AC 2007-1744: ARE FRESHMAN ENGINEERING STUDENTS ABLE TO THINK AND WRITE CRITICALLY?

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Are Freshman Engineering Students Able to Think and Write Critically?

Abstract

"**Critical Thinking is defined as** reasonable reflective thinking that is focused on deciding what to believe or do. More precisely, it is assessing the authenticity, accuracy, and/or worth of knowledge claims and arguments. It requires careful, precise, persistent and objective analysis of any knowledge claim or belief to judge its validity and/or worth."[1]

This paper reports on a study done to determine critical thinking skills of freshman engineering students measured by assessing an assignment written in response to a cooperative in-class activity. The class, a freshman level, one hour course, "Introduction to Engineering" has been taught by Dr. High (an engineer) for eight years. The class meets for 15 hours during the semester and covers six main areas: academic success; professional success; engineering information; engineering design and problem solving; societal issues of engineers; and personal development. Essentially, this course addresses "professional skills" as defined by ABET criteria. For the purpose of this study three sections with 66 students total were chosen to participate.

The cooperative, in-class activity, "The Airplane Design Challenge" asks students to jointly find solutions to the problem of designing an airplane with limited materials and production challenges in order to learn the essential notions in engineering of process and product design. The written assignment asks students to complete a reflective assignment in which they consider their impressions from the activity, how well their group functioned together, describe their group's product and process design, provide definitions of product and process design and draw conclusions about what this exercise tells them about what engineering is and what an engineer does.

A perfect setting for practicing and assessing critical thinking skills, the "Airplane Design Challenge" was modified in the fall 2006 semester to include an explicit question about the students perspective on the activity: Was the "Airplane Design Challenge" a good way to learn to understand the similarities and differences between product and process design? This question acted as the central idea students could develop through the reflections and definitions traditionally required of the assignment. Dr. High, Dr. Damron (an English faculty member) and another English faculty member assessed the students for critical thinking and writing ability using university-wide assessment rubrics.

Background

Increasing attention has been given to the development of what have been called the "soft" skills in engineering, which the recent accreditation criteria of ABET (Accreditation Board of Engineering and Technology) call "professional" skills. These professional skills highlight recognition in the field of engineering that in order to compete in a global context, students must be prepared to communicate, work in teams,

understand the impact of various decision-making processes, and engage in lifelong learning among others. Shuman, Besterfield-Sacre and McGourty[2] outline the elements of these professional skills and categorize them as either "process" or "awareness" skills and argue that these skills can be taught and assessed. The challenge then becomes how to teach these skills. Smith, Sheppard, Johnson and Johnson[3] discuss the effectiveness of "pedagogies of engagement" which include problem-based learning, team projects and cooperative learning classroom practices which can aid engineering educators in developing learning environments that are in keeping with current approaches to teaching, and which aid in the outcomes for the training of professional skills as outlined by ABET.

Of particular interest to this study are two categories of what Shuman et al.[2] call lifelong learning skills: the ability to demonstrate effective writing and critical thinking skills. Critical thinking consists of "reasonable reflective thinking that is focused on deciding what to believe or do. More precisely, it is assessing the authenticity, accuracy, and/or worth of knowledge claims and arguments. It requires careful, precise, persistent and objective analysis of any knowledge claim or belief to judge its validity and/or worth."[1] Critical thinking is grounded in engagement with problems. In fact, for Dewey[4] from whose work problem-based approaches to teaching are drawn, engagement has to do with wrestling with the context and conditions of the problem. So, deciding what to believe or do comes with a process that includes analyzing and judging assumptions as well as exploring alternative ways of thinking about a topic. Bean[5] proposes that the connection between writing and critical thinking is that "writing is both a process of doing critical thinking and a product communicating the results of critical thinking." As such, critical thinking and writing go hand in hand.

For the engineering educator, implementing and integrating the professional, institutional, and pedagogical goals and expectations into a course is complex and becomes much more so when developing and implementing curricula for freshman students. These students are not always comfortable with problem posing situations, and as the tasks increase in complexity, so does the difficulty in thinking and writing about those tasks[5]. Bean suggests that teaching the process, which involves engaging, developing, complicating and clarifying ideas through writing, is slow and developmental. In order to help students through this process, Bean suggests that the teaching should create 'cognitive dissonance' or using 'decentering' exercises, exercises that challenge students to look at other perspectives; in addition, knowledge should be presented as dialogic; and we should create opportunities for active problem-solving that involve dialogue and writing.

This paper reports on a study conducted in an Introduction to Engineering Course in which the students participated in a cooperative activity, "The Airplane Design Challenge" and subsequently wrote a formal assignment. Students were required to discuss this experience and asked to draw larger conclusions about a key engineering concept. The papers were then assessed for writing and critical thinking skills using rubrics developed for Oklahoma State University. The purpose of the assessment was to address the main question of this paper as presented in the title—to what extent are

freshmen engineering students able to think and write critically? In addition, the results of this study are expected to contribute to the benchmarking process for the rubrics at Oklahoma State University.

The Introduction to Engineering Course

The major goal of this course is to increase retention of freshman students by introducing the students to engineering concepts and experiences. Another major goal of the course is to address the 'professional' skills of ABET. There are 25 sections of the class taught in the college with sections typically having 21 students. Three sections with a total of 66 students during the fall 2006 term were chosen for this study, all taught by one instructor. Two of these sections were populated with "engineering entrepreneurship" students (with overflow enrollment due to demand). The third section was for an all-female group engaged in a living and learning community called "Maude's Quad" named for the first female graduate of the Engineering College in 1928.

The three sections identified for the study consisted of college freshmen engineering majors from across the College of Engineering. The class met for 15 hours during the semester, plus extra time for meetings with success coaches/peer mentors and additional speakers. The six main areas covered in the class are detailed below:

- Academic Success- study skills, time management, finding help for classroom material, test-taking skills, and college survival skills.
- Professional Success – career planning and effective presentations.
- Engineering Information – career and advisement information and research presentations/laboratory tours.
- Engineering Design and Problem Solving – creativity, effective teams, brainstorming, process design, and product design.
- Societal Issues of Engineers – ethics, diversity/international issues, environmental issues/sustainability, medicine and bioengineering.
- Personal Development – stress management and other wellness issues.

This course is a particularly good class to do problem-based, cooperative activities because it addresses the goal of giving students engineering experiences that truly engage the students. Adding the Airplane Design Challenge experience to the class fits these goals with the added potential of acting as a means of retaining students, a college and university level goal.

The Airplane Design Challenge

The Airplane Design Challenge was developed for this course because it is problem-based, gives students a chance at cooperative learning, involves dialogic opportunities for thinking, makes students consider other perspectives, builds team learning, promotes student engagement, simulates how the design process/product works and helps make connections to what engineering is all about.

The Airplane Design Challenge is conducted in the fifth week of the semester because the students have had a chance to get to know each other which make the teamwork easier

and engages them early enough to use these experiences in later semester activities. The airplane challenge is an activity that is done in a fifty minute class period. The students first are placed in multidisciplinary teams of three to four and asked to create a name for the team after which they receive a handout containing the materials and instructions for the challenge (Figure 1.)

Figure 1 – Airplane Challenge

Product/Process Airplane Design Challenge

Given the following items:

Toothpicks	Ziploc bag
Rubber bands	Lunch bags
Paper clips	Tootsie rolls
Post it notes	Lifesavers
Gum	

Design an airplane using materials given (10 minutes)

Place prototype at front of classroom on paper along with group name

Design a process/method to manufacture the airplanes (5 minutes)

Be aware that I will provide calamities/upsets

Build airplanes (10 minutes)

Deliver your airplanes in one (or more) lunch bag to the front of the classroom next to the prototype

Group name must be on lunch bag

Evaluate products (5 minutes)

Rank (individually) the group designs for those that meet specifications (looks like an airplane)

Next week I will tell which group "won"

Equal weights to product design/process design.

Keep track of activities/thoughts in your lab book!!!!!!!

Teams take toothpicks, rubber bands, paper clips, tootsie rolls, post it notes, lifesavers and gum and design a prototype airplane (doesn't have to fly). The team then designs a process/method to manufacture airplanes with the understanding that process calamities and upsets might occur during this phase (for example – a student might be made to simulate a work related accident by not allowing them to use an arm or supply chain issues are simulated by removing some of their tootsie rolls or power outages simulated by shutting of the lights and not allowing anyone to work). The teams then build as many airplanes as they can in 10 minutes and deliver them in a shipping container (lunch bag). Students individually rank the group designs for those planes that meet specifications (looks like an airplane). The team receiving the most points from the ranking wins the product design contest and the team producing the most airplanes wins the process design contest. Students keep track of details in a lab notebook.

The Writing Assignment

This assignment was designed against the backdrop of assessment work being done at Oklahoma State University. The Critical Thinking Assessment Committee has suggested that freshman-level courses lack explicit requirements or assessment of critical thinking. The components of the assignment were developed to specifically address University developed writing and critical thinking rubrics making the resulting papers suitable for rubric assessment and development. This assignment afforded a writing experience for the students within their own disciplinary work unlike typical writing experiences in freshman composition by writing about and assessing an in-class engineering experience.

The students were also given a copy of the writing assignment (Figure 2.) at the beginning of the hour so that they knew what was expected of them. By having the writing assignment ahead of time, they were provided with a focus which would provide for meaningful entries in their lab books.

Figure 2 – Writing Assignment

Product/Process Design Homework
Due Week of October 2, 2006
30 points

Prepare a 2-3 page double spaced 12 point font Microsoft Word document (paper/essay) that addresses the following. Be very clear in your document about which of the items you are addressing. Remember that all course documents are on Blackboard. I will be adding more resources on Blackboard to help you understand product and process design.

1) Your name, your group name, and members.
2) Was the "airplane design challenge" a good way to learn to understand the similarities and differences between product and process design? This is the main theme of your paper.
3) Use documents provided in class, on Blackboard, as well as at least one other resource that you find to provide definitions and to support your claims for #2 above. Provide references to your sources.
4) Discuss your group's product and process design.
5) Describe how your group functioned together. Were they effective?
6) Conclude by summarizing your key points (to support #2 mostly but others for #4 and #5 as needed) and describing how important product and process design is in engineering.
7) Provide a bibliography of your sources.

Students were provided with design resources[6,7,8,9] that assisted student learning of engineering product and process design concepts. Students were required to find outside sources used as evidence to support their claims about the Airplane Design Challenge and its ability to help them understand the difference between product and process design (see

Table 2). In addition, this task helps the students learn to do research of relevant literature.

Because group work is a very important part of engineering and important for the students to start considering what make a good team and how they can be good team members as addressed by ABET, the students were asked to consider how their groups functioned together. The assignment was also written to get the students to realize that the exercise itself required critical thinking. The exercise made them question their own assumptions about design and engineering. It required them to consider alternatives in both the product and process design phases.

Demographics of Students

All students who participated in the study were engineering students from across the college. Demographic distinctions between sections are shown in Figure 3:

Figure 3-Demographics of Students

Section A:

23 Students (3 males did not complete the assignment) 16 male and 7 female
Male and Female students in an Entrepreneurship Engineering section
One of the first sections of Engineering 1111 to fill up (cap usually is 21 students)

Section B:

19 Students (all completed assignment)
All Female students in Women in Engineering Section

Section C:

24 Students (2 males did not complete the assignment) 19 male and 5 female
Male and Female students in an Entrepreneurship Engineering section
Section opened up during the middle of summer enrollment after Section A filled

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It was hypothesized that the all female group would perform the best on the written assignment and would show higher critical thinking ability based on the instructor's observations of the students for the first five weeks of the semester as well as prior experiences with highly motivated female engineering students. It was also expected that Section A would perform very well because of their desire to enroll early, be in an engineering entrepreneurship section, as well as observations from the first 5 five weeks. Students interested in Entrepreneurship tend to be ambitious and internally motivated. Section C was expected to perform the lowest on the assignment. These students had not been very engaging in the first weeks of the semester and appeared to lack motivation. They had already established a pattern of complaining about any amount of work.

Assessment

Because one of the goals of the this study was to contribute to the process of developing the assessment instruments for the university assessment committee, the writing

assignment and assessment measures were designed to complement this process. At the current time, the committee is establishing a benchmark of students that evaluates the current abilities towards critical thinking. Once this benchmarking has occurred, the appropriate interventions for improving the critical thinking ability of the students will be determined. The fact that the products resulting from the assignment were in written form generated curiosity about using both the writing and critical thinking rubrics and the relationship between the two.

To obtain the results for the study, three faculty members were selected to do the rating using both rubrics. Two faculty members, from the English department are heavily involved in the teaching writing on campus and have extensive experience with writing skills: the director of the Freshman Composition program and the Director of the university Writing Center. The third rater was from the College of Engineering and an instructor of the course profiled in this study. The rubrics are explained in Figure 4.

Figure 4-The Rubric Criteria

The Writing Rubric used the following three criteria:

1. Content
2. Organization
3. Style and Mechanics

The Critical Thinking Rubric uses the following seven characteristics:

1 – 4: Essential Characteristics

1. **Identification** and/or summary of the **problem/question** at issue
2. Presentation of the **STUDENT'S OWN perspective and position** as it is important to the analysis of the issue.
3. Assessment and appropriate use of **supporting data/evidence.**
4. Discussion of **conclusions,** implications and consequences.

5-7: Optional Characteristics (evaluate where appropriate)

5. Consideration of **OTHER salient perspectives and positions** that are important to the analysis of the issue.
6. Assessment of the **key assumptions and the validity of the supporting/background information.**
7. Consideration of the influence of the **context** on the issue (including where appropriate, cultural, social, economic, technological, ethical, political, or personal context)

The papers were ranked on a 1 to 5 scale for each with 1 being low and 5 being high. For this project, the students work was ranked for the three writing criteria with an overall score and for the seven critical thinking criteria with an overall score. The three faculty members were provided with anonymous copies of the student work. Each professor rated the papers with the 1 to 5 values for each component of the two rubrics. This rating was completed after the end of the semester and after course grades were assigned by Dr. High.

Interrater reliability was determined for overall ratings and ratings on subsection as indicated in Table 1.

Table 1-Interrater Reliability

	W1*	W2	W3	WO	C1	C2	C3	C4	C5	C6	C7	CO
R1R2**	0.189	0.367	0.189	0.204	0.100	0.157	0.550	0.475	-0.038	0.274	0.110	0.365
R1R3	0.308	0.275	0.297	0.297	-0.102	0.252	0.418	0.125	0.191	0.205	0.187	0.332
R2R3	0.436	0.172	0.172	0.172	0.048	-0.110	0.205	0.122	0.073	0.151	-0.019	0.087
OA	0.53	0.49	0.34	0.49	0.22	0.25	0.60	0.47	0.22	0.34	0.26	0.49

*W1 corresponds to writing criteria 1, etc. WO is overall writing score, C1 corresponds to critical thinking criteria 1, etc. CO is the overall critical thinking score.

**R1R2 is Rater one compared to Rater two, etc. and OA is the overall interrater reliability.

Reliability was calculated using a formula, which took the average *r* correlations, converted to Z scores to allow for *r* distortion. Table 1 shows that the reliability was quite low among raters across the board. A score of 0.75 is on the low end for non-normed situations; ideally, it is desired to be closer to 0.9. Raters tended to be more internally consistent within and across rubrics. Part of the reason for the lack of consistency among raters could be the fact that not all raters were familiar with both rubrics prior to participating in this study and time constraints prevented a proper norming session among raters prior to rating. There may also be a challenge with the validity and reliability of the rubric itself. Additionally, engineering faculty may be looking for different things than English faculty as they review the artifacts.

Results

Table 2 contains the results of the ratings by section and by criteria on both rubrics.

Table 2– Assessment Results

	W1**	W2	W3	WO	C1	C2	C3	C4	C5	C6	C7	CO
Overall Average	2.94	2.86	2.81	2.88	2.97	3.25	2.85	2.73	2.15	2.43	2.51	2.90
Section A	2.88	2.81	2.70	2.77	2.95	3.21	2.89	2.74	2.12	2.54	2.75	2.84
Section B	3.15	3.17	2.96	3.15	3.02	3.38	3.10	2.94	2.23	2.56	2.50	3.06
Section C	2.82	2.65	2.79	2.77	2.95	3.19	2.60	2.54	2.11	2.21	2.26	2.81
Difference A-average BC	-0.09	-0.08	-0.16	-0.17	-0.03	-0.07	0.07	0.01	-0.04	0.17	0.38*	-0.08
Difference B-average AC	0.29*	0.44*	0.21	0.37*	0.07	0.17	0.36*	0.30*	0.12	0.19	-0.01	0.24
Difference C-average AB	-0.18	-0.32*	-0.03	-0.17	-0.03	-0.09	-0.39*	-0.28*	-0.07	-0.34*	-0.37*	-0.14

** W1 corresponds to writing criteria 1, etc. WO is overall writing score, C1 corresponds to critical thinking criteria 1, etc. CO is the overall critical thinking score.

* These numbers show where a paired t-test between the section and the other two sections showed that there was a significant difference at $p<0.05$, a statistically significant difference at the 95% confidence level.

These scores are the average of the three rater's scores. The overall (for all sections) average score that the students performed the best in was Criteria C2, "presentation of the

students' own perspective" which may be an outcome from the assignment specifics that asked for their perspective. The lowest score was seen for Criteria C5, "consideration of other perspectives" (an optional criteria used by the raters). The assignment, however, did not specifically ask for the students to do this. Freshman students may not have the maturity to consider the addition of this.

Upon comparing the sections, Section A was able to consider the influence of the context of the issue (Criteria C7-optional) and Section C performed the worst. In both cases these were very large differences. Section B (the all women section) had a large positive difference from the overall average on Writing W2, Organization and the overall writing score WO. They also had a positive difference for C3, use of supporting data. Section C appeared to have challenges with use of supporting data (C3), assessment of assumptions (C6), and influence of context (C7). The performance of the sections on the writing and critical assessment rubrics reflects grades assigned by the instructor. Section A average on the assignment was 23.83, section B average 28.84, section C average 23.67. Overall course grade averages for section A were 3.65, Section B 4.00, Section C 3.63. Course grades are based on participation, attendance, and turning in assignments.

Correlation between the overall writing scores and the overall critical thinking scores, yielded interesting results; there was a better correlation for the all female section. The R^2 for the correlation for sections A and C (mixed) was 0.4871 and the R^2 correlation for the female only section was 0.7513. This indicates that while the overall critical thinking scores are fairly consistent (no statistically significant differences) among the sections, the writing scores were enough higher to give a better correlation between writing and critical thinking for the female only section.

As stated, one of the objectives of the assessment committee is to revise the rubric as necessary. One of the raters provided some input that will be forwarded to the committee.

> "I thought it was a challenging assignment to rank them by the criteria. I had some trouble with the optional criteria, in particular, as I wasn't sure always how they should apply to this assignment. Mostly, I didn't consider those marks in calculating an overall score."

Dr. Damron provided another quote:

> "In working closely with the two, I thought the critical thinking was easier to use—once I decided what I was looking for."

As the University is currently at the benchmarking stage, University level critical thinking scores are not available for comparison. Informal observations indicate that for a majority of the students (who are predominantly upperclassman) the scores are in the upper 3 to 4 range.

Concluding Comments and Future Directions

The main research question was "Are Freshman Engineering Students Able to Think and Write Critically?" Based on application of the University rubric for critical thinking to three sections of Engineering students, the answer is "somewhat." The reality is that the rubric predominantly measures critical writing skills. At this point, the authors can only infer that it also measures the thinking skills.

Future data collection strategies need to include a larger engineering cohort. This data should have class level and major information in order to more fully determine significant differences in skill levels. Similar classes of University-wide students need to be appraised. There currently is very limited data on University freshman and most classes do not present them with the types of assignments that require critical thinking and writing. It will also be interesting to determine if it is possible to come up

To emphasize further connections between discipline and writing and critical thinking skills, the Dr. High and Dr. Damron have considered a student cohort for fall 2007 that would be clustered in a paired composition class and Engineering 1111. Writing and critical thinking skills would be compared with a control group that was not paired. An initial assignment would be given to the students that would assess their beginning skills. Course content and projects would be given to the students in the two classes to expose the students to critical writing and thinking skills. A final project would be given to the students to determine the effect of the interventions. Freshman from the fall 2006 class possibly would be used as writing fellows for the fall 2007 students. Writing fellows are assigned to work in our University Writing Center with freshman composition sections and are undergraduate peer tutors who assist in developing writing skills through work with students on course papers. The authors have also discussed asking the research question a bit differently, to what extent do the student critically think and write as opposed to are they able to critically think and write.

The interrater reliability information provided some interesting questions for future research:

1) How effective are norming sessions on reliability?
2) How do Engineering faculty see writing and critical thinking differently than English faculty?
3) How reliable and valid are the Oklahoma State University rubrics for writing and critical thinking?

Since the work of helping students mature in their writing and critical thinking skills is a developmental process, future work might consider how to develop similar approaches for higher level students. The impact on upper level discipline specific courses would be determined through use of the same writing and critical thinking rubrics and compared with the freshman results.

Bibliographic Information

(1) Seattle Central Community College, LIB101 - Introduction to Information Resources Course, 2003 http://www.seattlecentral.org/faculty/jshoop/glossary.html

(2) Shuman, L.J., Besterfield-Sacre, M., and McGourty, J. "The ABET "Professional Skills"-Can They Be Taught? Can They Be Assessed?", *Journal of Engineering Education*. Vol. No., 2005, pp.41-55.

(3) Smith, K., Sheppard, S.D., Johnson, D.W., and Johnson, R.T. "Pedagogies of Engagement: Classroom-Based Practices," Vol. No., 2005, pp. 87-101.

(4) Dewey, J. *Democracy and Education*. Macmillan, New York, NY, 1916.

(5) Bean, J. *Engaging Ideas: The Professor's Guide to Integrating Writing, Critical Thinking, and Active Learning in the Classroom.* San Francisco: Jossey-Bass, 2001.

(6) Lumsdaine, E. M. and Lumsdaine, "Chapter 13-What is Design," *Creative Problem Solving and Engineering Design,* McGraw-Hill, New York, NY, 1999.

(7) Nazemetz, J., "Chapter 2 - What is Design," *Engineering 13x2*; *Engineering Design with CAD,* Prentice Hall E-Source, Upper Saddle River, NJ, 2004.

(8) Cussler, E., and G. Moggridge, "Chapter 1 – An Introduction to Chemical Product Design," *Chemical Product Design*, Cambridge University Press, New York, NY, 2001.

(9) Jensen, J., "Chapter 7-Engineering Design Method," *A Users Guide to Engineering*, Prentice Hall E-Source, Upper Saddle River, NJ, 2004.