

Catalyzing Capstone Project Success through Readiness Reviews and Reflection

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Abstract

The two-semester team-based capstone sequence in the Industrial Engineering Program at Northeastern University has incorporated *internal* Project Readiness Reviews (PRRs). These reviews supplement a robust set of existing mechanisms for review, feedback, and iterative learning, including *external* design reviews. They are intended to strengthen both the technical work of the teams and their overall success in the capstone experience. The PRRs take place near the end of the first term of the sequence, after the students have presented their work to capstone peers, faculty advisors, and the two coordinators. The PRRs occur a few days after presentations and involve frank feedback from the course coordinators. They follow a semi-scripted rubric that assures coverage of course objectives, ABET student learning outcomes, and client needs. These readiness reviews serve as internal design reviews and provide feedback based on missing elements, known pitfalls, best practices, and established success factors. Based on student feedback, they also include an extended interactive component, allowing more two-way communication than seen in formal presentations. Teams have the opportunity to implement some of the recommendations in their first-term report, and are asked to reflect on their experience with the PRR in an end-of-term survey. This effort is in its first full year, and results to date have been positive, both in terms of student feedback and perceived effect on student performance.

Introduction

Capstone projects are a common way to culminate an undergraduate engineering education and in fact are required for accreditation. As outlined by ABET (Accrediting Board for Engineering and Technology) in General Criterion 5: Curriculum, students should have “a culminating major engineering design experience that 1) incorporates appropriate engineering standards and multiple constraints, and 2) is based on the knowledge and skills acquired in earlier course work” (ABET, 2021). Capstone Projects have many advantages, but they can get off track for a variety of reasons. This can fuel disparate results, both technically and in terms of students’ educational experience. A small but growing body of work supports the idea of internal Project Readiness Reviews (PRRs) to help ensure that *all* students have a successful capstone experience (Gravell et al., 2021; Gravell et al, 2020). In some cases, this is characterized as faculty coaching by leadership, distinct from advising (CalStateLA, 2021; Pembrige & Paretto, 2019; Adams et al., 2017). This paper describes the first phases of an implementation of internal PRRs in the capstone program in the Industrial Engineering (IE) Program at Northeastern University (NU).

Existing Program and Motivation for Experimentation

The undergraduate program in the Mechanical and Industrial Engineering (MIE) Department at NU requires a 2-semester capstone sequence. A capstone experience is a required part of the accredited NU degree program. It contributes to all categories of the new ABET assessment standards [Jaeger et al. 2019; ABET, 2021]. Four- or five-person teams are formed to tackle

projects proposed by faculty or industry partners (clients/sponsors) and supervised by individual faculty members (advisors). Two faculty members (coordinators) lead and manage the course requirements and grade most of the work, although advisors have a significant influence on the final grade through their assessment of project progress and success.

Capstone 1. During the first semester in Capstone 1, teams formulate a problem statement, conduct necessary background research, outline solution alternatives, and make preliminary selections of tools and potential solution techniques. There are a variety of capstone-specific class sessions, exercises, and assignments in the first semester to coach students to key milestones as well as encourage initiative and autonomy. Examples of module topics include Meeting the Client, Formulating a Problem Statement, and Conducting Background Research. Capstone 1 work concludes with a presentation and a report. By the end of Capstone 1, teams are expected to have outlined a path forward in preparation for Capstone 2. However, teams may not have made comparable progress, owing to the variety of projects and factors unique to each project, problem, and client.

Capstone 2. The majority of the technical work is typically accomplished in the second semester, Capstone 2. Among other assignments, a midterm presentation and report serve as practice and a chance to iterate towards the final products, which include an executive summary, an on-line juried presentation, an in-person poster-and-pitch day, and a final report.

Feedback. It is well established that constructive feedback is enormously valuable, particularly if certain conditions are met: It should come from a respected source, it needs to be relatively immediate, and it should be delivered with thoughtful clarity from a “more knowledgeable other” (Salalahi, 2019). Further, the recipient(s) ought to be in a receptive and ideally solution-oriented frame of mind (Stone & Heen, 2014). Throughout the capstone experience, teams benefit from feedback, questions, expert guidance, and coaching (Adams et al., 2017).

More specifically, Northeastern’s IE Capstone program integrates multiple opportunities for teams to receive feedback. Regular assignments, weekly advisor meetings, frequent client interactions, coordinator check-in sessions, open class Q&A, peer-to-peer feedback, and written faculty evaluations during presentations all serve as sources of feedback. The writing coordinator meets with every team once a term to provide detailed feedback on the writing assignments, and assure the teams are poised to create high-quality documents. The writing program is described in a recent Capstone Conference paper (McManus, 2022). Further, all teams are strongly encouraged to seek out faculty members for consultations in their areas of expertise.

Table 1 shows the major feedback events and course milestones over the two-term sequence, with the PRR activities designated with brackets. Not shown are weekly or bi-weekly meetings with the teams’ advisors and/or sponsors, the details of smaller assignments associated with the writing program, and specialized assignments in topics such as safety, research methods, or proper treatment of human subjects.

External Design Reviews. It is a standard practice to have capstone project teams conduct external design reviews (DRs) with subject matter experts and/or stakeholders outside the university (Ramos, 2021; Hill & Campbell 2018, Pierrakos et al, 2013). Northeastern is no

exception. External design reviews are common in industry to evaluate a project against initial requirements and highlight any need to reprioritize and refocus future efforts. Capstone DRs can further ensure that the work follows appropriate methodology and can confirm that the solution incorporates sound principles and processes. A DR can ask probing questions as well as provide novel insights that teams may not have considered. (Cardoso et al., 2014). At the beginning of Capstone 2, students in the NU plan and carry out an external DR with outside experts and report on the outcomes. These DRs best happen at a point in the sequence when the teams and projects are becoming firmly established (Enemuoh, 2021).

Uncertainty, Professional Development, and Self-efficacy. Capstone Design projects –if well chosen– will necessarily have ambiguity as part of each project’s challenging profile. More specifically, Industrial Engineering projects have the tendency to be processed-based, as opposed to delivering a tangible product. The requirement to abstract across most aspects of a problem poses unique challenges to IE teams (Bauer et al., 2012).

Table 1. Major Milestones and Feedback Events throughout the Two-Semester Capstone sequence. PRRs and their assessment are bracketed in Capstone 1 weeks 13 and 14.

TIME FRAME	EVENT/MILESTONE	FEEDBACK SOURCE	TOPIC
Cap 1 Week 3	Teams and Projects assigned		
Cap 1 Week 8	Team check-in	Course coordinator	Project Focus
Cap 1 Week 9	Writing Consultation	Writing coordinator	Skills and Organization for Writing
Cap 1 Week 11	Capstone 1 Presentations		
	Faculty Evaluations	All advising faculty	Technical aspects and approach and presentation
	Student Feedback	All capstone students	Presentation, tech. aspects
Cap 1 Week 13	Internal Project Readiness Reviews	Course coordinators	Technical and Organizational Readiness for Cap 2
Cap 1 Week 14	Data collections through Student Reflection and assessment	Teams	Readiness for Cap 2 Cap1 experience, including PRR
	Capstone 1 Report		
Cap 2 Week 3-4	External Design Review	External Subject Matter Expert	Technical approach, tools used, possible opportunities
Cap 2 Week 7-8	Capstone 2 Midterm Presentation + Report		
	Faculty Feedback	All advising faculty	Technical and presentation
	Student Feedback	All capstone students	Presentation, tech. aspects
Cap 2 Week 10	Team check in	Course coordinator	Project Completion
	Writing Consultation	Writing coordinator	Readiness for Final Report Writing
Cap 2 Week 14	Executive Summary	Writing coordinator	Project Status Overview
Cap 2 Week 15	Final Presentation to Jurors	Jurors, through an established rubric	Technical depth, skill acquisition, innovation, soundness of solution
Cap 2 Week 16	Poster, Pitch, and Final Report		

Invariably, there will be adjustments and pivots in the process, no matter how well the students plan, even for the more conceptual projects (Jaeger-Helton & Smyser, 2017). Part of the full capstone experience for engineering students entails addressing these challenges and yet prevailing despite setbacks (Jaeger et al., 2010). Research has shown that individual student temperament and team culture can each have significant impacts on managing complex and uncertain project scenarios, but they are not the only factors in the project's momentum (Smyser & Jaeger, 2015).

In most capstone offerings, student teams are guided by their advisors, course instructors, coordinators, and even peers throughout the process, further helping them navigate the uncertainty. Earlier capstone research has shown that emphasizing the need to develop and practice problem-solving approaches, along with the requirement to learn new skills outside their domain, supports student development (Dunlap, 2005). PRRs aim to support these aspects of professional growth.

Rationale and Opportunity for Timely and Customized Feedback. Despite the existing feedback mechanisms, coordinators observed that some teams tended to be unprepared to address the ambiguity and open-ended nature of their projects and were underprepared for the beginning of Capstone 2. Even well-organized teams sometimes missed opportunities to take advantage of tools or data at their disposal. Still other teams were inordinately challenged by the multifaceted nature of their project profiles. A key element of student success is related to their ownership of all facets of their project (Jaeger & Smyser, 2014; Joshi et al., 2019). Providing feedback, establishing student accountability for project success, and contributing to their professional growth became the goals for our next improvement opportunity.

The Capstone sequence has metrics for student outcomes in all seven of the ABET criteria (ABET 2022). Students are expected to cover many aspects of engineering in their work and communication, including new (to them) topics such as intellectual property, ethics, and societal and global impacts (Bauer, 2012). Some groups failed to fully understand these requirements or missed out on opportunities to increase the value of their work by including them.

An intervention to improve this situation was desired, but the bandwidth of both the student teams and the course coordinators was very limited. Success data and student comments collected over several years suggested a possible approach. Student feedback on the coordinator team check-ins and writing consultations were quite favorable as seen in Figure 1 later in this paper. Students clearly valued any amount of personal attention, coaching, and mentoring from the course coordinators. This combination of factors made an experiment with internal PRRs a promising opportunity.

Internal Project Readiness Reviews

Given the success of the individual meetings with course coordinators, ratings and commentary from student reflections and select remarks from course evaluations, the authors likewise saw the value in directed personalized feedback sessions. Inspired further by the capstone work of Gravel et al., (2020, 2021), the authors developed and implemented *internal* design reviews providing opportunities for each team to have a dedicated time to meet with the two course coordinators to

discuss their projects—and associated challenges and pathways—as Capstone 1 was drawing to a close. As noted, these were called Project Readiness Reviews (PRR).

PRR Program implementation. The PRRs were inserted into the existing program near the end of Capstone 1. They were carried out by the course coordinators, working as a team. As seen in brackets in Table 1, the reviews took place after the Capstone 1 presentation. This had the major advantage of ensuring that the coordinators were fully briefed on the students' work, so the students did not have to lead off the meeting with a progress report. A total of 18 student teams were reviewed, in two cohorts. Ten teams of 4-5 members took Capstone 1 in Summer 1 term of 2021, and eight more in Fall 2021. All teams took Capstone 2 in Spring of the following year.

Setting the Stage: Student Preparation. The PRRs were scheduled during class time in the same order as the Capstone 1 presentations, approximately one week later. This gave each team an opportunity to view their presentation video, consider the questions from their presentation Q&A session, and receive and review written faculty advisor evaluations and classmates' peer-to-peer feedback. We encouraged teams to look for patterns in the written feedback and evaluate all input in relation to their project work (Hurst & Nespoli, 2019). Following this reflection period, all members of each team attended their PRR. The students were told that the nature of the PRR was to provide guidance and outline areas that could require additional consideration and effort, with the goal of contributing to their project's success. Any reflection and preparation that they could do in advance and bring to the review was encouraged, but none was officially required.

Setting the Stage: Coordinator Preparation. Before the PRR meeting, teams were assessed on a variety of measures by the two course coordinators. The coordinators divided the assessments between them; both assessed every team, but on separate criteria aligned with their individual areas of expertise and their roles in the course. The assessments were done using (a) a set of informal prompts or thinking points (Table 2), and (b) a more formal rubric which was aligned with the ABET student learning outcomes (Table 3). The informal prompts created notes and discussion points for the review; the rubric was assessed with a letter grade and accompanied by specific comments. These were not shared directly with the students; rather they were used as talking points by the coordinators during the discussion and were updated after the review to capture a record of the discussion.

It is important to note that although they were in attendance facilitating the activities of each day, the coordinators did NOT participate in the Capstone 1 final presentation Q&A. The reasons for this were three-fold: (1) this allowed more participation by and interaction with peers and faculty advisors, (2) from their capstone leadership experience, the coordinators often have more remediating suggestions that could inordinately alter the tone of the presentation experience, and (3) given the coordinators' deeper familiarity with each project, customized advice was reserved for the private PRRs. Coordinators still completed evaluations during the presentations, however.

PRR Meetings: The Flow. The reviews lasted 20-25 minutes. Most PRRs started with a statement of intent, along with assurances to set the students' minds at ease. As noted above, students were told that the aim of the review was to help guide them, focus their efforts, support them, and align their goals and those of the IE capstone program. It was stated that the

conversation would be frank—“You can’t know if *we* don’t say something” was the operative phrase—and the students were also invited to speak freely, because “We can’t know if *you* don’t say something.” There was no grading impact from any aspect of the PRR, which helped assure the students they were being assisted, not judged. The PRRs were private, allowing more frankness, thus informing students of problems that might otherwise have been downplayed, and informing faculty of student concerns that they may have been reluctant to discuss in public.

The coordinators addressed the topics outlined in Tables 2 and 3, as was fitting for each project and team. They made observations and provided recommendations, accompanied by select questions. The proportion of question-asking and fielding responses varied across the two rounds of PRRs, with the second round providing more opportunity for interaction and even rebuttal as was appropriate.

Table 2. Informal Prompts for the Project Readiness Reviews, curated by the Coordinators

Coordinator 1: Areas to address as necessary	Coordinator 2: Areas to address as necessary
Project Management	Current and/or Competitor Practices
Literature Review & Background	Statement of Impact - Social, global
Inclusivity Addressed & Bias mitigated	Technical Detail - Tools & Methods
Technical Detail - Tools & Methods	KPIs CSF Metrics/Measurable Results
PS & Approach: Scoped well and Feasible	Human Subject Research Prospects
Establish Basis of Work	Delivering: Paper? Process? Data? Plan?
Intellectual Property Prospects	What will you learn that is NEW? How?
What IE IS: Efficiency, Productivity, Optimization, System Improvement	

Table 3. Rubric with Sample Evaluation and Comments Created prior to the PRR by Course Coordinator

ABET SO	Criteria	Sample Evaluation (notional, not a real team)	
1	Problem Definition	A	Well done, responsive to feedback
7	Background	C	Late start, still working
1,2	Solution Approach	C	Issues considered but Path not clear
2,6	Plan	C	Next steps are not outlined enough to be actionable
5	Roadblocks	B	Issue understood, solution paths not identified
7	Technical Knowledge	A	Strong start. Difficult technical problem. Any issues we should talk about?
6	Success metrics	B	Is it good enough to just do a study? More Opportunity to contribute to the field?
5	Teamwork	A	No cracks or issues visible at this time
4,2	Impact (global, social, ethical)	A	This could be huge, tell the story
3	Writing	C	Needs work, needs proofreading and team editor
3	Presentation skills	A	Great work! How did you accomplish this so well?

Assessment of the Project Readiness Reviews

In the first iteration of PRRs, the notes and rubrics prepared by the coordinators were covered systematically, with suggestions for improvement methods and resources provided where needed. The students could ask questions and were given the opportunity for a short comment at the end, but the format was not highly interactive. Perhaps in the spirit of frank discussion, the students gave some explicit feedback on the organization of the reviews, which is discussed below. As a consequence, the second time the reviews were held (one term later) the format was considerably more interactive, and no further negative or change-suggesting feedback was received.

Paired with the PRRs were student reflections. The reflection exercises were incorporated into an existing feedback event on the last day of Capstone 1. These were carried out by the students in their teams. They were asked to discuss the questions outlined below and provide a single team answer. As part of our internal assessment, students had already been asked to reflect on their readiness for Capstone 2 and to provide general feedback on the course. Questions were added that explicitly addressed the PRR process, and the students were asked what they took away from the PRRs that would help them in Capstone 2.

Specifically, students were asked to assess the course resources, including the PRRs:

Think about the course resources - lectures, but also videos, handouts, on-line (Canvas) resources, exercises, etc. How useful were they in helping you achieve success in Capstone? 1 = Not really helpful, 3 = Somewhat helpful, 5 = Very helpful

They were asked what they took away from the reviews:

Consider the end-of-term [Project] Readiness Review. It was intended to let you know how course coordinators thought your project was doing, allow you to share your thoughts on your project status, alert you to potential technical and organizational issues, and give you a chance to ask key questions and clarify expectations. Name four things you took away from the [Project Readiness] Review.

They were given dedicated class time to discuss the questions and answered using an on-line form. All 18 teams provided feedback.

Student Reflections on PRR Format and Implementation. The reflection following the first round of PRRs provided some key feedback. Some representative student comments are:

“We learned a lot more during our one-on-one meeting with Prof. [] as it was more of a discussion than in the readiness review. A discussion is always better than just providing feedback!”

“The readiness review was greatly appreciated, however after a group discussion post review, we felt feedback was slightly vague so we did not entirely walk away with a new approach or new direction. We appreciate the time, but felt it was a little ambiguous.”

“[We] would have really appreciated that the readiness review was more two-sided, a discussion.”

Adjustments made following Round 1 Feedback. Patterns in the feedback above were taken to heart for the second round of PRRs. Namely, (a) the aim of the review meeting was outlined at the beginning of every PRR with a clear and consistent set of objectives and assurances, whereas in the first round this was done informally and somewhat sporadically; (b) the coordinators conducted an informal Pareto Analysis, focusing on the key areas that were critical and specific to each team—not all topics were fully visited; (c) the coordinators were more intentional about delivering reality-based recognition for aspects of the project, progress, and/or presentation that each team had done well; (d) the coordinators spent some time asking each team about their greatest challenges and sources of uncertainty, *and they listened and responded*. For (d) above, we drew motivation from a key piece of external design review advice: foster inquiry and ask questions, both planned and responsive (Cardoso et al., 2014). Although not originally a motivation, we found we had converged upon some known best practices in formative assessment (Nicol & Macfarlane, 2006). The student response to the changes were positive, with slightly improved quantitative feedback, and no further negative comments pertaining to the implementations of the PRRs.

Student Ratings of Course Resources. The quantitative data collected was a comparative assessment of course resources. In the aggregate data across both rounds, the readiness reviews were judged somewhere between “somewhat helpful” and “very helpful” by students; they were judged less helpful than the other personal interactions, but more helpful than the topic-based lectures and other resources. The most interesting thing about this result is the fact *that the personal interactions and mentoring resources were consistently rated higher than lectures or other resources, with 5 of the 6 top-rated resources being interactions, while all of the bottom 5 were lectures and/or videos.*



Figure 1. Student assessment of helpfulness of course resources

Student Listings of PRR Value and Lessons. The students were asked what they took away from the PRRs. Teams provided three or four items, typically in bullet or short sentence form. Through contextual analysis, the results were examined, and clear categories of responses emerged. Figure 2 shows the number of responses in each category.

Planning. One third (66.7%) groups reflected that they needed to plan out their work more effectively. Responses ranged from the basic “Establish more concrete plan moving forward” to the almost poetic “The route to a solution is just as important as the solution itself.”

Writing. More than half of the teams (55.5%) reported both skill improvement and organization around creating reports as focus points emerging from the PRRs. Reflections included “Have someone designated to proofread and edit the final report” and “Practice and improve our technical writing skills.” Students also realized they needed to establish sound KPIs and other success metrics.

Positive Affirmation. Almost 40% of the teams expressed some element of positive affirmation from the PRR. “It was nice to hear we are on the right track for the upcoming semester,” “We are doing better than we thought,” and “Our silent work is recognized” were typical comments. This was an unexpected result. Evidently hearing from the course coordinators, in an environment of honest exchange, that they were doing at least some things right, was a good thing for the students.

Technical Aspects. About 40% of the teams reflected on a variety of specific technical issues. This indicates that the PRRs can serve as a forum for technical critiques, but the relative number of these reflections indicates the PRRs are effective well beyond the technical domain.

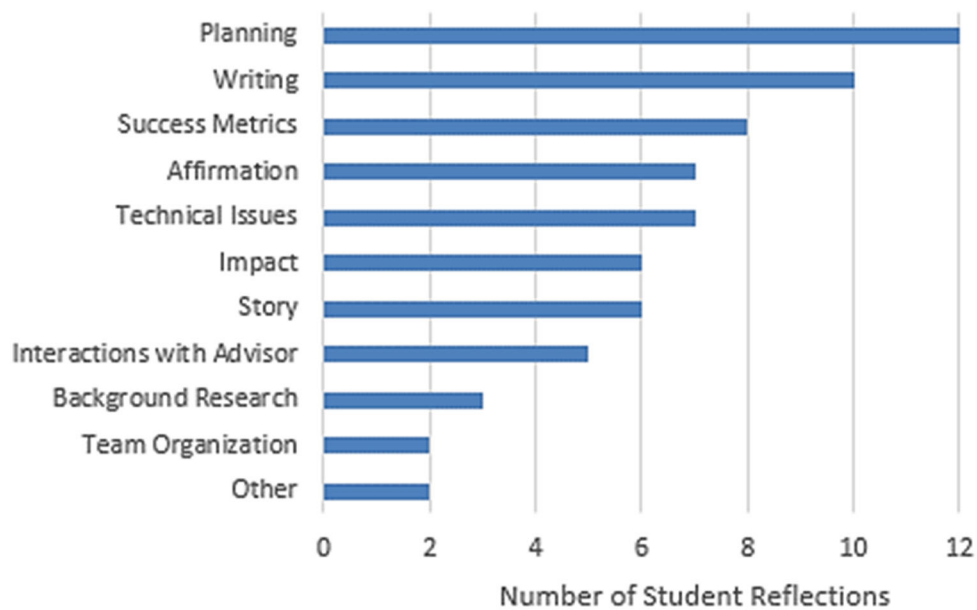


Figure 2. Student Reflections on Lessons from PRRs

Ethics and Impact. One third of the teams reflected on ethics and impact. Most of these were realizations that the groups should think more about potential impacts: “*Think more [about] and highlight the impact of our project.*” Others were more contemplative: “*Consider importance of emphasizing compassion as engineers.*”

Clarity of Vision, Foundation, and Communication. Other categories included understanding the need to explain their work, e.g. “*Focus on our story and relevance to real world,*” as well as improving lines of communication to advisors and sponsors, better background research, and improved team organization.

The Assessment Initiative. Students appreciate having a voice. In the same way we provide them with constructive feedback and expect them to be open to it and implement it, we needed to model the same receptivity discussed earlier (Stone & Heen, 2014; Urbanic, 2011). Further, students tend to be effectively motivated by formative feedback received along the way as opposed to being driven solely by the summative capstone results (Kiefer & York, 2021). The very act of authentically serving the students and their projects through the PRRs and asking about the value of the PRRs has had a positive effect on the course tone.

Integration of Internal Project Readiness Reviews into the Capstone program.

The integration of the PRRs into the overall Industrial Engineering Senior Capstone Design program has been smooth. A welcome effect was seen at the formal Capstone 1 presentation: the coordinators took a background role, collecting information for the PRR, resulting in much richer engagement between student peers and with non-coordinator faculty during the presentation Q&A. The students noted they could apply the feedback from the PRRs immediately in their first-term reports; this seemed to have a positive effect although this is only anecdotal at this point.

The PRRs have been an efficient use of the coordinators’ time. Preparations are quick, using the prompts and rubrics to collect information during the student presentations and via a (brief) review of other team submissions. The PRRs themselves occupied periods which would have otherwise been office hours. There may even be some time savings; if the students act on their reflections, they will avoid issues later in Capstone that would require more faculty intervention.

Conclusions

The implementation of coordinator-guided internal Project Readiness Reviews is ongoing. The positive effects seen in the two rounds of data collected to date—with feedback-based improvement—have propelled this initiative toward a practice to be permanently integrated into Capstone 1. The positive student reflections indicate that the PRRs have already driven improvements in their project work. The implementation of PRRs have also served to connect the coordinators with the student teams in a meaningful way. The teams have received timely customized feedback from the coordinators, heard private critiques, and had opportunities to discuss issues and be heard. Finally, the guiding topics covered in the PRRs help ensure that ABET criteria are met intentionally and authentically. The success of the implementation and improvement of the pilot round of PRRs, and the positive effects on student projects, have been more than sufficient to earn the PRRs a place in the crowded syllabus. We look forward to reporting on more quantifiable success in the near future.

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