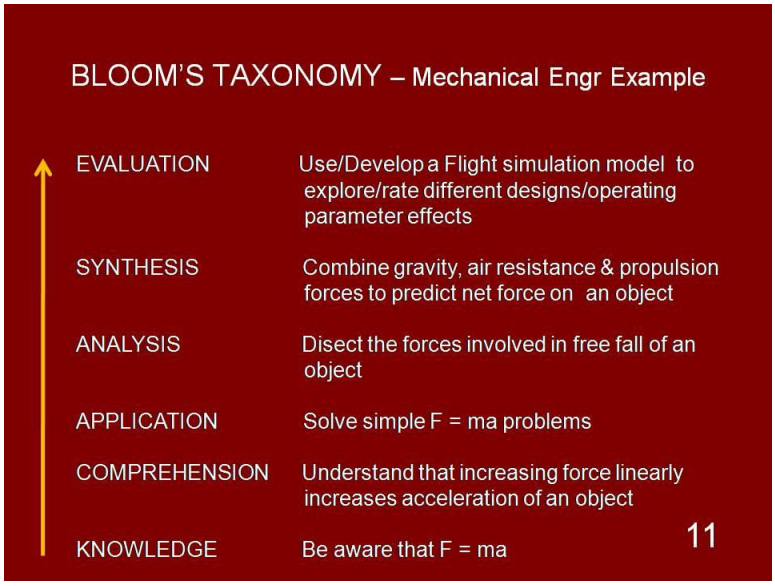

Figure 3.2: Mechanical Engineering example using Bloom's Taxonomy

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 critical thought elements. For example this is one of the challenge problems from this past year:

> If the gap between the basketball and the tape is equal all around the circumference of the ball, and the gap between the earth and the tape also is equal all around the circumference of the earth, how much larger is the gap around the ball than the gap around the earth? Assume the earth is a perfect sphere.

The students are asked to start to think about how they might approach arriving at a solution to the questions. Before beginning the breakout portion of the class, a final slide attempts to convey to the students the importance of applying critical thought.

Figure 3.3: Concluding slide from lecture on critical thinking.

3.2. Critical Thinking Breakout Session

The breakout portion of the class is conducted in groups of about thirty students, subdivided into teams of four or five members. At the beginning of the breakout session, 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 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. After each problem, 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 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.

In the next section of the breakout session, a mini-case study of a civil engineering type problem is discussed. In this past year's class, the problem description was as follows:

> A house in the path of new road construction was condemned and purchased by the state. The house was then sold at auction. The new owner moved the

house out of the path of the new road to a nearby property. Blasting for the new road construction occurred. The house now shows some signs of damage.

Photos of exterior of house (brickwork, stairs, windows, patio, porch and sidewalk) are shown to the students. Students are asked to work in teams to answer the following questions:

- What has happened?
- Did blasting cause the damage?
- What is the basis for your opinion?

The students are prompted to organize their thinking using the elements of thought:

- What is the purpose of thinking/question to be answered? (Is is clear?)
- What information do you have? (relevant, complete, clear and accurate).
- Any assumptions made in your thinking?
- Analyzed data from all points of view?
- What conclusions (clear, how accurate, completely answer)?
- Are there any inferences or recommendations to be made? (Should assumptions be verified, need to gather more information or need to check accuracy of information?)

Each team discusses the problem and attempts to reach a consensus. After reaching a consensus, the team presents their analysis and conclusions to the class. Everyone is asked to listen to what others have concluded and the reasoning of how they reached their conclusions.

The breakout session concludes with the well known NASA "Lost on the Moon - Survival" problem. A team of five students is asked to work together to reach consensus on the most important items needed to reach a rendezvous point for survival. 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. The students compare their individual answers with the team consensus after discussion. 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 reevaluate once they see the NASA rankings.

3.3 A Specific Critical Thinking Assignment

After the critical thinking lecture and breakout session, the students are assigned a reading taken from a newspaper editorial page. The subject is chosen with the intention that it be relevant and of interest to students. This past year the subject of the reading was an editorial related to the safety issue of cell phone use while driving a car[8]. The editorial is listed in its entirety in Appendix A. The editorial argued that use of cell phones while driving should be banned by law. After reading the editorial, students were asked to assess the expressed opinion against the elements and standards of critical thought. The students were given a quiz regarding elements of

critical thought and the presence or absence of the elements in the editorial. There are a total of 8 questions, six pertained directly to the editorial and two were more about critical thinking in general. The quiz questions are listed in Appendix B; the results are given in Section 4 and discussed in Section 5.

3.4 Critical Thinking in ENGR 100 Case Studies

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/Data Analysis, Solution/Design creation. 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. At the university, there are seven engineering disciplines available for study – Chemical, Civil and Environmental, Computer Engineering and Computer Science, Electrical and Computer, Industrial, Bio-Engineering and Mechanical. 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.

Case studies are organized as portions of three or four class periods. In the first class period, a presentation/lecture introduces the case study giving the historical and background information concerning the subject. During this first class session, the main objectives of the case study work are introduced. The objectives can consist of creating an engineering document such as a process development basic data report or to answer questions pertinent to the case study, such as, "Who is most responsible for the failure?". The second class of the case study begins with a lecture giving a little more information and insight regarding the case. The class then breaks into individual teams. Each team then discusses the information gathered by each team member and, using the compiled information, completes the main objective of the case study, typically a one page document answering the main questions posed in the objective of the case study. In the third class period a presentation is made of the instructor's findings and conclusions regarding the case study. Here, the instructors can model their own critical thinking for students. After the presentation, students are encouraged to question and debate any differences or discrepancies with their own findings and conclusions. The aim is for the students to be able to compare their critical thinking and analysis versus another engineer or group of engineers. For more technically complex case studies, these activities are spread across four class meetings instead of three.

Critical thinking is an implicit and explicit part of the case study component of the course. In their presentation of case study material, instructors model critical thinking to students. They use key words from the Paul-Elder model (without make 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 that follows the instructor's presentation of his or her findings, students are being 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 discussed earlier; giving the students a chance to see and implement critical thinking as they work on the case study assignments and activities.

3.5 Pre and post Critical thinking assessment

As previously mentioned, this past year a pre and post assessment of critical thinking was added to the ENGR 100 course. The assessment was designed with engineering students in mind. The assessment consisted of five multiple choice questions, and five Likert Scale ranking questions and one open ended question. Only the multiple choice questions are relevant for this paper. The five multiple choice questions had two themes. Two of the multiple choice questions pertained to the concept of critical thinking, asking students to demonstrate their understanding of critical thinking. A listing of the assessment questions is available in Appendix C. For example, one of the questions was:

> Aspects of critical thinking involve all of the following <u>EXCEPT</u>:
>
> a. Critical judgments
> b. Elements of reasoning
> c. Essential intellectual traits
> d. Universal intellectual standards

Three additional multiple choice questions required students to do some critical thinking. These were "puzzle" type questions where the answer was not obvious, but discoverable through the application of some analytical thinking or logical reasoning. Students needed to pick the correct question from among five possible answers. An example of one of these questions is:

> A man buys 9 gallons of paint. He can only carry 2 at a time to the car. How many trips from the store to the car does he have to make?
>
> a. 4.5 trips
> b. 5 trips
> c. 9 trips
> d. 10 trips

The same questions were given to students twice, once before any of the explicit critical thinking instruction, specifically the lecture on critical thinking and the Paul-Elder model, and once after the second case study. The assessment was not used in determining the students' grade in the course. However, a small number of extra credit points were assigned to encourage students to take the assessment seriously.

There were several goals for administration of the pre/post assessment component. First and foremost the assessment would provide some indication of the effectiveness of the explicit lecture component and presentation of the Paul-Elder model on students' understanding of critical thinking. The first two multiple choice questions specifically addressed this by asking students to associate presented vocabulary with critical thinking. The second goal was to determine the effect on students' behavior, that is, did they exhibit better critical thinking. Specifically, did students show improvement on the multiple choice questions that required critical thinking.

4. Critical Thinking Assignments/Assessments Results

All data presented here is from students 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's Institutional Review Board. For the critical thinking assignment, discussed in Section 3.3 and administered after the critical thinking lecture and breakout session, the average score was 80.13%. More than 90% of students answered questions one through three correctly. By far question 4 was the questions most students answered incorrectly. Table 4.1 shows the percentage of correct answers for each question. The newspaper opinion/editorial[8] can be found in Appendix A and the assignment questions in Appendix B.

Table 4.1 Results of Critical Thinking Assignment

Question	Percentage of students who answered correctly.
Question 1	90.19%
Question 2	90.19%
Question 3	97.38%
Question 4	60.13%
Question 5	81.04%
Question 6	75.16%
Question 7	83.00%
Question 8	70.58%

For the pre and post assessment no statistical difference between the pre assessment and post assessment of the multiple choice questions was observed ($t=0.075$, $df=145$, $p>0.05$). The average score for both the pre and post assessments was 48%. There were two question on which an overwhelming majority of students answered incorrectly, question one and question three. The assessment questions are available in Appendix C.

5. Conclusions and Future Directions

The newness both of this course and the attempt to include explicit and implicit critical thinking instruction are reason to expect mixed results as far as the effectiveness of the course in improving the critical thinking skills of students. Based on their experience during the semester, the instructors of this course continue to see the explicit teaching of critical thinking as beneficial and needed. Many students do not necessarily exhibit a complete lack of critical thinking ability, but neither do they have a firm grasp on what critical thinking is or how to think critically.

Based on the results presented in Section 4, there is plenty of room for improvement, and the instructors are committed to making such improvements.

For the critical thinking assignment, the students performed the best on the questions regarding the more concrete Elements of Thought. Questions one, two and three focus almost entirely on the purpose, the question at hand, and the author's point of view, and over 90% students answered these question correctly. By contrast, question four required the students to separate fact from opinion and this proved to be more difficult for them.

The results from the pre and post assessments showed no difference statistically or numerically. There are many possibilities that could be responsible for this outcome. The first possibility is the students didn't take the assessments seriously enough since they were only being used as extra credit. It is also possible that the lecture regarding Critical Thinking and the Paul-Elder model needs to be modified with the goal of helping the students improve their critical thinking. Yet, another possibility could be that students' mental models change slowly. As Bain[9] mentions, students do not always like problems where the answer is either not directly obtainable or involves deep thought to determine what parts are necessary. The assessment may need modifications to determine if it is truly testing what the instructors think it is testing. Since ENGR 100 is only offered to students in the fall, there is time to make changes in the course design or in the assessment.

It is important to acknowledge that these assessments reflect the instructors' best efforts, but may not be effectively measuring the desired critical thinking abilities or understanding. These are not "proven" instruments, and therefore complete confidence in their results would be a mistake.

Finally, the instructors realize that teaching students to be critical thinkers will not occur in a single course, but it is their hope that the ENGR 100 course will provide a solid foundation on which they can continue to develop their critical thinking skills. Since the i2a initiative emphasizes critical thinking, the students should be exposed to more critical thinking opportunities as they progress towards graduation. Improved development of critical thinking skills, assuming it occurs, should produce better engineers.

In Section 5.1 some of the currently planned revisions are discussed. Section 5.2 addresses how the students will have follow-up assessments to track their progression towards graduation. It is the hope of the Speed School of Engineering that the follow-up assessments show an increase in critical thinking skills.

5.1 Planned course revisions

The ENGR 100 course is currently going through a comprehensive curriculum (syllabus, assignments and evaluation) and assessment revision. The goal of this revision project is to explicitly include the Paul-Elder model of Critical Thinking throughout the course. This revision is supported by the department and has been awarded a Supporting Undergraduate iNnovation (SUN) grant. Due to the ongoing nature of this revision, some planned parts are vague to allow the instructors some leeway in the direction that their taken.

One key element in the design and layout of ENGR 100 is the emphasis on the students' development of critical thinking skills. The fundamental premise is that with critical thinking skills, the student will be more prepared to tackle the adjustment to college life and college work. Additionally, in order for students to become truly aware of the engineering profession, they must understand, recognize and be able to implement critical thinking. Critical problem analysis and critical thought are at the core of most engineering activities. Therefore, the purpose of many of the classroom experiences and homework assignments is to put the student in the role of the engineer, letting them evaluate the problem, critically think and then recommend solutions with a clear and logical defense of their proposed solutions.

With this explicit inclusion of the intellectual standards and the elements of thought from the Paul-Elder model in class room meetings as well as the curriculum, it is expected that the students will become more conscious of their thinking as well as the thinking processes of others. By providing explicit feedback on assignments based on the Paul-Elder model, it is the faculties' hope that the students will become aware of areas for their improvement in critical thinking. It is also expected that students' ability to communicate and critically analyze material will significantly improve.

As previously discussed, some of the assignments in ENGR 100 are case studies. These case studies allow students to explore engineering as an activity in greater detail. Using the language of the Paul-Elder model, the critical thinking or engineering reasoning in these case studies will be made explicit (or at least more explicit) to the students during case study discussions. Students also participate in the analysis of the case studies, through team based exercises and assignments. These assignments will include implicit critical thinking components. The critical thinking portion of the assignment will help reinforce the importance of engineering reasoning to the students. By making critical thinking an explicit outcome of the course, students should be better prepared to strengthen and enrich their critical thinking skills in future (upper level) courses.

Also, planned in the revisions of the course is the creation of a standard case study evaluation rubric that will be used to evaluate parts of the case study assignments. This rubric will allow the course instructor(s) as well as any TAs to consistently grade these assignments. This consistency will allow the students to better understand where improvement is needed in their assignments and more importantly, their critical thinking skills. This case study evaluation rubric will need to include such things as the clarity, depth, relevance, logicalness, preciseness, and significance of the answer as well as the importance of each part.

5.2 Follow through assessment

Critical thinking cannot be developed in a single course or at a single point in a student's educational career. Mature critical thinking takes time to develop, it must be practiced, and it must be practiced in many different domains. Exposure of incoming engineering students to critical thinking both explicitly through formal definitions and models, and implicitly by example is the first step towards an integrated approach to strengthening the development of critical thinking skills of engineering students at the J.B. Speed School of Engineering.

The early presentation of the Paul-Elder model should help students begin to notice relevant elements of critical thinking in their other courses, especially as courses reflect faculty involvement in on-going i2a activities such as: Faculty Learning Communities, SUN Grants, and general awareness.. To continue to track the progress of students' critical thinking development, specific critical thinking assessments in upper level course can and will be conducted. Courses for which it is currently planned to conduct ongoing critical thinking assessments are: ENGR 205 (differential equations), co-operative reports (turned in after each of their three co-ops and each department has a separate course), CEE 452 (Foundation Engineering), ECE 542 (Physical Electronics), IE 541 (Simulation), ChE 461 (Process Control) and additional departmental courses may be added later.

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Appendix A The Opinion of the RGJ Editorial Board[8]

Most Americans surely were horrified when they heard the allegations that an engineer was texting on his cell phone just seconds before his passenger train hit a freight train head-on in Southern California last month, killing 25 people.

The nation's railroad regulators certainly were. One day after the accident involving a Los Angeles Metrolink commuter train, the Federal Railroad Administration issued an emergency

order banning the use of cell phones or other electronic devices by rail workers. The order noted that there were six train accidents, four of them fatal, involving cell phone usage between 2000 and 2006.

The National Transportation Safety Board has yet to determine the cause of the Metrolink accident, in which the passenger train passed a red signal light without slowing, but phone records indicated that the engineer was sending a text message to some railroad enthusiasts just 22 seconds before the collision.

It seems reasonable to conclude that the brief time that the engineer's attention was diverted by the cell phone while he was controlling a speeding train would have been enough for him to miss the signal that would have kept him off of the occupied track.

So, the railroad administration was right to take quick action to ban cell phones.

But that action raises a bigger question:

If it is dangerous for the engineer of a train on a fixed track with little traffic and signals designed to warn him of danger to use a cell phone, does it make any sense for drivers of motor vehicles, such as cars and trucks, on the open highway with far fewer safety features to be allowed to use them?

Despite warnings from public safety experts about the dangers of using a cell phone while driving and their urging drivers to pull over to talk, cell phones seemingly have become ubiquitous on the highway. Watch a vehicle on the highway in front of you drifting out of its lane, and the odds will be good that the driver has a cell phone plastered to his or her ear.

The problem is an old one. Americans simply do not seem to believe driving to be the complex activity that it really is. It takes complete concentration to pilot a vehicle moving at 65 to 70 miles per hour on a crowded six-lane limited-access highway. Even when the job appears to be simple — on a lengthy straightaway with few other vehicles to be concerned with, for example — there is considerable danger lurking.

It is difficult enough to react when another driver unexpectedly changes lanes, or a tire blows, or the vehicle hits a pothole, or a trailer breaks loose or any other of a myriad of hazards pops up on the highway. That hazard can turn to tragedy, however, if a driver is distracted by a conversation on the phone (or, perhaps, a spilling cup of hot coffee and so on).

Driving a car or truck on the highway is no less dangerous than driving a train on the track. In both cases, the driver's attention needs to be on the job at hand, not on someone else at the end of a phone line.

Cell phones have no business in the engineer's cab ... or in the family car.

Appendix B Critical Thinking Assignment

Question 1 – The main purpose of this editorial is to

1. Condemn cell phone use by train engineers
2. Persuade individuals not to use a cell phone while driving a car.
3. Document the pervasive use of cell phones while driving
4. Fill space in the news paper

Question 2 – The key question addressed in this editorial (whether stated or unstated) is

1. "is it safe to use a cell phone while driving a train?"
2. "Is it safer to ride a train than drive and use a cell phone?"
3. "did the Federal Railroad Administration make the correct decision to ban the use of cell phone?"
4. "Is it safe to use cell phones while driving a car/"

Question 3 – The author of the editorial presents information in a way to lead the reader to assume that cell phone use contributed to the train accident in Southern California last month that killed 25 people

- True
- False

Question 4– The author provides strong evidence for the conclusion that American use cell phones while driving because they simply do not believe driving to be a complex activity

- True
- False

Question 5 – The author cited railroad data involving cell phone use. However, there are no data cited on automobile accident rated involving cell phone use. Including this data in the editorial

1. Was not needed since every one driving is using a cell phone
2. Would have been useful in supporting or undermining the author's editorial argument
3. Was not needed since everyone knows cell phone use impacts car accident rates.
4. Was not needed since driving a car is more dangerous than driving a train.

Question 6 – The author reports that the National Transportation Safety Board has not determined the cause of the train accident. The author states that the engineer was texting just 22 seconds before the collision. From the data given in the editorial, it is proven without a question the time of texting is relevant to the cause of the collision.

- True
- False

Question 7 – When applying critical thinking it is important to make sure all the information that one is using in his/her thinking is accurate and precise. However, if the information does not support the thinkers' desired conclusion the data should be omitted.

- True
- False

Question 8 – The statement "most dogs weight over 300 pounds" is a clear piece or information. However, it would not be applicable for use in critically thinking about pets because it is

- An assumption
- Not accurate
- Lacking a point of view
- Not relevant

Appendix C Critical Thinking Assessment

A. Select the best answer to the following 5 multiple choice questions:

1. Aspects of critical thinking involve all of the following EXCEPT:
   a. Critical judgments
   b. Elements of reasoning
   c. Essential intellectual traits
   d. Universal intellectual standards

2. A characteristic of critical thinking is
   a. brevity
   b. judgementalness
   c. logicalness
   d. subjectivity

3. A race track is one mile long. If a driver goes around once at 30 miles per hour, how fast must he drive in the second lap to average sixty miles per hour over both laps?
   a. 30 miles per hour
   b. 60 miles per hour
   c. 90 miles per hour
   d. Impossible to accomplish

4. A man buys 9 gallons of paint. He can only carry 2 at a time to the car. How many trips from the store to the car does he have to make?
   a. 4.5 trips
   b. 5 trips
   c. 9 trips
   d. 10 trips

5. Victor, Virgil, Vincent, Vito, and Vance are brothers performing in a five man traveling circus known as the little big top. They are in no particular order, a clown, a juggler, an acrobat, a magician, and a strong man. Whenever they perform, their acts appear in the same order. The clown comes after Victor and Vito, but before the magician. The acrobat comes on third. Neither the strong man nor Vincent is the first or the last to perform. Virgil, Victor, and Vito perform in that order. Who performs first?
   a. Vance
   b. Victor
   c. Vincent
   d. Virgil
   e. Vito

B. Indicate the extent you agree or disagree with each of the following statements:

		Strongly Agree	Agree	Disagree	Strongly Disagree	Neutral
1.	People either are or are not critical thinkers.	A	B	C	D	E
2.	A person's critical thinking occurs automatically with self discipline.	A	B	C	D	E
3.	Critical thinking can be learned and developed.	A	B	C	D	E
4.	An aspect of critical thinking is being critical.	A	B	C	D	E
5.	Critical thinking is important, but not essential to success as an engineer.	A	B	C	D	E

C. Complete the following sentence on this assessment form. Do not mark the scantron.

Critical thinking is _____