AC 2011-331: ANALYSIS OF REFLECTIVE MEMOS

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Analysis of Engineering Capstone Design Student Reflective Memos: What Students Say and What They Don’t Say

Abstract

Having students articulate and reflect upon their experience is a valuable and important way to reinforce an appreciation for lessons learned in the context of capstone design. Taken together with peer evaluations, end-of-semester student reflective memos can be an invaluable source of assessment information and provide guidance for continuous improvement of the educational processes in line with ABET criteria and outcomes. However, concerns about the proper use of these reviews abound. Foremost, is the qualitative and subjective nature of reflections and the challenges this presents to translating the reflections into recommendations for course improvements. Because reflective memos do not readily lend themselves to numerical analysis, they can be easily overlooked over time and the value they potentially represent lost.

This paper provides an analysis of end-of-semester student reflective memos collected over five years from a capstone course based on real world multidisciplinary design experiences. Disciplinary participation included students from biomedical, computer systems, electrical, industrial and mechanical engineering. The analysis focuses on a study of what students express as relevant learning points. We have found students to be surprisingly frank about what they learned and where they thought their experience in the course fell short. Over time we have observed common themes that emerge among students concerning their ability to deal with project changes and team dynamics and have charted the resulting ebb and flow of enthusiasm and motivation over the course of a semester.

Background

Capstone projects represent a major milestone in a student’s academic career and professional development where they are expected to integrate knowledge and skills from prior coursework. Capstone also represents a major checkpoint for assessing ABET curricula program outcomes[1]. Our approach to capstone is based on the premise that there should be little or no formally prepared content delivered to students. An experienced staff engineer provides mentoring to each project team, but the basic assumption is that students should be prepared and ready to work on an open-ended real-world project at the culmination of their undergraduate academic careers and demonstrate an ability to apply the theoretical and abstract concepts learned in prior courses. A capstone project is in essence a semester long exam that measures how students will perform as practicing engineers.

Traditional wisdom and best practice in education promotes a clearly defined set of learning objectives. This can be a major challenge for multidisciplinary capstone design where a diversity of student interest and background must be matched to an open-ended project-based team experience. The very nature of an open-ended design experience represents a conflict with the idea of highly specified content. This leaves us with the
interesting quandary of defining and pursuing clear learning objectives in the context of ambiguous and ill-defined real-world problems. One way that we address this is with a front-end process to match individual student interests and capabilities to the learning experience. Another important element is the end-of-semester memo where students are asked to reflect upon their experiences and tell us what they think they may have learned. Typically, we only use this information as a real-time calibration for assessment purposes and minor semester-to-semester course adjustments\[^{2}\]. Until now, relatively little has been done to record, organize and analyze these student comments on their capstone experience.

The foundation of the approach described in the research presented here is that student articulations about their design experiences represent valuable information. While peer evaluations and reflective memos can be used to provide guidance and calibration for student assessment, what students say, can and should also be used to provide both short and long term direction on course and curriculum improvement\[^{3}\]. Questions we had when approaching this study included: Are we satisfying course objectives? What areas might we be missing? How could we make improvements? Student reflective memos, along with peer evaluations provide a rich source of potentially untapped information that can supplement other sources of course evaluations such as end-of-semester course surveys, project results and sponsor feedback.

The analysis, in essence, listened to what the students have said and have not said: focusing on what students expressed in their end of semester reflective memos as their relevant learning points, including motivation, interests, and accomplishments during the semester. The analysis generated two sets of indicators: one that matched visibly what the students said, and another that they missed – or, what we expected (or hoped) they would say, but they did not or just barely. Both sets were categorized based upon ABET and capstone course objectives, and hence, collectively they represent a comprehensive measure of the accomplishment of curriculum goals. The data came from the student reflective memos collected over five years from a multidisciplinary capstone design course, which is based on real world sponsored engineering design projects. Disciplinary participation included students from biomedical, computer systems, electrical, industrial and mechanical engineering.

It turns out that what they said – i.e., the first, visible set of indicators, coincided with the conventional measures of the effectiveness according to the capstone course objectives, such as applying engineering knowledge to solve an engineering design problem. What they did not say (or at least not to any great extent), the second set, pertained largely to the other non-conventional, broader goals; and hence showed the invisible lacking of accomplishments in these broader issues.

We regard the missing of the second set of accomplishments as an opportunity for improvement. To the extent that our experience is not unique, this paper advocates a renaissance of the engineering curriculum to respond to the new realities of knowledge-based economies: the vast majority of engineering graduates will need a new kind of
liberal education to solve general and non-engineering problems in the broad society, where an analytical mind may matter more than the traditional engineering skill set.

This paper starts by highlighting ABET program outcomes to lay the groundwork for how learning objectives map to what students say in their end of semester reflective memos. Next we describe the overall approach and methodology for collecting and organizing the “lessons learned” from student reflective memos. This will be followed by a summary of the data collected along with observations and interpretation. We will conclude with a discussion and analysis of how we interpreted what students are telling us in their reflective memos and how this information can be used to help make improvements to capstone pedagogy and to the engineering curriculum in general.

Learning Objectives and Outcomes

ABET program outcomes call for students to demonstrate an ability to “(c) design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability”. We view this program outcome as central to engineering practice. First and foremost, the end results of engineering are system designs that come from the design process. The results of engineering design are ever present in virtually every facet of society and the connections between how engineering solutions address societal needs and how technology impacts people is an important factor relative to addressing shortfalls in students choosing to pursue an engineering education. We contend that it is important for engineering students to understand how engineering design affects society and how society may affect how we as engineers do design.

The remaining ABET program outcomes call for a foundation of knowledge that facilitate, enable and essentially support the practice of engineering design. These include an ability to; (a) apply the knowledge of mathematics, science, and engineering, (b) design and conduct experiments, as well as to analyze and interpret data, (k) use the techniques, skills, and modern engineering tools necessary for engineering practice, (e) identify, formulate, and solve engineering problems and have (f) an understanding of professional and ethical responsibility. Since successful engineering design is rarely achieved in isolation, it is also important that students have an ability to (d) function on multi-disciplinary teams and (g) communicate effectively.

In accordance with ABET program outcomes, our syllabus calls for the following learning objectives:

1. Apply engineering practices to solve a given engineering design problem
2. Address the following issues in a given engineering problem: economic, environmental, sustainability, manufacturability, ethical, health and safety, social, and political considerations
3. Work with others as a member of a team
4. Express oneself orally and in writing
In the context of “real-world” capstone design projects, it is implicit that students would also build upon the knowledge gained in courses they have taken in the humanities and social sciences to (j) develop an appreciation and knowledge of contemporary issues. Likewise, it follows that students would (h) develop the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context and (i) recognize the need for, and develop an ability to engage in lifelong learning[1].

Approach and Methodology

For the work presented here we systematically organized and analyzed student responses to questions submitted by ten capstone design teams over a five-year period from 2005 to 2009. In total, over 200 learning points from 68 student reflective memos were identified and used for the study. Project teams were selected from each semester over the study period based upon diversity of multidisciplinary participation and project type. Each team had at least two disciplines represented from the sample population consisting of mechanical (63%), electrical (25%), computer systems (9%), industrial (3%) and biomedical (3%) engineering students.

We selected projects representing a broad cross-section of areas, including industry-sponsored, service and entrepreneurial efforts, in part, to see if there was any relation between the type of project and how students responded to the challenge. For industry-sponsored efforts the project goals were often more clearly specified and resources were more available to respond to both technical and non-technical questions than for service and entrepreneurial projects. Industry-sponsored projects included a variety of product development and process improvement areas, but also some projects that we might characterize as research and exploratory. In addition, service-related and entrepreneurial projects were included in the study. Service-related projects included development of devices and systems for people with disabilities, sustainable design, and new ideas for product invention. These projects were typically less well defined than industry-sponsored efforts, although objectives became more evident as each project progressed. The names and associated objectives for each of the ten projects are shown in the table below.

<table>
<thead>
<tr>
<th>Project</th>
<th>Objective</th>
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<tbody>
<tr>
<td>CRUD Catcher (S05)</td>
<td>Design and build magnetic CRUD filtration system</td>
</tr>
<tr>
<td>Water Droplet (F05)</td>
<td>Explore technology and devise a system to monitor turbine blade erosion</td>
</tr>
<tr>
<td>Sustainability (S06)</td>
<td>Reverse engineer products to assess design sustainability</td>
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<tr>
<td>Senior Living (F06)</td>
<td>Design and build assistive devices to help senior citizens</td>
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<tr>
<td>Inspection System (S07)</td>
<td>Design a system for inspecting needles used for fabric making</td>
</tr>
<tr>
<td>Heat-set System (F07)</td>
<td>Design a new heat-set machine used for industrial fabrics</td>
</tr>
<tr>
<td>Blade Actuator (S08)</td>
<td>Design and build system for turbine blade dynamic wind tunnel testing</td>
</tr>
<tr>
<td>Solar Shade (F08)</td>
<td>Design and build prototype for reliable low-cost solar shade</td>
</tr>
<tr>
<td>Plasma Flow (S09)</td>
<td>Design and build system to demonstrate plasma air flow control</td>
</tr>
<tr>
<td>Rehab Toilet (F09)</td>
<td>Design and build prototype of rehabilitation toilet seat and frame</td>
</tr>
</tbody>
</table>
Each end-of-semester reflective memo was systematically reviewed to identify and record how students responded to specific questions that were asked in the context of the assignment (see Appendix). The questions used in the assignment were adapted from NSF research designed to elicit thought and reflection in the context of a capstone design experience to understand what students think they learned and what influenced their motivation[4]. These responses were recorded in a spreadsheet and organized using a process of affinity organization. Using an iterative process, categories of learning points were developed from an analysis of ABET learning objectives, the learning objectives stated in our syllabus, and the learning points that were expressed by students in their memos. The process resulted in the organization of each learning point being grouped according to a similar expression of learning points within the following categories:

1. Design Process: Problem solving, project planning, iteration, requirements definition, methodology
2. Teamwork: Understanding ones own and others contribution to an effort
3. Communications: documentation, presentation, communication with team, customers, vendors, experts, etc.
4. Technical Knowledge: Learning about specific technologies such as machines, circuits, optics, controls, statistics, electromagnetism, etc.
5. Critical Thinking: applying theory and abstract concepts in practice, calculations and analysis
6. Resourcefulness: Research, finding information, initiative to learn and take action
7. Test and Experimentation: Performing tests, collecting data, interpreting results

For each student’s reflective memo we systematically recorded his or her responses to the question, “What do you think you learned?” that was asked in the context of the assignment. Student rate of response ranged from none to twelve, with most students on average expressing three distinct learning points.

An excerpt from one of the student reflective memos follows. In this case, each phrase indicating a response to the question is italicized and followed in parenthesis with the category in which it was organized. For this particular example, six distinct learning points were recorded:

“I learned an enormous amount about the work ethic of both myself and others. It became clear that each person brings different expertise to a group (Teamwork). I was also able to gain knowledge about the purchasing process (Communication) during a project, which will be very useful once I enter industry and am required to work on projects similar to this one. I learned a tremendous amount about magnetic theory and how to model magnets to determine their flux (Technical Knowledge). One of the most important things I was able to take away from this project was learning the benefits of creating prototypes and testing these prototypes to their extremes. I found that theory couldn’t always be applied to each and every situation. It became clear that work must be checked numerous times, as errors can
be overlooked without careful analysis and may cause unfortunate end results. I learned the value of testing and how it is essential to perform such actions (Test and Experimentation). Asking others, not necessarily directly involved in the project, for advice on subjects regarding the project proved to be very beneficial (Resourcefulness). This leads to ideas that may not have been thought of by members of the project team. Another valuable lesson learned was keeping a record of everything that happened at team meetings and the dialogue that took place (Communication). This greatly reduces time when discussing meetings at later dates and trying to remember specific points.”

In addition to recording the learning points expressed by each student we took notes of motivation levels and student responses to the following questions: How motivated were you to work on the project? Were you really excited, moderately interested or somewhat apathetic? What influenced your motivation level? How did things change as the semester progressed?

To chart motivation, we took note of whether a particular student expressed high, moderate or low levels of excitement and enthusiasm about the project over the course of the semester. These levels of motivation were charted based upon major course milestones including project initiation, when students first learned their project assignments; proposal, when students defined their statement and deliverables for the semester; mid-term, which constituted an interim review usually coinciding with a proposed solution or possible alternative solutions, and final review, report, and demonstration of the semester deliverables.

Summary of Data: Observations and Interpretations

Our population of students extends beyond the study period with a population of over 3500 students who have participated in 20 to 25 capstone project teams each semester over the past ten years. We believe that the results from the study group were representative of observations from the larger population. Our findings fell into two general categories of (1.) student reflection on learning points, (2.) factors influencing student motivation.

Student Reflection on Learning Points

Over the past ten years our use of reflective memos has provided a means of calibrating our assessments with the student viewpoint at the end of the semester. However, given the rather subjective and qualitative nature of student reflection, there has been relatively little past effort to interpret the information in a more organized fashion over a period of time. Figure 1 presents a summary of the learning points expressed by students in the five-year study based upon percent of frequency in which a particular category of learning point was expressed.
Consistent with our learning objectives there was confirmation that students learned about the engineering design process. Students expressed learning about the design process eighty four percent (84%) of the time. Fifty one percent (51%) of students said they learned about teamwork and forty four percent (44%) said they learned about communication. In this case, we are fortunate to have prior coursework at the sophomore level that focuses on professional development to reinforce learning in these two areas resulting in more effective teamwork and communication at the capstone level\textsuperscript{[5]}. Forty one percent (41%) said they learned about a technical area pertinent to the project. We believe that this area can possibly be increased with better matching of student capabilities and interest to technical areas needed for each project. Overall, we interpret that student comments on design process, teamwork, communication and new technical areas as indicating that the course is achieving a good level of successful learning experiences on these points.

By contrast, the remaining three areas that were mentioned less frequently by students are a cause for concern. Only thirty-four percent (34%) of students said they learned about and developed critical thinking skills related to bridging theory with practical design analysis and calculation. This is in line with our observations that only our best students develop confidence and ability in this area. We have noticed, as we are sure other capstone instructors have too, that exercising critical thinking skills in the context of a real-world capstone design project is often very challenging for students. Issues and potential barriers that we have seen with students attempting to conduct analysis and calculations in the context of capstone include the following:

1. Many students have preconceptions about real world engineering and will often express interest in a “hands-on” design and build experience, failing
to recognize the important role of analysis and test in the context of engineering design.

2. Real world problems often do not lend themselves to a straightforward formula solution, forcing students to somehow match fundamental principles with the problems at hand.

3. Depending upon the stage in design development, a system concept may not be fully defined or defined well enough to make productive use of analysis and calculations.

4. Parameters needed to make calculations may be missing and need to be estimated requiring students to engage in iterative solution finding, which is often an unpracticed skill.

5. Given their lack of experience, students are often not calibrated to the relative size and scope of the systems they may be designing, resulting in performance parameters that are orders of magnitude larger than required for practical application and with excessive factors of safety.

6. Simple arithmetic or unit conversion errors leading to questionable results that an experienced engineer would recognize as unreasonable and needing to be rechecked can go unnoticed by students.

As instructors, another area we have often noticed relates to student initiative and their ability to deal with unanticipated changes in project direction. In our study, only twenty eight percent (28%) of students said they learned about resourcefulness. The relatively low frequency of occurrence of students expressing “resourcefulness” as a learning point may be related to student motivation and frustration with the varying degree of open-endedness associated with capstone projects. At one extreme, student tolerance for change and ambiguity may be a function of prior learned behavior that reinforces a mindset of “tell me what I need to do to earn an A”, while at another extreme, it could be a function of student resilience and maturity, and that some students not mentioning resourcefulness as a learning point means they were comfortable with an open-ended problem as a result of prior experiences either on industry internship, coop assignment or some other prior experience. No doubt, other scenarios might also be applicable.

Over the years, we have implemented changes to help students be more successful at delivering significant project results, but there may be conflicting trade-offs. Students understandably want clear direction about what they need to do to be successful. As instructors we have become very good about systematizing the capstone experience for efficient delivery. The question remains as to whether this is the right thing to do.

Of the ten projects in our study, we have observed that three teams described motivation levels that could be characterized as “mixed”, meaning that motivation shifted throughout the course of the project from enthusiasm to frustration and back and forth. These projects, that is, water droplet, senior living, and solar shade projects, could be further characterized as having greater levels of “open-endedness” and ambiguity. For example, the water droplet erosion project could be characterized as research or technology exploration. Students involved on the senior living project were unclear on customer requirements and had difficulty converging on a single concept. The entrepreneurial
nature of the solar shade project resulted in high expectations that contributed to student frustrations. In each of these three cases, students on these teams collectively noted “resourcefulness” as one of their top three learning points, whereas all other teams, with motivation levels consistently positive, “resourcefulness” was never identified in the top three categories of learning points.

The final and least mentioned learning point among the students in our study concerns that of conducting tests and experimentation. Only sixteen percent (16%) of students mentioned learning about this area in their reflective memos. Once again, this is another area often noticed by instructors as an area needing attention. Unfortunately, in the context of a capstone design experience we have often found that test and experimentation often occurs later in the semester, thus leaving minimal time to actually observe and analyze test results. Our response to this deficiency in recent years has been to implement a more rigorous process of project definition prior to engaging students on a project, thus factoring test and experimentation in up-front during project definition.

Perhaps most interesting in our findings relates to what students did not express to any significant level in their memos. Despite the fact that many of the projects concerned themselves with important and worthwhile topics related to addressing contemporary issues that demonstrate the impact that engineering can have on society, economics, politics, safety and health, and the environment, relatively few students mentioned learning points concerning these broader issues and thus no category of learning points were identified to address these desired programmatic outcomes.

Other than for the issue of “resourcefulness” and the degree to which we found that projects with a higher degree of “open-endedness” forced students to take more initiative, we found no clear relationship between types of projects and the frequency of a particular learning point. We hypothesized that we might find some projects with a clear service orientation would promote an expression of learning points related to the broader issues. Instead we found little or no mention of the broader issues. Whether a project was industry sponsored, service related or entrepreneurial, there was no distinguishable difference in the frequency of learning points expressed by students.

Factors Influencing Motivation

Based upon what students expressed in their reflective memos we found that motivation levels was influenced by a variety of factors depending upon the stage in project development and team formation.

At project introduction, motivation was influenced by:

1. the student’s ability to see familiar aspects of the project related to their own technical area or prior experience and interests and/or,
2. the opportunity to participate on a real world project and apply knowledge from prior coursework,
During the first few weeks of the project and up to mid-term, factors influencing motivation included:

1. the enthusiasm of mentors and sponsors for the project and
2. student ability to see a clear vision and direction with respect to project goals. Conflicting and ambiguous information, mid course corrections and changes in project objectives or scope resulted in student frustration.

Particularly during the last half of the semester, student motivation was influenced by the very nature of:

1. working with others as members of a team. Good teamwork translated into well-motivated students, whereas poor teamwork translated into poorly motivated students.

**Broader Impact of Engineering on Society**

There is another area, beyond the seven categories of learning points identified by ABET that deserves mention. That is, broader impacts of the student’s engineering efforts on society. We were concerned by what we did not see from these reflective memos regarding accomplishments on the broader issues ranging from social awareness and ability to integrate economic, global, and cultural issues. Although some projects may not naturally motivate students to include such broader concerns in the memos, others that should have, such as sustainable design and service type of projects, still did not.

To remedy the shortcomings we are considering the following actions:

1. Ask students to investigate the broader issues for each and every project: The students must define the specific issues and topics to investigate, with consultation with the instructing team. The course could provide general guidelines and examples: including the organizational contexts such as value system and reward system for engineering design (e.g., why should engineers care about sustainability design, and why should the company care about it); the economical and managerial issues such as the business models and strategy behind the new product design (e.g., what is the value added for the particular cloud computing facilitation apps that you are developing, and what alternative ways you have to deploy them in the marketplace); and the social awareness such as assessing the significance and implications of the greater context of the new design/technology on the society (e.g., what is the wind turbine industry’s potential economic impacts).

2. Mandate a study on extending personal horizon and cultivating personal growth for individual members of the project team. Each student must define a personal study goal and be evaluated by it, in consultation with the instructors. This individual component will ideally complement the teamwork, but could be conducted independently as well on the project, if warranted. For the multidisciplinary teamwork environment, a personal
component may also help address concerns about individual fitness for the project assignment.

3. Devise a feedback mechanism to diagnose students’ performance on the broader issues and channel the results to faculty, departments, and the school for engineering curriculum design: Although the traditional models should have this mechanism in place already, in whatever forms, the new concerns here would naturally call for an extension of the mechanism to reach out to possible collaboration with faculty and curricula beyond engineering. Alternatively, a new curriculum structure that thoughtfully integrates the social sciences into the engineering curriculum may provide insights on how to devise such a feedback mechanism[6].

Conclusion and Discussion

Engineering capstone design is a well-established practice that enjoys continuing support and interest from both the faculty and the administration of engineering schools. ABET places it as a priority to assure the quality of engineering education. Continuing improvement requires continuing review of not only what the field has accomplished, but perhaps more importantly what the field has missed. When the research was first launched, our intent was simply to improve our understanding of multidisciplinary capstone to gauge student reflections. This intent was soon broadened by our discovery of aspects that we could do better. Moreover, we wondered if we have just unveiled a common limitation in the field of engineering, after all? The paper offered a much-needed direct measure of what we have accomplished in the form of an analysis of students’ end of semester reflective memos. In this sense, it further confirms that we are on the right tract and the lessons established are worth consideration by the field. However, the paper also advocates that we do not stop here.

The analysis reported in the paper was based on listening to two stories: one that the students said; and another that they did not say. Both were expected by ABET. The data came from the student reflective memos collected over five years at the capstone design course at a prestigious private research institution. It turns out that what they said coincided with many of the conventional measures of the effectiveness of the capstone education according to the conventional goals, namely, learning about the design process and teamwork, learning to communicate and expanded their technical knowledge base. What they did not say (enough) included critical thinking, resourcefulness and testing. Another missing area concerned the broader goals, such as social awareness and life-long learning. We regard this missing area as a cause for reform, because the vast majority of engineering graduates ultimately enter fields of occupation that are not “hard core” engineering. In other words, to stay relevant, engineering education must prepare the students to apply their engineering-trained analytical mind for solving non-traditionally engineering problems in the broad society, in a liberal arts sense.
Therefore, instead of congratulating, we offer warning, too, to make a case for moving forward. Does current engineering education prepare our students for the broader kind of real world problem solving? Does engineering education need, not just want, a new generation of engineers that foster personal development with a liberal arts style analytical mind? The paper, based on the new analysis, proposed a rethinking of some of the conventional wisdom and presented some possible extensions to the current paradigm of engineering capstone design.

References:


Appendix

Assignment for Final Semester Reflective Memo

Write a final semester memo that summarizes your accomplishments and design process. Consider this to be your opportunity to provide direct input to your individual performance appraisal. Include in your memo a brief statement of the original project objectives and respond to the following questions. How motivated were you to work on the project? Were you really excited, moderately interested or somewhat apathetic? What influenced your motivation level? How did things change as the semester progressed? What do you think you learned? What kinds of challenges did you face? Was the challenge level too high, just about right, or too low? What were the obstacles to achieving your goals? What is your assessment of your individual performance? Did you play a special role? What kinds of significant contributions did you make toward achieving project goals? Review your design process and list two or three things in the following areas:

Keep: Things you plan to use (do) again in your next design project
Problem: Things that did not work, and you plan to watch out for in the next design project
Try: Things you plan to try in your next design project