



Data-Driven Uncertainty Management in Capstone

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At the beginning of the two-semester capstone sequence in Northeastern University's College of Engineering, students receive a course overview outlining the general objectives of Capstone and the associated deliverables. They learn that teams will be formed and projects will be assigned following project introductions and a bidding process. Two cohorts of the same Capstone program were asked during their first day of Capstone to outline (1) Their concerns and questions, and (2) what they were excited about and/or looking forward to in the capstone experience. After reviewing the responses from the first group in summer [Cohort 1], capstone coordinators noted relatively short-sighted attention to the mechanics of project assignment and team formation as primary concerns. The coordinators adjusted the introduction for the next group of students in the fall [Cohort 2] to provide additional transparency to the team creation and project allocation process. Thematic analysis for the same questions yielded richer and deeper areas of focus for the students in Cohort 2 who were more settled with the early-capstone logistics. While there were several common topics across both cohorts related to concerns about budget, resources, guidance from advisors and final deliverables, the percentage profiles were markedly different. The approach with Cohort 2, which clarified some of the predictable housekeeping questions up front, resulted in a clearer sense of students' longer-view concerns and questions. These included taking initiative, managing workload and effort, staying on track and recovering from failed approaches, as well as requests to identify pitfalls to avoid and success factors to model. This revised approach (1) gave coordinators immediate feedback to address with the class at hand and (2) provided incentive to adjust the introductory approach for future classes. Further, the ability to neutralize students' initial apprehensions allowed for deeper analyses of their questions, and brought to light additional areas that could be clarified preemptively in future orientations. It also fostered a shift from a pattern of short-term focus to longer-term thinking in the capstone lens and lead to a more grounded capstone launch. This paper concentrates on the concerns of the students, while the positive anticipation aspects will be covered at a later date.

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Introduction and Motivation

In many colleges and universities, the Capstone Design experience (Capstone) is heralded as the crowning culmination of a student's academic journey (1, 2). In the College of Engineering (CoE) at Northeastern University (NU), Capstone is discussed at recruitment events, at Welcome Days, Orientation, in introductory courses and throughout the CoE curriculum. Students hear about it from colleagues and classmates who are taking it. They see the challenges and concerns, they pass by the Capstone Studio and see all kinds of technically advanced activity, and a fair amount of uncertainty (3, 4). They see how the pursuit of a complex engineering solution –in addition to navigating team dynamics– can consume their dedicated colleagues.

While Capstone can be transformative and immensely rewarding, by design capstone problems are open-ended and not merely task-oriented (5, 6). The best projects tend to be vaguely defined, largely self-directed, and at times, fraught with multifaceted trials. In the course culture, each capstone project is slanted toward 'solution', and successes are celebrated leading up to and on Final Capstone Day. However, it also can be fraught with ambiguity, especially at the beginning, unintentionally preceded by intimidating myth and folklore (7, 8).

Given pre-capstone concerns at NU, capstone leadership can preemptively address key issues and appropriately guide students through (and into) the various challenges that necessarily accompany the capstone journey.

Background

The Mechanical & Industrial Engineering Capstone Program at Northeastern University is offered in a two-semester academic profile of Capstone 1 and Capstone 2 over the course of an academic year. In the industrial Engineering (IE) program, students from the same graduating class take Capstone 1 in one of two profiles: (1) They attend during the first half of summer with a 6-month co-op interval before Capstone 2, which occurs in the following spring. This is an accepted feature of the program and projects are planned and set out accordingly for this gap. (2) The second set of classmates meet in the fall semester and move right into Capstone 2 separated only by the winter break. Both sections join together for Capstone 2 in the succeeding spring semester. With the exception of some of the course timing, these sections are comparable in composition, content, and goals. They even share the same syllabus and same general timeline.

Methodology

On the first day of Capstone 1, students in both summer (Cohort 1, $n=36$) and fall (Cohort 2, $n=33$) received an overview of Capstone intended to address the syllabus contents, the outline the overall objectives of Capstone, and present the project options for the year. This past year, the first cohort was asked two key questions at the outset of Capstone. Namely:

- Uncertainty/Wondering About: “*What are at least 3 things that you are wondering about in relation to Capstone? Not only Capstone 1 and not just tomorrow, but across the Capstone Experience?*”
- Excitement/Looking Forward To: “*What are at least 3 things that you are excited about and/or looking forward to in relation to Capstone? Not only Capstone 1 and not just tomorrow, but across the Capstone Experience?*”

Every student responded to the two questions with at least three entries –some with even more– providing a generous overview of sentiments. As noted in the abstract, this paper will focus only on the first question, the “Uncertainty/Wondering About” concerns, reserving the Excitement aspect for future analysis and inquiry.

Following a thematic review of the responses from the summer Cohort 1, the coordinators noted a strong tendency to focus on immediate concerns relating to getting a preferred project, contribution level of potential team members, and the method of forming teams.

The profile of Cohort 1’s clear priorities presented a ready opportunity to make use of this feedback to prepare for the next group in the fall offering. Accordingly, the

Capstone orientation for Cohort 2 was shifted to a more intentional and thorough overview of the project allocation and team formation processes as well as a more detailed description of the project types. Then, the same two questions were posed to Cohort 2 in Fall semester at the corresponding Capstone 1 orientation stage.

Thematic analyses and key findings are outlined below.

Results and Discussion

All responses for each of the cohorts underwent a multirater thematic analysis to identify and compare patterns and common themes (9). Some were combined into slightly broader categories –for example, the entries ‘meaningful project’, ‘implementable project’ and ‘relevant project’ combined to form the general grouping of ‘impactful project’.

Cohort 1. The response pattern for the first cohort is seen in Figure 1 below, showing that exactly 50% of the class had a concern about the *Project*: type, topic, and interest level, and nearly 33% were concerned about the *Team*: composition, effort level, and commitment. Likewise, nearly 33% expressed concerns about the allocation *Method* of projects and team members. Other primary areas of focus were the form of the final *Deliverable* (18%) and the level of *Independence* vs. *Guidance* provided by advisors and coordinators (14%).

The Cohort 1 profile shows a concentration on the short-term logistics of launching in Capstone, with minimal references to process the end product and even less focus on the project’s inherent value. Less than 20% were concerned with the *End product* (~14%) or *Process* (7%).

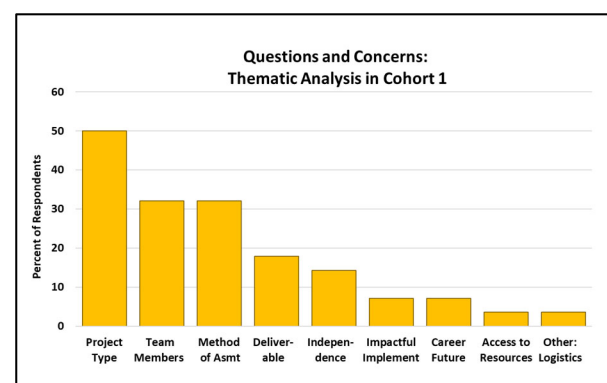


Figure 1 – Cohort 1 open-ended responses about uncertainties and items they were wondering about at the outset of Capstone.

Cohort 2. As noted in the Methodology section, minor but strategic adjustments were made to the introductory session in the fall Capstone offering. The coordinators systematically outlined the methods to be used in the project bidding and assignment process as well as how

the teams would be formed using student preferences as a key part of the algorithm. The fairness and essential aspects of systems thinking were emphasized just prior to the introduction of each of the candidate projects. The team-formation linear algebra was described such that $4x+5y = enrollment$ and $x+y = \# approved total projects$.

The same questions were then posed for Cohort 2 with remarkably different results, as seen in Figures 2 and 3.

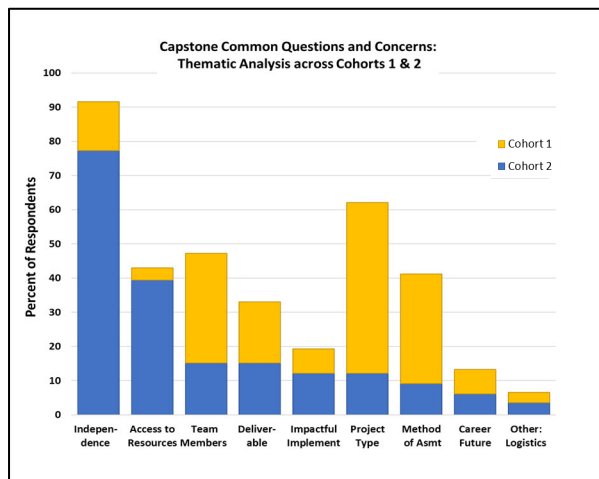


Figure 2. Cohort 2 (blue) open-ended responses (from most → least) about uncertainties and issues of concern at the outset, following a modified orientation. Cohort 1 (yellow) is stacked.

Refer to the ordered blue columns in Figure 2 for the Cohort 2 results that corresponded with the existing Cohort 1 categories. The yellow stacked columns represent the respective Cohort 1 values, rearranged from Figure 1. With the concerns about the assignment methods eased, over 75% of the fall students in Cohort 2 revealed more meaningful uncertainties about how much *Independence* they would have along with the amount of guidance they may receive from advisors.

At ~40%, the next common area of concern related to the *Access to Resources*. After those top two points of curiosity, the areas related to the *Form of the Deliverable* at ~ 15%. The students were moving into process and solution mode much more readily than their counterparts in Cohort 1. Finally, only ~15% of this group expressed concern over the *Composition of the Team*. All other common values were 12% or under for Cohort 2.

Cohort 2 had a much wider array of uncertainty topics than Cohort 1. While Figure 2 above presented the common themes across both cohorts, it is supplemented by the topics in Figure 3, which presents additional areas of concern and curiosity found in the Cohort 2 responses.

A large percentage of the Cohort 2 students also revealed concerns about in-course elements, such as the *Workload*

and *Effort* payoff (~51%), *Keeping to a Timeline/Meeting Deadlines* (~45%), and managing *Course Logistics*, assignments, and demands (~36%). These three areas, along with the *Independence* (~77%) and *Access to Resources* (~40%) previously reported, comprised the top 5 concerns for the second cohort. These prioritized areas indicate that the students' lenses are trained on becoming immersed in the project by turning their minds to project management and ability to deliver.

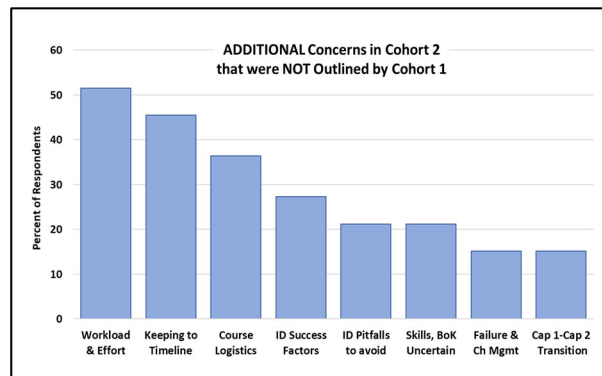


Figure 3. Additional Cohort 2 open-ended responses about uncertainties and issues of concern at the outset of Capstone. These are topics that were NOT listed by Cohort 1 students.

Moving further along to the right on the column graph in Figure 3 shows further focus on the capacity to deliver with quality. Here, ~27% would like us to help them identify success factors and over 20% were wondering what pitfalls they could avoid. Another 20% were looking to figure out how to obtain the required body of knowledge (BoK) and skills if they did not already have what was needed to successfully complete the project.

These findings present a strong case for assuaging basic concerns right away and then framing the right questions at the right time to gain additional insights into students' perspectives. This still allows the typical array of capstone challenges to be experienced and overcome by the teams throughout the Capstone Experience.

Lessons and Conclusions

Asking the students for their initial sentiments at the beginning of Capstone provided valuable and actionable information. This work delivered several benefits:

- Students were welcome to freely express their early concerns in writing with the promise of receiving timely and thorough responses.
- Capstone coordinators were able to understand the topics weighing on the minds of the students as Capstone was beginning and were able to then address those concerns effectively in real-time.

- With timely responses from the coordinators after each feedback review, many students learned that they were not alone in their worries and that several others shared their questions and uncertainties.
- For cases in which changes were not going to be made on the basis of student feedback (i.e. conditions would remain unchanged for specific systemic reasons), the coordinators had the opportunity to provide reasons and context for those conditions. Team size is an example.
- Capstone coordinators were able to adjust the next round of orientation messages to allay some of the concerns of the subsequent incoming cohort.
- Students were able to convey deeper and more meaningful themes around their uncertainties once the organizational mechanics were clearly and succinctly addressed.
- Moreover, students were able to look further ahead and were freer to focus on and express their thoughts about more advanced aspects of the capstone profile.
- In turn, the more evolved thought processes in the second cohort provided an additional iterative feedback loop, contributing to an improved level of responsiveness by the coordinators.

With the above benefits, coordinators can move ahead to foster initiative, promote independent learning, support calculated risk-taking, and champion resilience (10).

In the final analysis, it is hard to say whether there were any seasonal effects may account for the difference in the cohorts' responses, with the following considerations.

- Cohort 1 in summer had more days on campus together before the start of Capstone -and had been discussing their concerns, which may account for their more homogenous responses.
- Cohort 1 in summer may not have been as concerned about next-spring deadlines as those in the fall semester due to the longer planning horizon.
- Cohort 2 in fall just completed an accelerated term and may have been more tuned in to deadlines and deliverables than Cohort 1.

Recommendations and Future work

Requests for this type of student-centered feedback will continue in the future, not only at the outset of Capstone, but also throughout the Capstone experience during the academic year. Further iterations and clarifications to the course orientation –and other class elements– will be made as necessary in future Capstone offerings.

The next set of evaluations will assess the findings on the positive side, exploring what the students are excited about at the beginning of Capstone under the basic and then revised orientation conditions.

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