

## **Switching Midstream, Floundering Early, and Tolerance for Ambiguity: How Capstone Students Cope with Changing and Delayed Projects**

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# Switching Midstream, Floundering Early, and Tolerance for Ambiguity: How Capstone Students Cope with Changing and Delayed Projects

## Abstract

Industry-sponsored projects are a staple of senior capstone design, and provide our advanced level students with valuable real-world experience. Because of the many players involved in an industrial-sponsored project, there are occasionally changes of scope or project goal adjustments that may occur midstream; this can be frustrating to students, despite best practices in selecting and vetting all project sources. Similarly, there have been research-based as well as industry-based projects that have been slow to launch, taking an inordinate amount of time in the first of the two capstone terms to solidify the problem. Recently, a Capstone offering at Northeastern University had a higher than usual number of projects (46%) which experienced substantial changes in topic or scope after a significant amount of work had been completed by the students. Others (~16%) were slow to launch due to logistics in connecting and/or onboarding with project sponsors, and required extra time to sufficiently define and scope their projects. While this situation created concern for the students, it also generated an opportunity for the capstone course directors to study student *tolerance for ambiguity* in design as well as other factors associated with resultant success levels. Some student teams rose to the challenges and accomplished successful projects, while others realized poor outcomes in terms of implementation and completeness of their solutions. Students were surveyed at the end of the first term of the sequence (Capstone 1) to determine what they were most proud of, what was surprising about Capstone, and they were also asked other questions designed to explore their attitudes and approaches toward the course and its content. Textual content analysis was used to determine major themes and reveal patterns that correlated with final project outcomes in Capstone 2. There was no statistical difference between prototype/success scores for teams who changed topics or launched later and those who did not at the  $\alpha = .05$  level. However, some clear differentiators did emerge. Teams whose topics changed or lagged *and had high prototype scores* reported being proud of their team flexibility, their project and time management abilities, and their positivity and preparedness. Teams whose topics changed or lagged and *had low prototype scores* were primarily proud of finishing the project, and reaching the finish line without reference to the quality of the outcome or personal growth. Looking back to the end of Capstone 1, low-scoring/low success teams were also surprised by the difficulty of the work, the vague nature of the problems, and the time investment, while those who earned high scores/had high success reported being pleasantly surprised by the amount of freedom and time they had to scope the problem and develop a solution. Developing early strategies for students to see open-ended and vaguely-scoped problems as an opportunity and a benefit, rather than a difficulty and a struggle, can accomplish several things: It can (a) help students whose projects have had major roadblocks to succeed; (b) provide perspective for faculty to reinforce the value of Capstone Design as a personal development opportunity; (c) offer opportunities for coordinators and advisors to explicitly outline the nature of the “capstone experience” thus distinguishing it from a standard course – before Capstone, at the beginning, and during the capstone experience; (d) lead to improved outcomes for other industrial-sponsored and research-based projects; (e) inform curricular modifications in order to prepare engineers earlier in the undergraduate experience through more exposure to open-ended problems in their courses prior to Capstone.

## Introduction

Engineering capstone design courses have been extensively studied due to their unique ability to teach integration of engineering principles as well as professional soft skills. Students are provided a chance to prepare themselves for practicing real-world engineering design prior to entering the workplace while simultaneously learning project management, resiliency, and teamwork skills [1]. We have observed great engineering students become disillusioned quickly with the capstone process when they encounter customary levels of uncertainty in their projects. We have students who have, up until the onset of capstone in their senior year, encountered mostly non-open-ended problems, with predominantly pre-defined, closed-form solution sets. Even more challenging for the industrial engineering population is that they tend to crave order, processes, lists, and procedures, either by self-selection into the major or through inculcation. Once they arrive at capstone, they are commissioned to solve problems that don't have an explicit algorithm, list, or established process to solve them.

Due to the real-world nature of senior capstone, in effect the students receive a blank sheet of paper, hearing "go figure out what the problem is –and solve it". In addition to this, there are some sponsors who may not respond very quickly, or change their minds, or receive the initial data and then want more. Figuratively, in many cases, a team has a blank sheet of paper and it feels like it is being pulled away from them every time they work to get the page half full. Some groups manage this well. They take the information they gathered from the first problem they received, and either adapt it or change it to fit the new problem. Others blame the course, the sponsor, and/or the advisor and feel that change is an injustice.

**Capstone Experience vs. Standard Coursework.** Most standard university courses have a planned path, especially in engineering. If they are well organized, the student experiences are progressive, rich and varied, with a strategy for periodic qualitative and quantitative feedback. Many problem sets have solutions – or feasible ranges; programs and projects have foreseeable outcomes, and even the stochastic and simulated models can be objectively evaluated. The capstone experience by design commissions advanced students to tackle open-ended complex problems, which tend to shift for a variety of reasons. Yet capstone is designated as a 'course' in the academic model; typically courses have one set path. If the path changes, that feels unfair somehow and at times this creates a sense of disequilibrium at best, and extreme frustration in some cases. The question stands: How can we best prepare students to manage the challenges that necessarily accompany capstone? This is critical, especially when the circumstances are more dramatic in the cases of late starters and those who have projects that switch focus midstream.

## Background Research

**Tolerance for Ambiguity and Uncertainty.** The skill our students may need to develop or cultivate is *tolerance for ambiguity* [2]. Mohammed et al. studied tolerance for ambiguity and its effect on student design performance [3]. They were focused on first-year programs in particular, but the observations are applicable to capstone design as well. Industry-sponsored design projects are particularly valued because they are real-world, complex, challenging, and motivate students to use teamwork and learn project management and other industrial practices [4]. However, students may have a negative view of industrial projects when they are too open-ended, particularly if they have had little practice in open-ended projects. Mohammed et al. found that students with a higher tolerance for ambiguity show higher levels of collective efficacy, team satisfaction, and conflict resolution than students who have a low tolerance for ambiguity [3]. They found that not only did ambiguity tolerant students perform better on open-ended projects; they tended to react somewhat negatively to straightforward, guided projects. These students did not just tolerate ambiguity – they preferred and sought it.

Hsu and Cardella looked specifically at how industrial engineering capstone students dealt with uncertainty in their designs [5]. This study only looked at one team of 5 students. However, they found that these students tended to use mathematical thinking while they dealt with uncertainty in their designs. In other words, they used some of the same strategies used in math classes, specifically previously established problem-solving strategies and social resources (other students, advisors, tutors) and material resources (textbooks, reference sources, computers). Successful designers using mathematical thinking separated problems into subproblems, transformed complex problems into simpler problems in the face of uncertainty, and less frequently, used a relatively systematic guess-and-check strategy to narrow down possibilities. Although mathematical thinking can be used as a way of getting students to think more positively about design uncertainty, it may depend on how they were taught mathematics, and their ability to transfer the closed-ended skills used on a typical math problem to an open-ended problem.

**The Reflective Practitioner.** A study by Valkenberg and Dorst discussed the use of descriptive and reflective practices in design [6]. This paper drew heavily on Schön's paradigm of reflective practice [7]. Schön contends that every design problem is necessarily a unique challenge. Teaching students the skills to reflect on their design while innovating, in order to advance the design, is essential to teaching design. This also can lead to problems, since if every problem is unique, and the students want a single concrete roadmap for how a project should go, there is bound to be conflict. Valkenberg and Dorst discussed four different design activities: *naming*, *framing*, *moving*, and *reflecting* [6]. These terms were used to describe the activities performed by student designers, in an effort to quantify how much time various teams spent on each activity and relate that effort to team outcomes.

*Naming* includes low-level tasks such as creating a list of topics to pursue. *Framing* involves medium-level tasks, such as creating a subproblem or a partial solution to be used in further exploration. *Moving* includes medium- to high-level tasks generating solution ideas, sorting information, combining ideas, or comparing and contrasting. Finally, *reflecting* is a high-level metacognitive task that critically ponders previous actions in order to know what to do next. Students who get stuck in the naming and framing tasks/levels may be particularly subject to disruption due to scope changes or project delays. In other words, if all you feel you have completed is the low-level tasks, and those tasks took a long time to do, then it is particularly demoralizing to have to discard 'all that work' to start over. However, students who reflect frequently have synthesized greater knowledge from those low-level tasks, which provides ideas on where to go if there is a scope change or adjustment required.

Other researchers have studied reflective practices in capstone design specifically [8]. They note that having participated in complex capstone design projects doesn't automatically guarantee that they will learn the skills and knowledge expected, or that they will be able to transfer these skills elsewhere. One study examined what teamwork issues students reflected on, and whether instructor prompts had any effect on the way students reflected [8]. They evaluated where students fell on a continuum from not reflecting at all to metacognitive reflection on the process of reflection. Although they saw student responses at all points on the continuum, *they did not specifically connect the reflection to student outcomes*. This paper will identify and assess patterns in responses and connect the cognitive level of the responses with outcomes in terms of prototype quality and final grade.

**Writing as a Window to Attribution.** Through standardized writing analyses, researchers Kiniry et al. and Rosenthal examined student reports and compositions to identify attitudes and mindsets towards their work and success [9-10]. An implicit focus was the target of *attribution*, that is, to which factors success and/or difficulty were attributed. An attribution is a causal explanation for an event or behavior. Harvey and Martinko note, "The formation of causal attributions is vital for adapting to changing environments

and overcoming the challenges we are confronted with ...” [11-12]. While there are complex theories as to how attributions are formed, the *presumed sources of outcomes* provides rich insight into individuals’ perspectives. That is, whether successes are primarily attributed to self (internal) or others/circumstances (external factors) and likewise whether challenges and failures are attributed to internal (self) or external factors (others, circumstances, situational conditions) maps predictably to maturity levels as well as relevant performance measures [13].

In the research by Kiniry and Rosenthal, they found that *low-level* skills and attitudes are characterized by a focus on external factors as the source of any difficulties. *Medium-level* comments show the ability to make distinctions between external factors and internal factors as reasons for success or failure. These individuals are able to summarize and compare both the positive and negative aspects of the project work, and are able to move somewhat beyond the focus on course details. Medium-level attitudes tend to be more neutral when facing setbacks and uncertainty, but still are not fully mature. Those with *high-level skills* and attitudes exhibit professional maturity and a growth mindset. They manage, anticipate –and even welcome– change and uncertainty. There is minimal expectation that every aspect of the path will be straightforward, with the belief that they are responsible for a project’s success through their own problem-solving skills, resourcefulness, resilience, and mindset.

## **Methodology**

**Capstone Course Elements and Subject Population.** In the Mechanical and Industrial Engineering Department at Northeastern University, Senior Capstone Design is a two-semester sequence. In the first semester, students are presented with a list of projects which are either proposed by faculty members or by industrial sponsors. Occasionally, students propose projects, which must be vetted and approved by the capstone coordinators. Students are asked to form groups of 4-5 people and rank all the prospective project options based on their interests. Students who are not able to form groups on their own may submit project preferences as individuals, pairs, or trios. The course coordinators then form groups from the individuals based on common project interests and teammate requests.

During the first term of senior capstone design (Capstone1), students are tasked with defining and scoping the problem. This includes background research, initial studies with outside companies, problem formulation, brainstorming, and proposing initial solutions and solution paths. In the second semester, students are responsible for selecting a final solution, fully developing and implementing it, and testing or validating the solution. Deliverables include a final paper and an oral presentation at the end of Capstone 1. In Capstone 2 a design review, two midterm presentations, and three reports are required. Two weeks before the end of the second semester, the teams compose an executive summary that is sent to the alumni jury. The projects are also assessed at the point of the executive summary on how complete their final designs are and also how complete their validation testing is. Their design is scored on an established standards-based scale of 1-5 for completeness, where 5 is a fully functional solution or prototype, and 1-5 for testing and validation, where 5 is a fully tested and validated solution [14]. The final presentation involves a poster session and an oral presentation in front of a jury of alumni and outsiders from industry.

**Procedures.** At the end of the first capstone semester, students were surveyed as individuals to determine attitudes toward their project and the course (Appendix A). For this study, 26 industrial engineering capstone teams were examined, of which 65% were industrially sponsored. Others were research-based or internally generated. Groups were examined based on various demographics such as the number of students on the team, the number of female students, and the number of international students as well. Further analyses were done on project phase, English proficiency, and writing competency. In order to

perform correlation analyses, groups were ordinally categorized based on the origin of the project (1 = primarily faculty proposed with no student participation in project development, 2 = industry proposed, various levels of student participation, 3 = entirely student proposed), and the way the team was formed based on level of student involvement (0 = entirely faculty formed to 1 = entirely student formed). English proficiency was rated based on objective assessments by the capstone communication coordinator of oral presentation and written report skills (High = 3, Medium = 2, Low = 1). It was also noted whether or not the project was a continuation of a previous multi-phase project, or whether it was a new project, with the phases being ordinally assigned.

Student answers to the questions “What was surprising/unexpected about Capstone from your original impressions?” and “What are you most proud of in yourself and/or your team from this term in Capstone?” were rated based on whether they showed low, low-medium, medium, medium-high, or high skill levels and attitudes. The attitudes and skills ratings were adapted from work by Kiniry et al and Rosenthal [9-10]. This was accomplished through standardized content analysis and identification of textual patterning in the responses [15]. The content analyses were performed by the authors and a doctoral graduate assistant while checking for interrater and intrarater consistency.

## **Findings**

Following the ratings of the student responses across questions, the scores were mapped to the work of Kiniry and Rosenthal and interpreted along their metrics [9-10]. The comments then underwent deeper evaluation in the context of capstone in two ways: (1) to correlate the students’ attitudes and responses with their subsequent capstone success levels, (2) and to identify addressable patterns to help us prepare and guide the students toward success in capstone and beyond. The profiles that emerged are outlined and interpreted below, followed by categorical metrics associated with the assigned response levels. Finally, quotations by students at each level are presented.

**Low-level skill and attitude ratings.** Students submitting low-level responses tended to focus on procedural course details, and be rather negative in the face of difficulty. They listed tasks that they did and tended to see the course as a checklist that needs to be completed, rather than an open-ended project. The lower-level comments show evidence of fixed mindset [16]. Low-level attitudes focused on chronological discussion of work and schedule, tended to report outcomes instead of analyzing the causes of difficulties, and were inclined to be proud of meeting the basic requirements. These show much more of a linear, course-based focus than a project or problem-solving focus and tend to have unrealistic impressions of what is expected from capstone.

**Medium-level skill and attitude ratings.** Students providing the ratings that were designated as medium-level seemed to begin to recognize that groups will have different paths to completion, and some paths will be more arduous than others. They also appeared to recognize and appreciate the need for professional skills. At this level, students also recognized the necessity to apply concepts from their coursework. However, it tended to be more of a force-fit than an informed application of solution tools. For this level, the course was still a primary focus, and these groups had started to accept the open-ended nature of capstone. However, the open-ended nature with its concomitant uncertainty still was a source of ongoing frustration rather than motivation to develop or seek alternative creative solutions.

**High-level skill and attitude ratings.** Here, we saw evidence of productive integration of previous coursework and an appreciation of engineering concepts from the students’ major. They were proud of using scientific argument and relating their work to previously published studies. The open-ended nature

of capstone and freedom to find solutions was exciting to these groups, not threatening. The project and its associated opportunities were the focus, and they were proud of valid progress and accomplishments. Comments were detailed and forward looking, and tended to be very positive. Students were able to handle setbacks well, work around roadblocks, and were proud of this fact.

**Metrics.** Table 1 below shows the results of a Pearson’s Product Moment correlation analysis of the number of responses in each category compared to the team prototype scores. Effectively, this relates success to attitudes toward the course. Again, all analyses here are associated with teams whose projects had problems or issues that resulted in significant delays or alterations in direction or scope. Low-level responses are very negatively correlated ( $R^2 = -0.66$ ) with high prototype scores. Low-medium level responses are also negatively correlated with high prototype scores, but to a lesser extent at ( $R^2 = -0.33$ ).

**Table 1: Pearson correlation factors relating number of responses of each level with prototype scores.**

| Level of Response: Number in each Response Category                                      | Correlation factor with Project Prototype scores |
|--|--|
| Low  | -0.66  |
| Low-Medium   | -0.33  |
| Medium   | 0.34   |
| Medium-High  | -0.07*   |
| High   | 0.51   |
| <i>*Strong individual outliers and a smaller n account for the profile at this level</i> |  |

As seen in Table 1, medium and high-level responses are both positively correlated with high prototype scores ( $R^2 = 0.34$  and  $R^2 = 0.51$ , respectively). Students who are able to achieve, apply, and recognize the value of high-level skills early in the capstone experience –at the end of the first term– tend to be able to achieve better outcomes. Students who are focused on course details, rather than project elements, or are negatively reacting to the work load and/or the uncertainty rather than embracing the multifaceted open-ended nature of capstone, tend to produce lower quality projects in the end. The medium-high responses are unexpected. This could be due to a relatively small number of comments deemed medium-high.

Currently, prototype scores are available for all the projects from one course section; the remaining are in progress. However, when all groups were compared using factors other than prototype scores, certain aggregate patterns emerged that help characterize factors that provide insight into the findings. The number of team members, females, and international students for each team as well as information on team formation method, project phase, and English communication ability were correlated with the number of responses of each level. The factors were all ranked ordinally as discussed above.

Table 2 shows correlations with various factors grouped by response level. As noted above, prototype scores were positively correlated with high-level (0.51) and-medium level (0.34) responses. Prototype scores were negatively correlated with low-medium (-0.33) and low-level (-0.66) scores. This would corroborate the theory that high-level skills, and the ability to articulate high-level skills, leads to more sophisticated outcomes. *Writing scores* were positively correlated with high-level responses (0.41) and low-medium (0.28) level responses and were negatively correlated with low-level responses (-0.34). There seemed to be less of a clear relationship between writing scores and high-level scores. It could be that students are able to, in some cases, write well about low-level outcomes.

Table 2. Correlative relationships between level of commentary and select factors.

|                | Negative Correlations | Positive Correlations                       |
|----------------|-----------------------|---|
| High-Level     |                       |   |
| Med-High Level |                       | <p>No <math>R^2</math> values above 0.2</p> |
| Medium-Level   |                       |   |
| Low-Med Level  |                       |   |
| Low-Level      |                       |   |



Many industry-sponsored projects require a higher level of student involvement in the problem development stage in order to be successful. A higher proportion of *student involvement* is positively correlated with high-level responses (0.36). *Industry-sponsored projects* were negatively correlated with low-medium (-0.40) and medium-level responses (-0.29). There is also a small positive correlation between industrial sponsorship with less student involvement and the lowest level of responses (0.21), which is more difficult to explain. *Student-formed* teams also showed a high-level of student involvement throughout the project and a positive correlation with high-level responses (0.26). This is reflected in the high-level responses discussing team efficacy. There was also a positive correlation between having changes in a project scope or direction and whether or not that project was industry-sponsored (0.46).

High-level responses were positively correlated with high *English proficiency* (0.43) and *writing grades* (0.41). There was a negative correlation between the number of *international students* on a team and the number of high-level responses (-0.32). This could indicate that some of the low-level responses could potentially be a result of poor English skills, or that high-level responses are being misunderstood due to uncertainty in expression in some cases.

An interesting observation was the effect of the *number of female students* on the caliber of response. The number of high-level responses was positively correlated with the number of female students (0.43). There were negative correlations between the number of females and the number of medium (-0.30) and low-medium (-0.38) responses. It is not clear why this is true. There are also some effects with the *phase of the project* as well. Phase 1 projects are positively correlated with high-level responses (0.29) and negatively correlated with med-high (-0.19) and low-med level (-0.19) responses. Phase 1 projects require a larger number of high-level activities, because they have to build from the ground up. Phase 2 or higher projects generally are at least partially defined by their nature, and may not elicit as many high-level responses.

### **Quotations from Student Responses**

To provide context, below are select responses to the questions in each of the categories set out above. They are listed from low to medium to high for the two questions: “surprising/unexpected” and “most proud of ...”

#### ***Low-level answers to:***

***“What was surprising/unexpected about Capstone from your original impressions?”***

*“The method of teaching/supervision”* (Class focused)

*“How well organized the structure of the capstone course has been..”* (Class focused)

*“I thought the concept phase of the project would be easier.”* (Frustration with challenge)

*“The [rapid] speed/pace that Capstone 1 runs”* (Class focused, frustration with challenge)

*“The project was more focused on improvement instead of analyzing”* (Expecting a set path for the project)

*“It was more constant work than I expected. It was necessary to meet at least twice a week.”* (Unrealistic expectations of capstone, especially given that at least one class/week was dedicated to team/advisor meetings)

*“I was surprised with how long it took to determine the scope of [our] project and how difficult it was to contact our sponsor.”* (Frustration with challenge)

*“I thought we would have more of a choice in our project topic (we got our 8th choice, then the project got changed/suddenly cancelled.”* (Class focused)

*“I was expecting more detailed project requirements and demands. The project given to my group was very vague and open-ended. Dialogue to establish what the project sponsor was difficult and the team often found itself pulling teeth to find out what the sponsors requirements were.... I would have appreciated more explicit requirement information from the sponsor in order to better develop our ideas on what to do. I felt like we had to do a lot of guesswork on what the sponsor wanted and invented a solution that may or may not live up to their demands.”* (Class focused, external factors causing problems)

**Medium-level answers to:**

***“What was surprising/unexpected about Capstone from your original impressions?”***

*“How open ended it is –there’s not one right answer”* (Recognizing the nature of the course)

*“The impact of the project is really important”* (Beginning to see beyond the course to a project focus)

*“I was surprised how open-ended it is. I’m having a hard time figuring out how to narrow our scope.”*  
(Recognizing open-ended nature, but still struggling with it)

*“I expect more guidance from the Capstone advisors; instead they gave us a lot of freedom and independence”*  
(Frustrated by open-ended, but beginning to accept it)

*“Holding down a project was surprisingly difficult. It all worked out fine, but it was surprising compared to my original impression”* (Unrealistic course expectations, but still persevering)

*“To be honest I am a little disappointed with the type of projects we have as options. I wish IE students had a bit more options. There were more healthcare projects than anything else. But I’m really happy with my project.”* (Moving beyond frustration)

*“I definitely thought we would have had more guidance as far as the guidelines for the paper and presentation, but it seems to work out anyways and is a growing experience. I also thought our contact would have had a more clear vision of what she wants from us.”* (Slightly negative, but recognizing the benefits of the experience)

**High-level answers to:**

***“What was surprising/unexpected about Capstone from your original impressions?”***

*“The difficulty of the project is solely based on how hard we push ourselves”* (Maturity in outlook)

*“That there is so much flexibility and so much left up to our interpretation”* (Celebrating flexibility, freedom)

*“How your project can actually have a significant impact on something greater, not all about receiving a grade”* (Fully looking beyond the course)

*“The amount of freedom and independence that our advisor and sponsor gave us with the scope and process of our project”* (Celebrating flexibility and freedom)

*“That it’s much more student-driven. I was expecting more push and involvement from our advisor. But it’s a great opportunity that we have this autonomy”* (Embracing open-ended nature in spite of original expectations)

*“I was surprised by the freedom to operate. I thought teams would roughly go through the same process of problem formulation and data gathering.”* (Recognizing potential for multiple paths)

**Low-level answers to:**

**“What are you most proud of in yourself and/or your team from this term in Capstone?” include:**

“Background research” (Focused on basics)

“I am proud that we managed to stay on track” (Assuming a fixed path)

“The overall results of the presentation and the report” (Focused on basics)

“Staying on top of our work for the most part and seeing our advisor every week” (Focused on basics)

“I like how we clarified our scope and started to formulate our next steps for the fall.” (Focused on basics)

“I am proud of how our presentation turned out and how well prepared our team was.” (Focused on basics)

“Contributed to the brainstorm, and established a timeline and milestone for the project” (Focused on basics)

“We manage to catch up with the other teams, as our project was changed after the first week.” (Assuming all projects should have a similar path or progress rate)

**Medium-level answers to:**

**“What are you most proud of in yourself and/or your team from this term in Capstone?” include:**

“Actually working [with] and understanding real hospital data to find an optimal solution” (Moving toward higher level skills)

“Our team has done a good job of managing our time and getting things done ahead of time.” (Appreciating professionalism)

“I’d say I am very proud of how flexible each member in our group was as far as scheduling meetings and helping each other with parts of the paper. I am also proud of the positivity and how well our group has worked together so far.” (Appreciating professionalism)

“Most proud of the team’s organization throughout the process and working through busy schedules” (Appreciating professionalism)

“I am proud of the coordination our team had while trying to get things done. We worked well together and everyone did their tasks on time and in a professional manner.” (Evidence of collaboration and focus on outcome)

“We were able to finally get things going in the last few weeks of Capstone I. Project stakeholder started to get excited about the potential solution to the problem and the next steps that should be taken become more clear.” (Seeing beyond the course)

“I’m proud me and my team were able to complete our project as we wanted. I learned about a topic I was really interested in.” (Showing self-directed learning)

**High-level answers to:**

**“What are you most proud of in yourself and/or your team from this term in Capstone?” include:**

“We kept an open mind and stayed motivated.” (Mature viewpoint)

“Relating previous literature/existing algorithms to the specific problems of the [client]” (Application of high-level research skills)

*“We wasted no time because of good project management. We got base level ideas in front of our sponsor as soon as we could get her feedback and thus put us on the correct path.”* (Using previously learned skills)

*“I am very proud of my team being able to develop a clear path for this project. We started with nothing else other than the notion that we were dealing with a company with issues and we developed a challenging but feasible project out of it.”* (Embracing challenge and open-ended problem)

*“I am proud that the team was able to gain a thorough understanding of human psychology, memory and learning processes, and data tracking equipment in such a short period of time. The team members and I have never taken courses related to this field and relied on our IE background to understand the process. I think we did a good job of understanding the background information in depth and preparing ourselves to be able to adequately present the information during the presentations. I think we did an amazing job of taking a very vague project statement and developing experiments that will generate useful data.”* (Mature viewpoint, application of previously learned skills, advanced analysis, self-directed learning)

## **Discussion**

The work by Mohammed et al. indicated that students with a higher tolerance for ambiguity would show higher satisfaction with their team, higher collective team efficacy, and greater conflict resolution skills [3]. High-level comments tended to also show these markers for ambiguity tolerance. A typical high-level comment from a high performing group stated:

*“I’d say I am very proud of how flexible each member in our group was as far as scheduling meetings and helping each other with parts of the paper. I am also proud of the positivity and how well our group has worked together so far.”*

Low performing teams showed a lack of tolerance for ambiguity, as illustrated by responses such as:

*“I was surprised with how long it took to determine the scope of [our] project and how difficult it was to contact our sponsor.”*

The low performing teams seemed to expect that they would be presented with a well-defined, circumscribed project on the first day, and a sponsor who was waiting by the phone for their call, with volumes of data. They seemed to think that all projects would follow the same path, and that there would be a series of tasks to check off in order to finish capstone. The fact that this was not the case tended to bewilder, frustrate, or anger the low performing teams. While some of the higher performing teams also may have expected a predefined, focused path, they then embraced the fluid nature of their projects.

*“I imagined Capstone being more technical and “by the book” when it came to our projects. I was surprised to see how much liberty we had on defining the scope of our project and the amount of time we had on our hands to create our own work schedules. I am proud of the advances we made as a team on a project where the scope wasn’t well defined. At first it seemed scary to have such a broad range of options as to where to take the project, but with the help of our advisors and through research and discussions (which also brought us together as a team) we successfully narrowed the scope of our project and defined our goals.”*

High-performance teams demonstrated a collective resilience, integrated previous coursework, and were project focused. They were flexible, procedurally agile, and displayed growth mindsets. In terms of attribution for success and meeting goals, they were outwardly focused in productive ways, and on the other hand, attribution for challenges did not blame instructors, advisors, industry sponsors, or course structure for their difficulties. Problems and setbacks were seen as par for the course, something requiring acceptance, adjustment, ingenuity, and perseverance.

Low-performance teams tended to be collectively more rigid, and expected the capstone course to be self-contained, rather than requiring information from previous courses or knowledge that needed to be learned by the team. They tended to be very focused on the course –schedules, reports, and procedural details– rather than the project and overarching objectives. They focused inward, either on their own individual needs and wants, or occasionally on the team, and far less so on the needs of the other stakeholders in the project. Because of the need for a rigid, set path, deviations from what they expected capstone to be threw many teams into a tailspin. Difficulties were seen as a failing on the part of the sponsors or the instructors, not just part of the normal design process; all are examples of external attribution for challenges faced.

## Summary

These findings represent an opportunity for those of us in capstone leadership and engineering education in general to work to prepare our students and our faculty in a more informed way around the foreseeable challenges inherent in the design experience. We have the unique opportunity to reframe the students' perspectives on the unscripted aspects of capstone in particular. Accordingly, we can accomplish the following throughout the academic process:

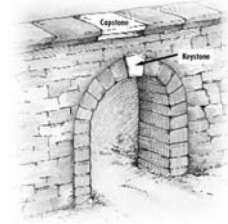
- ***Early in the engineering curriculum***, infuse experience in managing challenges through more practice in *problematic*-based learning, which includes failing early and recovering in low-risk situations;
- ***Prior to Capstone***, orient the incoming students to the essence of course, its path, and general objectives;
- ***In the process of orienting new faculty and in preparing for a new term***, align with the advisors and faculty who oversee the teams to model strategies to manage ambiguity and coach the teams;
- ***At the outset of Capstone***, discuss the expectations, problem-solving approaches, and mindsets that accompany successful teams and projects;
- ***Early in Capstone, present research findings*** to the class and involve them in generating a profile of effective situation ownership and management;
- ***When immersed in Capstone***, model the behaviors that the students are expected to embody: respectful communication, creative problem solving, managing unintended outcomes, regrouping;
- ***Following Capstone***, enlist available graduates to present to future students through examples, stories, coaching, and mentoring.

Promoting ambiguity and uncertainty as challenges to be welcomed as a normal part of engineering design at all of the above stages in the Capstone experience and across all constituents –coordinators, advisors, sponsors, and students– will help keep teams from floundering during scope changes or temporary setbacks. We want to not only prevent or offset students' stress and frustration due to project changes, but also to raise their level of professional skills in expecting, coping with, accepting, managing, and even embracing uncertainty as preparation for their professional careers. These are skills and perspectives that we can also embody as faculty, to serve as examples and role models to our students.

## References:

- [1] Dutton, AJ, Todd, RH, Magleby, SP, & Sorensen, CD, "A Review of Literature on Teaching Engineering Design Through Project-Oriented Capstone Courses", *Journal of Engineering Education*, Vol. 17 (1997) pp 17-28.
- [2] Furnham, A & Ribchester, T. "Tolerance of Ambiguity: A review of the Concept, Its Measurement, and Applications", *Current Psychology*, Vol. 14, No. 3 (1995) pp 179-199.
- [3] Mohammed, S, Okudan, G, & Ogot, M. "Tolerance for Ambiguity: An Investigation on its Effect on Student Design Performance", *Proceedings of the American Society for Engineering Education Annual Conference*, Chicago, IL (2006).
- [4] Magleby, SP, Todd, RH, Pugh, DL, & Sorensen, CD, "Selecting Appropriate Industrial Projects for Capstone Design Programs", *International Journal of Engineering Education*, Vol. 17, No. 4 (2001) pp 400-405.
- [5] Hsu, MC & Cardella, M. "The Use of Mathematical Thinking to Deal with Uncertainty in a Capstone Design Course", *Proceedings of the American Society for Engineering Education Annual Conference*, Austin, TX (2009).
- [6] Valkenburg, R & Dorst, K. "The Reflective Practice of Design Teams", *Design Studies*, Vol 19 (1998) pp 249-271.
- [7] Schön, DA. *The Reflective Practitioner*, Basic Books, New York (1983).
- [8] Gerlick, R, Davis, D, Brown, S, & Trevisan, M. "Reflective Practices of Engineering Capstone Design Teams", *Proceedings of the American Society for Engineering Education Annual Conference*, Louisville, KY (2010).
- [9] Kiniry, M & Strenski, E. "Sequencing Expository Writing: A Recursive Approach" *College Composition and Communication*, Vol. 36, No. 2. Writing in the Academic and Professional Disciplines: Bibliography Theory Practice Preparation of Faculty (1985) pp 191-202.
- [10] Rosenthal, LC. "Writing Across the Curriculum: Chemistry Lab Reports", *Journal of Chemical Education*, Vol. 64, No. 12 (1987), pp 996-998.
- [11] Harvey, P, & Victoravich, LM. The influence of forward-looking antecedents, uncertainty and anticipatory emotions on project escalation. *Decision Sciences Journal*, Vol. 40 (2009) pp 759-782.
- [12] Martinko, MJ, Douglas, SC, & Harvey P. "Attribution Theory in Industrial and Organizational Psychology: A Review. In G.P. Hodgkinson and J.K. Ford (editors), *International Review of Industrial and Organizational Psychology*, Vol. 21 (2006) pp 127-187. Chichester, UK: Wiley.
- [13] Graham, S. "A Review of Attribution Theory in Achievement Contexts", *Educational Psychology Review*, Vol. 3, No. 5 (1991).
- [14] Smyser, BM & Kowalski, GJ. "Assessing the Effect of Co-op sequence on Capstone Design Performance", *Proceedings of the American Society for Engineering Education Annual Conference*, Vancouver, BC, Canada (2011).
- [15] Hsieh, HF & Shannon, S "Three Approaches to Qualitative Content Analysis", *Qualitative Health Research*, November (2005) pp 1277-1288.
- [16] Dweck, CS. "Mindsets and Math/Science Achievement." *Carnegie Corporation of New York-Institute for Advanced Study Commission on Mathematics and Science Education*, Stanford University (2008).

APPENDIX A: Survey Content



**Capstone 1 Input 2016**

1. What was surprising/unexpected about Capstone from your original impressions and expectations?
2. What are you most proud of in yourself and/or your team from this term in Capstone?
3. Why do we have more classes scheduled than actually meet (3 real reasons)?
4. What information could have been conveyed in a more productive, clear, or timely way for you?
5. What makes a good advisor? What makes working with an advisor particularly challenging?

6. What were the most challenging and rewarding aspects of working in your team?
7. What did you appreciate about Capstone 1 and/or the Capstone experience as it developed?
8. We are working to compile a student handbook to avoid uncertainty as well as minimize extra emails and announcements for routine elements. Any suggestions for content?
9. Finally, it has been shown that Capstone is best formulated as a series of seminars, even if all topics do not apply to all students at the time of presentation. What additional topics would you like to see covered in Capstone by experts (i.e. liability issues, how to obtain technical resources without a subscription, more policies for working with Human Subjects, ...)
10. Any other constructive thoughts, ideas, input, celebrations and parting thoughts?

*Thank you!*