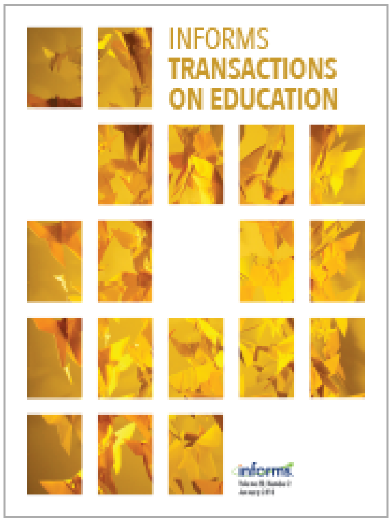

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Are Our Students Prepared? The Impact of Capstone Design Pedagogical Approaches on Student Skill Development During Industry-Sponsored Fieldwork

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Abstract. Capstone design courses are field-based courses in which students work on real-world industry-sponsored projects. The structure of engineering capstone design courses varies between institutions as well as within an institution in the context of faculty engagement, industry involvement, and course learning objectives. We present a summary of an ongoing study focused on assessing engineering skills prefieldwork and postfieldwork experience at two institutions with different course structures in their respective industrial engineering programs. Our research goals are twofold: (1) to develop a framework for measuring the changes in students' engineering skills during their capstone course and determine how these skills align with industry expectations and (2) to explore how differences in capstone course delivery impact the capstone experience. We developed two assessment instruments, one that involves student self-assessment across a set of engineering skills, and one with which the industry partners involved with mentoring participants in the projects evaluate the same students' engineering skills using the same assessment items. The results of this case study inform educators on students' perceived skill levels as well as industry expectations of a newly graduated engineer's performance across a range of skills deemed important for workplace success. We also discuss the impact of pedagogical approaches and fieldwork course structures on skill development and project success.

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Keywords: capstone • fieldwork • team project • engineering education

1. Introduction

A capstone course provides students a culminating experiential fieldwork learning experience and a valuable opportunity to solve large, unstructured problems in a classroom setting. For the purpose of this study we use "fieldwork" and "capstone design course" interchangeably. Throughout the capstone experience, students find themselves faced with complexities not found in traditional courses, particularly because the projects are industry sponsored. Often, these team-based projects reflect industrial settings where operations research (OR) and management science (MS) methods, such as scheduling and simulation, are used to address a problem. Although engineering courses increasingly integrate project components into course design, a capstone course is a prominent part of engineering degree programs. A key characteristic of capstone design projects is that the solution approaches require demonstration of comprehensive knowledge and skills from multiple courses and these projects tend to be sponsored by, or in partnership with, local organizations. Capstone courses are an essential part of industrial engineering degree programs in many countries and are central to the development and assessment of student professional competencies for program accreditation (Davis et al. 2003).

Motivated by accreditation requirements (e.g., ABET criteria 3 and 5 in the United States) and by industry concerns about workplace preparedness of engineering graduates (George et al. 1996, Lang et al. 1999), many degree programs across OR/MS and engineering disciplines have adopted the use of industry-sponsored field training experiences as part of the capstone course. Although the instructional objectives of senior-level undergraduate capstone courses are generally consistent from one academic program to another, the manner in which these objectives are achieved varies widely (Neumann and Woodfill 1998). Many different paradigms exist for developing a senior design capstone course (Todd et al. 1995). At a time when student learning and assessment in capstone courses are increasingly important to program accreditation (Davis et al. 2003), capstone course instructors are challenged by the need to plan and facilitate such a course.

Our research goals are (1) to develop a framework for measuring the changes in students' engineering skills during their capstone course and fieldwork experience and determine how these skills align with industry expectations and (2) to explore the delivery of the capstone on the students. For this initial study, we chose two programs: North Carolina State University's Edward P. Fitts Department of Industrial and Systems Engineering (NCSU ISE) and Worcester Polytechnic Institute's industrial engineering program in the Foisie School of Business (WPI IE).

Scant research exists in the capstone design teaching community concerning best pedagogical practices for field training and how these practices affect student learning and preparation for the workplace. Accordingly, the purpose of this study is to inform the pedagogical development of capstone project courses that use OR/MS/ industrial engineering (IE) methods. Our research questions are as follows:

1. Do students experience a perceived improvement in their engineering skills after completing their field-based capstone projects?
2. Do students' engineering skills meet the expectations of the industry partners?
3. How can different field-based capstone course delivery be implemented to meet student, industry, and faculty needs?

We answer these three questions by developing an assessment instrument based on the set of learning outcomes for capstone design courses consistent with the desired attributes of an entry-level engineer. We chose the learning outcomes and desirable attributes resulting from the research of the Transferable Integrated Design Engineering Education (TIDEE) Consortium, which collected results from various research efforts, such as capabilities published by professional societies, ABET Criteria 3 and 4, the Industry–University–Government Roundtable for Enhancing Engineering Education, and competencies developed by Iowa State University (Davis et al. 2003). In this paper, we present the findings of a two-year study addressing our research questions through a case-study approach using NCSU ISE and WPI's IE capstone design courses during the 2013–2014 academic year.

2. Background

2.1. Capstone Course Organization, Instruction, and Administration Methods

A variety of possible designs exist regarding how a capstone course might be organized, taught, and administered (Dutson et al. 1997). One of the first design decisions for a project course is the extent of faculty involvement in student team mentoring. The literature on the role of mentoring in the capstone course reflects a wide range of expectations for the mentors and their academic positions as well as interchangeable use of the terms *mentor*, *facilitator*, *advisor*, and *coach* (Bruhn and Camp 2004, Manuel et al. 2008). Some courses define the mentoring relationship as managerial in nature. For example, Stanfill et al. (2010) identify the role of faculty mentors as ensuring that the team meets the course goals, keeping the team focused on the design project, dealing with team management issues, aiding teams in meeting technical goals, and ensuring that the team achieves the accreditation outcomes. Kurkovsky (2008) indicates that the instructor must not only provide lectures, but also resolve issues that occur during challenging field-based tasks. Rather than using a hierarchical structure, some courses define the mentoring relationship as more informal. For instance, the department of electrical and computer engineering at the Rose-Hulman Institute of Technology uses a less formal structure in which a faculty mentor is not a member of the team, not a manager, and not a subject matter expert (Moore and Farbrother 2000). Rather, these faculty mentors are a resource for questions and problems encountered, in response to which they provide guidance and suggestions, review product design specifications, and obtain equipment (Moore and Farbrother 2000). Blended mentoring models also exist. Grand Valley State University deploys mentoring teams that consist of (1) a faculty advisory board that assigns students to their advisors, provides technical support, and coordinates the management of the project and (2) a faculty advisor who is responsible for the educational process and the development of student skills (Mokhtar 2010). Mentors for capstone courses need not always be faculty; they can be external to the academic institution. Design teams at Bucknell comprise an advisor, course coordinator, and industry mentors (Tranquillo et al. 2008). Although the extent of faculty involvement varies, the literature points to the critical role instructors have in shaping students' perception of their learning and success (Khan et al. 2007), skill development (Paretti 2008), project management (Milne and Zander 2012), and technical completeness (Armacost and Lowe 2003, Wankat 2005).

Given the varying roles of mentors, the pedagogical approaches vary between departments and institutions. Regarding the instructional component, a number of institutions have a course structure with formal instruction in the first few weeks and more informal meetings thereafter, and others have occasional instruction as needed throughout the course. Some courses use class time for students to meet with clients or advisors and to present informally to their peers (Howe 2010). Although instructors and institutions operationalize capstone courses in many different ways, these courses have several important similarities. Capstone courses provide senior students with a culminating experiential learning experience that allows them to solve a realistic problem by drawing on the technical and professional knowledge acquired throughout their undergraduate education. Fieldwork projects typically stem from ill-defined problems for which no single solution exists (Davis et al. 2003, Todd and Magleby 2005). These courses, although varied, typically involve some form of faculty mentorship, instruction, external sponsorship, extended duration, and teamwork. Pembridge and Paretti (2010) suggest further research to identify the teaching methods in capstone courses that best support learning. For a detailed example of how to develop a capstone course curriculum, including daily activities, roles, and responsibilities for project teams, clients, and educators, see Salo (2012). Likewise, Goldberg (2016) provides a recent review of capstone design course structures, including topics to cover, team logistics, and deliverables.

2.2. Assessment of Capstone Courses

Assessment of capstone course performance is receiving increasing attention. One stream of literature addresses capstone assessment criteria. For example, Gibson (1998) describes a very detailed assessment tool for a capstone design course delivered in a centralized format and provides examples of distribution of the final grade across a number of assignments. Livesay et al. (2010) developed a supplemental evaluation to assess student actions and attitudes important to a successful design experience. The authors note that traditional student evaluations of teaching and typical course- or program-related assessments of student design performance do not address the information needs of capstone design instructors. Hackman et al. (2013) provide details regarding an industrial engineering senior design grading formula encompassing 12 categories.

A second stream of literature investigates general capstone assessment frameworks. Beyerlein et al. (2006) developed an assessment framework for aligning learning outcomes and methods for examining performance related to these outcomes while providing feedback that improves student learning in these outcome areas. The framework incorporates three perspectives: those of the educational researcher, the student learner, and the professional practitioner. In a recent paper discussing the role of design experiences in undergraduate engineering education, Crismond and Adams (2012) identified key performance dimensions deemed central to informed design. They used these dimensions to develop a matrix that presents learning goals, teaching strategies, and behaviors of beginning designers as opposed to those of informed designers. Davis et al. (2003) present an assessment plan that may be used midprogram and end-of-program throughout an engineering curriculum. The authors provide rubrics with scoring scales that provide a uniform assessment process across programs, thereby facilitating ABET accreditation.

Against this backdrop of capstone course-assessment literature, many opportunities exist for developing a further understanding of how pedagogical approaches foster student skill development in the fieldwork environment, particularly how these skills align with industry expectations. We note that many of the current studies do not incorporate the viewpoint of the industry partner, and we argue that industry expectations provide a performance target for soon-to-be graduates and their faculty advisors. We developed a survey instrument to assess the change in student skill level precapstone and postcapstone and implemented the instrument at NCSU ISE and WPI IE. Simultaneously, we used the same items to assess industry expectations of students' performance and skills precapstone and assessment of actual performance postcapstone. We explore our findings and discuss the implications for design of the fieldwork experience.

2.3. Institutional Background

North Carolina State University (NCSU) is a public research-intensive university located in Raleigh, North Carolina, in the United States. NCSU has more than 34,000 enrolled students with historical strengths in engineering, agriculture, and life sciences. The Edward P. Fitts Department of Industrial and Systems Engineering has an undergraduate population of approximately 300 students; awards a bachelor of science in industrial engineering, and maintains ABET accreditation. As part of the BS IE degree, students must take the senior design course (ISE 498), which is a single semester in duration, offered in both fall and spring semesters. As of academic year 2016, approximately 45–50 students annually enroll in and graduate from this course. The objective of ISE 498 is to provide students with an industry-sponsored project experience in which to apply their ISE skill set in developing a solution to an engineering problem. Students work in teams and must demonstrate technical proficiency through their analysis and professional skill proficiency through a variety of communication and presentation requirements.

Worcester Polytechnic Institute (WPI) is a private research university located in Worcester, Massachusetts, in the United States. As a polytechnic, the university tends to be devoted primarily to the instruction and research of technical arts and applied sciences. It has a student body of just over 6,000. WPI maintains a project-based curriculum that requires all undergraduate students to complete (1) a sufficiency in the liberal arts requirement; (2) an interactive qualifying project (IQP) with students from other disciplines to study the social effects of technology; and (3) a senior design project within their own discipline, called the major qualifying project (MQP). Both the IQP and MQP are typically field based. The Foisie School of Business houses WPI's IE program. The program has an undergraduate population of approximately 45 students and awards a BS in IE to approximately 15–20 students each year. As part of the degree requirements, in completing the MQP, the student should focus on synthesis of all previous skills and information studied to solve problems or perform tasks in IE with confidence and communicate the results effectively. The MQP focuses on enhancing students' ability to design a system, component, or process; to function as part of a multidisciplinary team; and to communicate effectively.

NCSU students have varying levels of preparation for working on projects of the scale encountered in the capstone course through summer internships and previous work experience. Similar to NCSU students, WPI students have diverse degrees of work experience prior to beginning the capstone experience. As part of the preassessment, we asked students to indicate how many internship or co-op opportunities they have had and found no statistically significant differences (2.25 NCSU, 2.62 WPI). However, WPI students have a project-based curriculum, which may better prepare them for fieldwork.

3. Research Methodology

3.1. Assessment Tool Development

To understand how students' skills may change during the two different capstone courses, we collected preproject and postfieldwork project data at both institutions. We asked students and industry partners from both institutions questions related to engineering skills typically developed in an undergraduate IE degree program.

Our main assessment instrument was adapted from a set of learning outcomes for capstone design courses found to be consistent with the desired skills and attributes of an entry-level engineer (Davis et al. 2003). These outcomes are the result of research by the TIDEE Consortium (Davis et al. 2003). The TIDEE research focused on developing a profile of a successful engineer and integrated results from various research efforts, such as professional societies, ABET Criteria 3 and 4, the Industry–University–Government Roundtable for Enhancing Engineering Education, and competencies developed by Iowa State University (Davis et al. 2003). A team of industry and academic professionals convened to rank and revise the resulting 11 attributes. Our rationale for using the attributes listed by Davis et al. (2003) was to include measures that can address the evaluation of engineering behavior and skills for engineers in training. Because the results from that study present a profile of top entry-level engineers that exemplify ABET criteria, recommendations from industry, and input from engineering academics (Davis et al. 2003), the profile provides a relevant foundation to establish a set of questions for assessing capstone students at the completion of the course.

For this study, we selected eight of the 11 listed attributes from the study by Davis et al. (2003): motivation, judgment and decision making, innovation, client/quality focus, product development, professional/ethical practices, teamwork, and communication. The three remaining attributes (technical competence, business orientation, and change management) are more suitable for evaluating individuals with significant work experience as an engineer and are more appropriate for assessing engineering management ability or technical expertise rather than student performance. The survey items and corresponding statements appear in Table 1. Although the assessment tool is based on engineering skills, the assessment could be applicable to field-based courses in the operations research curriculum as many of the attributes listed are desirable in OR/MS professions. We measured all items using a five-point Likert-type scale, on which one is *poor* and five is *excellent*.

In addition to the survey, we gathered qualitative data from the industry partners upon completion of each capstone project. NCSU and WPI both have a process through which industry partners provide verbal or written feedback concerning project management, what it was like working with student teams, and lessons learned. Likewise, we also collected data from faculty at both institutions who are involved in the delivery of the capstone experience as a way of taking a closer look at the level of involvement with and assessment of students from their perspective. Individuals, in particular students, have a tendency to experience difficulty in self-assessing their own strengths and weakness (Kruger and Dunning 1999, Dunning et al. 2003). Gathering additional feedback from faculty and industry partners provided an additional insight into student skill development.

3.2. Deployment/Data Gathering

Using an online-based survey tool (Qualtrics) for the main assessment, students from each institution and

Table 1. Survey Items for Students and Partners by Attribute

	Survey items
Motivation	• I accept responsibility needed for an assignment. • I take necessary initiative and appropriate risks to overcome obstacles and achieve objectives. • I maintain focus to complete important tasks on time amidst multiple demands.
Judgment and decision making	• I can draw evaluation criteria from diverse sources and evaluate alternatives against these criteria and associated risks. • I can make decisions rationally and check viability of these decisions.
Innovation	• I can think creatively. • My behavior and practices support actions that enhance innovation. • I can search broadly to identify and formulate innovative approaches. • I can think independently.
Quality	• I can establish successful relationships with INTERNAL CLIENTS to understand their needs and to achieve or exceed agreed-upon quality standards. • I can monitor achievement. • I can establish successful relationships with EXTERNAL CLIENTS to understand their needs and to achieve or exceed agreed-upon quality standards. • I can identify causes of problems. • I can revise processes to enhance satisfaction.
Product development	• I can develop engineering products and processes that meet needs of society in the context of global, social, political, and environmental constraints. • I can apply state-of-the-art technologies in development of new products.
Professional/ethical	• I exhibit integrity and ethical behavior in engineering practice and relationships.
Team	• I show sensitivity and respect for perspectives and contributions of people from different cultures and backgrounds. • I build and maintain trusting, productive working relationships and resolve conflicts productively. • I perform as an effective team player who assists and values individual and team successes.
Communication	• I listen and observe attentively and effectively to assess audience information needs. • I organize and express thoughts clearly and concisely, when SPEAKING with necessary supporting materials to achieve desired understanding and impact. • I keep stakeholders informed about matters that affect their work while protecting necessary confidentiality. • I organize and express my thoughts clearly and concisely, when WRITING, with necessary supporting materials to achieve desired understanding and impact.

Note. For industry partners, all survey questions used the wording "The students" instead of "I."

industry partners participated in preproject and post-project assessments evaluating levels of engineering skills. The institutional review board (IRB) granted approval for this research, and completion of the survey was not a factor in determining student grades on their projects.

We asked students to self-report their own skills at the start of the capstone course and again at the conclusion of the course. For the students, the purpose of the preassessment and postassessment was to determine the change in skill level between the start and the end of the capstone experience. We invited industry partners to report expected levels of engineering skills in students prior to the start of the capstone project in their precapstone assessment and then evaluate the observed skills of the students they worked with at the conclusion of the project. During the preassessment, industry partners indicated their expectations of general student skills (i.e., not assessing a particular student), but during the postassessment, the partners evaluated the team with which they worked for the duration of the project.

We developed initial student/industry partner survey questions during the summer of 2013 and obtained feedback on clarity and structure from survey development professionals. After revision, the final survey instrument consisted of 25 questions. Data collection began in the fall 2013 term and concluded at the end of the spring 2014 term, capturing data from the 2013–2014 academic year. The data collection timeline varied by institution, given the one-semester versus two-semester course formats. Two NCSU ISE cohorts and a single WPI IE cohort were collected. The study involved four groups of subjects as shown in Table 2. During the following academic year, we conducted reflective interviews with faculty about student performance and project involvement during the previous capstone delivery periods. We based the instrument for the faculty interviews on the student and industry partner survey tool, with modified and redirected questions for an open-ended response. The purpose of these interviews was to gather more insight about the capstone delivery method from faculty who are directly involved with

Table 2. Description of the Study Participants

Group	Description	Respondents Pre	Respondents Post
1	WPI IE students completing their MQP during the 2013–2014 school year	10	11
2	Industry partner interacting with students in Group 1	4	4
3	NCSU ISE students enrolled in ISE 498 – Senior Design Project course during fall 2013/spring 2014	10/31	9/29
4	Industry partners interacting with students in Group 3	3/3	5/9

advising projects or teaching the course. The intention was not to rely heavily on this data for findings, but to support what has been collected from students and industry professionals. Interviews lasted on average one hour and were transcribed verbatim in preparation for coding and theme analysis (Patton 2003). The transcripts of the interview were read several times, looking for patterns and concepts (Thompson 1997) and for any major differences from the previously collected survey data.

4. Results and Findings

From NCSU, 41 students, 14 industry partners, and two faculty participated in the study, and 11 students, four industry partners, and two faculty participated from WPI as summarized in Table 2. We surveyed both industry partners and students, using a five-point Likert-type scale, concerning expectations about execution and performance of eight desired engineering attributes. Table 3 provides average scores and associated *p*-values for each attribute. Generally, the data show high evaluations with industry partners from both institutions indicating on the presurvey that they expected students to be at the four or five rating level and, for the most part, expected them to maintain these high scores at the conclusion of the capstone experience when their assessment would be based on observation. Project partners at both institutions gave indirect feedback by hiring graduates and agreeing to sponsor projects in 2014–2015. Likewise, students rated themselves fairly high precapstone, showing confidence in their abilities at that point in their undergraduate careers.

For each of the groups listed in Table 2, we compared data using the Mann–Whitney–Wilcoxon test ($\alpha = 0.05$). We conducted both intragroup analysis (i.e., comparing preassessments and postassessments for students) and intergroup analysis (i.e., comparing of students' self-assessments and industry partners' assessments). We analyzed each of the 25 questions independently rather than by category. This method allows analysis of the specific subcategory skills and identification of where capstone structure may correlate to more specific skill-level changes. We analyzed the survey results at the aggregate response level rather than the individual response level. For example, we compared the NCSU ISE students' spring 2014 preratings for each item with their postratings as a cohort (not individually). We used the same method for the data from NCSU ISE students in fall 2013 and WPI IE students' data.

4.1. Research Question 1: Student Self-Evaluation of Attributes

The analysis aimed to answer the following research question: "Do students experience a perceived improvement in their engineering skills after completing

Table 3. Summary of Results of NSCU Spring Students, WPI and Respective Industry Partners

	NSCU students spring 2014			NSCU industry partners spring 2014			WPI students			WPI industry partners		
	Average score pre	Average score post	*p*-value	Average score pre	Average score post	*p*-value	Average score pre	Average score post	*p*-value	Average score pre	Average score post	*p*-value
Motivation	4.6	4.4	0.40	3.5	4.0	0.32	4.6	4.7	0.61	4.5	4.5	0.40
Judgment and decision making	4.5	4.3	0.93	3.3	3.8	0.84	4.4	4.5	0.40	3.6	4.5	0.06
Innovation	4.4	4.5	0.38	3.5	3.5	0.95	4.3	4.3	0.69	4.1	4.5	0.27
Quality	4.5	4.5	0.83	3.3	3.7	0.48	4.3	4.7	0.25	3.7	4.5	0.00
Product development	4.0	3.9	0.92	2.3	3.8	0.09	4.0	3.7	0.86	3.1	4.3	0.13
Professional/ethical	4.9	4.8	0.64	4.7	4.4	0.55	4.9	4.8	1.00	4.3	4.8	0.39
Team	4.7	4.6	0.39	3.9	4.1	0.65	4.6	4.6	0.85	4.3	4.8	0.19
Communication	4.1	4.2	0.56	4.0	3.9	0.85	4.4	4.3	0.28	4.4	4.5	0.88

their fieldwork capstone project?" We compared students' assessments of individual attributes before and after the project. As expected, few cases of statistical differences in student self-evaluations occurred. Analysis of the NSCU fall 2013 cohort revealed statistical change in students' product development and teamwork skills as self-assessed, and the WPI students showed differences in their own assessments for only a single question in the quality skill category. The NCSU spring 2014 cohort did not exhibit any statistically significant change in self-rated skill levels. Although educators could interpret this result as disconcerting, it revealed some important insights. On many measures, the average student rating from both institutions was a 4.5. Therefore, in the postrating, there was little opportunity to improve their rating over the previous semester's rating. Even with these high average ratings, at both institutions, the proportion of students who rated themselves at a three or lower in the precapstone survey ranged from 0% to 29%, depending on the skill. This finding indicates that, prior to the course, for some skills, a considerable number of students did not feel proficient. Two of the skills with the highest proportion of NCSU students giving themselves a rating of three or lower were in the communication category. We then compared the proportion of students who rated themselves at a three or lower in the postcapstone survey. The proportion of students remaining in this category (three or lower) did not always decrease; in fact, in many cases, it increased or remained the same. There was a decrease in the number of students rating themselves as one or two because students within a cohort tended to increase their self-reported ratings to three, indicating that most students exhibited an increase in their reported skill level even if this increase was not statistically significant. At both institutions, there were cases in which the proportion of students rating themselves three or lower postcapstone increased (or stayed constant) in comparison with the same proportion precapstone. We hypothesize that this finding is indicative of students' overestimation of their skill level prior to the capstone experience. Thus, the fieldwork experience serves as a calibration or reality check. We observed this phenomenon at both institutions for many of the items addressing teamwork and motivation.

The analysis also revealed that results may depend on the student cohort. There are likely semesters in which a higher proportion of students have had significant work experience than in other semesters or have a higher proportion of students with relatively high GPAs. The student demographics may correlate with student self-assessment and potential for improvement. This demographic effect appears in the NCSU ISE data representing two distinct cohorts. The same instructor taught the course and presented identical material in both semesters; however, the fall 2013 cohort showed statistically significant changes in their self-reported skill ratings, for example, in the ratings of their communications skills. As shown in Table 1, the communication category had four specific subitems. The students in the fall 2013 cohort showed significant improvement in the second item only: "I organize and express thoughts clearly and concisely, when SPEAKING with necessary supporting materials to achieve desired understanding and impact." Of all the communication-related skills, the NCSU ISE capstone course particularly emphasizes development of presentation skills. It does so through integration of a technical communications expert who actively contributes to the class by providing course content and presentation feedback at an individual level.

When asked about student abilities at the beginning of the capstone experience, faculty from both NCSU ISE and WPI IE noted senior students tend to be motivated, eager to interface with industry professionals, able to work in teams, and have the ability to develop solutions to project challenges. The general assessment at both institutions is that students are relatively competent to complete their projects with appropriate outcomes. Similar to the student data, faculty also expressed differences in students based on cohort as to whether all students were at the same expected level of preparedness. Further, faculty discussed room for improvement in some areas of communication and decision making. Faculty are aware of, and anticipate, a transition period for senior students at the beginning of the capstone experience that affects their success. The precapstone assessment of skills does not reflect this adjustment; however, it could shed some light on why many of the students self-report high metrics for the eight skills.

> ...most of the students are very motivated and well informed about what they need to do, and also, they want to do a good job. But of course there are always some slackers, and they didn't do the work, and we had to push them extremely hard. But I would say 80% of the students or even higher are very motivated. —WPI Faculty

> I think in general the students are fairly motivated. I think we do run into an occasional student who has senioritis, so they're somewhat less motivated, but for the most part I think that they want to do a good job for their clients. ... Also, I think there's a transition that occurs during senior design where they start to gain more ownership of the projects, and realizing that they kind of control the deliverables and they have the relationship with the client.—NCSU Faculty

> ...I do see a marked change in their maturity and their independence of them taking a project, going forward and kind of really knowing the right type of questions to ask.—NCSU Faculty

By the completion of the capstone experience, faculty note that students have demonstrated an improvement in all skills in the survey, especially product development abilities, communication, decision making, and innovation.

4.2. Research Question 2: Industry Partner Assessments Compared with Student Assessments

Before the capstone course began, we asked industry partners about their expectations, across the eight categories, of the students with whom they would be working. At the end of the project, we again surveyed the partners to update their assessment of the students with whom they had worked. The goal of this analysis was to report on the following research question: "Do students' engineering skills meet the expectations of the industry partners?" At NCSU, both fall 2013 and spring 2014 cohorts revealed a statistical difference in how industry partners rated questions in the motivation, judgment, and teamwork categories compared with student responses. In addition, the fall 2013 student cohort showed a statistical difference in responses to items addressing product development, and the spring 2014 cohort revealed differences in assessments regarding the innovation, quality of solutions, and professional and ethical categories. In contrast, in the WPI cohort, the comparison of responses from industry partners and students revealed statistical differences in how each group rated the performance of students for only a single question (the first question in the motivation category).

These results indicate potential opportunities for improvement in student skill development during undergraduate education. NCSU ISE students work on several projects during their undergraduate careers, but the projects typically do not involve an external customer. At WPI, however, students have a project-based curriculum in which, prior to the capstone course, they complete at least one externally sponsored project. Another possible reason for observed variation could be cohort differences as discussed earlier. A third possible reason could arise from partner characteristics, such as previous experience working with a capstone team and number of years of work experience. These characteristics could factor into how the partners rate the students. Further assessment regarding the preparedness of IE undergraduates requires more data, quantitative as well as qualitative.

4.3. Research Question 3: Examining Capstone Course Delivery

Although no statistical evidence exists comparing the self-reported ratings between the two institutions, we wanted to explore differences in capstone course delivery. In doing so, we add to the ongoing discussions at many institutions regarding field-based projects and feedback from faculty and industry partners regarding the project experience.

NCSU ISE uses a centralized, structured delivery, and WPI IE uses a decentralized, unstructured delivery. In the first type of delivery, student teams receive instruction and evaluation in a formal classroom setting. In the latter, although students do not receive formal classroom instruction, they do receive faculty advising and evaluation although the frequency and content are not prescribed. Table 4 compares and contrasts the two programs. A number of similarities exist between the two courses. Both universities rely on the expertise of a faculty member to lead or contribute to the conceptualization, development, and implementation of the capstone experience and course materials. Both institutions require a passing grade for degree matriculation, and students typically enroll in the project during their senior year. Finally, both institutions follow what can be classified as the *authentic involvement model* (Harrisberger et al. 1976), which exposes students to real situations through entirely open-ended projects. Both institutions use external industry partners.

The primary differences between the two programs are delivery and course structure. NCSU ISE's course provides formal, weekly instruction from a single instructor for the duration of one semester. On the other hand, WPI leaves the format and frequency of contact up to individual faculty members. The NCSU capstone is structured such that the instructor delivers weekly lectures to the entire class on pertinent topics, such as project management. In contrast, WPI faculty tailor their instructional content to individual teams and are delivered in an informal setting. The major distinguishing feature between the two programs is that WPI instruction is project situation–driven whereas NSCU instruction is predefined topic–driven.

NCSU ISE students receive guidance through their capstone experience during a semester-long course that allows for targeted instruction. One strength of such a structure identified by faculty was that students show an improvement in communication skills attributed to a module designed especially for presentation skills.

> I would say the one thing that I think has been really good in our senior design has been the introduction of the communications component in helping the students communicate for both verbally, orally as well as in written form.

Faculty noted that one major challenge facing NCSU ISE students is that the capstone experience is the first time students are working on a fieldwork project of this magnitude and particularly with industry. This marked difference between the delivery methods at the two institutions is not necessarily a factor that puts one group of students at a disadvantage.

Table 4. Comparison of NCSU ISE and WPI IE Capstone Course Characteristics

Characteristic	NCSU ISE	WPI IE
Faculty responsibility	Single faculty instruction; project mentoring from other ISE faculty as needed	Single faculty instruction and advising by each OIE faculty member in department
Requirements for project completion	Final written report and one or more oral presentations	Final written report and one or more oral presentations
Team formation	Formed using the CATME tool and student project rankings	Self-formed
Average team size	Two to four students	Two to four students
Duration	One semester (15 weeks)	Typically, three terms (21 weeks) although some run one, two, or four terms. Each project is worth the same number of credit hours; the duration is subject to student and sponsor availability.
Delivery format	Structured class (lectures, guest speakers, and team time)	No formal class; instructional material (if any) defined by individual faculty; student-arranged meetings with faculty and team members
Role of industry	Project definition and resources, sponsorship fee, mentoring, formal team/project evaluation	Project definition and resources, sponsorship fee, mentoring, project feedback

> I think that students, over the course of senior design, learn that the relationship with the client evolves...that they are consultants to their client...there's some important attributes in the early stages of senior design in terms of training them how to be professionals and engage with the client that we sometimes might take for granted. They may have never been in an experience before where they're the lead consultant...

WPI exposes students to project-based learning from their very first year, and as a result, they have experience working in teams, developing solutions to ill-defined problems, and presenting their work to peers and other stakeholders. WPI IE students complete projects of comparable caliber to the capstone project during the junior year: the interactive qualifying project. This project delivers a similar learning experience; however, it focuses on social impact and interdisciplinary teams of students from across academic programs. Although the IQP is not a major-specific capstone project, it requires students to take on project management and fieldwork and develop solutions, often with a global and/or language component.

> Our students start out with a fairly high level of presentation skills...they do a lot of presentations in courses. I believe that you get better at presenting the more you present, so there's this practice piece. I think they get a lot of practice here at WPI, so they're not just learning it within the MQP.

A previous study conducted an inductive analysis of interview data from WPI alumni regarding how the project curriculum had a positive and long-term effect on their lives (UMass Donahue Institute 2013). Among the 13 factors cited in the report, alumni noted that completing both an IQP, generally in their junior year, and an MQP (senior design) was more beneficial than completing either one or the other alone would have been. Interviewees also noted that they felt better prepared to complete the MQP project once they had completed their IQP.

In addition to the results of the project partner survey itself, we collected qualitative data as part of the established data collection processes at both schools. Overall, qualitative feedback from project partners supports the quantitative evidence. Examples of such feedback expressed overall evaluation of the project experience:

> It was a pleasure to have the WPI students do this project at [Company X]. ... I was pleased to be involved. They did an excellent job.

> They [students from NCSU] worked independently and only used me as a sponsor instead of a project leader. They had several strong recommendations from different aspects at the end of the project, which gave the managers a lot of choice.

In addition to feedback from the partners, NCSU students receive feedback from external industry panelists on the course projects. Comments from these observers also note opportunities for improvement. For example, "incorporate more cost implications in the analysis, focus on the bottom line impact." Similarly, at WPI, each project report goes through an extensive external evaluation by an IE advisory board member (e.g., an industry representative) and an IE faculty member, neither of whom are affiliated with the project. These external reviewers also commented on technical weakness regarding cost implications:

> The analysis could have been more quantitative to really tie it together. Some minimal amount of financial info should have been included.

5. Discussion: Implications for Academia and Industry

The capstone experience clearly gives students an opportunity to use existing skills and knowledge in a multidisciplinary fashion. The literature indicates great variability in the use of mentoring and the pedagogical approaches to the capstone course. Although specific course requirements require sensitivity not only to a particular academic program, but also to the larger professional environment, our study intent was to provide an insight into skill development and industry expectations with respect to engineering skills by examining capstone delivery at two institutions. Although we collected useful qualitative data from industry partners and faculty, we contend that most insights gathered in this research stem from the preproject and postproject assessment tool distributed to students and industry partners. At both institutions, we found, for the most part, that industry expectations were met and students tended to rate themselves highly before the capstone course although the proportion that rated themselves at a three or lower could be significant for certain skills. For the skills in which students reported an incoming skill level of four or higher, there was little room for improvement over the duration of the capstone course. The implications of these results for educators and industry follow.

At both institutions, we found little difference in the students' self-assessments preproject and postproject. However, this finding is not surprising. People—and students in particular—are not adept at recognizing the limits of their knowledge and expertise. For several skills, the proportion of students who rated themselves at a three or lower remained constant or increased from the presurvey to the postsurvey, supporting this explanation. Several studies support this finding. For example, both Kruger and Dunning (1999) and Dunning et al. (2003) discuss why people tend to hold overly optimistic and inaccurate views about themselves. Boud and Falchikov (1989) analyze studies published between 1932 and 1988 that investigate student self-ratings compared with ratings of students by teachers, and they reported overrating and underrating of students. The authors compare these findings to student abilities and conclude that good students tended to underrate themselves and weaker students tended to overrate themselves.

Our findings stress that identifying the gaps in knowledge between students and addressing them during their fieldwork project and capstone course is a challenge for capstone instructors at many institutions. For educators, these findings highlight the challenge of assessing what a student has learned prior to starting the capstone project. Some students have had work experience, and others have not. In many cases, the students may not have had the opportunity to receive formal feedback on the critical skills identified by the TIDEE study. Given the variability of student experiences prior to the capstone term, we cannot make assumptions about their level of preparedness to take on this complex work. This study has revealed a need for more refined mixed-methods approaches to thoroughly assess the skill levels of senior IE/OR/MS students. Curriculum innovations in coursework prior to the senior year could undergo assessment precapstone; offering a more accurate measure of the students' skill levels at that time would enable improved curriculum assessment. Assessing industry expectations and students' actual performance is crucial in identifying necessary curriculum changes.

Further, educators could use our findings as motivation to redesign capstone and field-based experiences to address the eight attributes in the assessment tool to ensure content and skill exposure. After contemplating the results of our study, as capstone educators, we realize that there is an opportunity to conduct a skill assessment during other points in the field-based experience. For example, in response to perceived student overconfidence, we believe that there is an opportunity for the "preassessment" to be conducted once the students have understood the magnitude and responsibility of the field-based experience. We hypothesize that in the first quarter of a capstone course, students will be able to self-report a more accurate assessment of their own skills.

For industry partners, our findings could be useful for setting realistic project expectations. Although not reflected in our survey results, informal conversations with industry partners over the past several years have revealed that a few partners hold unattainable expectations of students and others have very low expectations of students. In a 2015 survey of more than 600 students and 400 employers, the Association of American Colleges and Universities (AACU) found that students consistently rank themselves as prepared in areas in which employers do not agree (Hart Research Associates 2015). In particular, in a number of key areas for employers (e.g., written communication, oral communication, creativity, critical thinking), students are more than twice as likely as employers to think that students are being well prepared.

For students, a better idea of their own weaknesses enables them to identify opportunities for self-improvement. Understanding skill strengths and weaknesses allows students to take greater ownership of the learning experience during the field-based project, perhaps choosing to focus more on improving weak skills. Additionally, awareness of strengths and weaknesses is helpful to students when preparing for job interviews and job market placement.

The study's findings are preliminary given the sample size but point to the value of understanding the impact of capstone courses on our students' preparedness. The intention of this work is to lay a foundation for future study and conversation among faculty, students, and industry partners. It would be interesting to extend this research to measure students' awareness of how these skills improve their teamwork and results. This research could be cast in the framework of expectancy-value theory, which posits that behavior is a function between expectations and the value of the goal one is working toward—in this case, engineering competency and success.

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