The Influence of Feedback on Teamwork and Professional Skills in an Authentic Process Development Project

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Abstract

Professional skills are believed to be a critical aspect of an engineer’s job. Providing students with feedback on professional skills can help students further develop these skills and enculturate them into disciplinary and industrial communities of practice. However, studies of the influence of feedback on students’ professional skills are uncommon and needed. This study presents detailed examples of feedback related to professional skills and investigates the influence of that feedback on student teams’ subsequent engagement in professional skills activities. It uses episodes as an analytical framework to examine meetings, termed coaching sessions, between a faculty member and student teams. We focus on using episodes to identify the major themes of discussion and to specifically identify the role of that guidance in the students’ subsequent engagement in activities.

We found that feedback in the project studied was given on the following professional skills: teamwork, communication (written and verbal), project management, impact of engineering solutions on the economic and societal context, symbols of legitimacy, and written documentation. On average about 40% of the total coaching episodes related to professional skills. Most of these episodes were nested within the context of core disciplinary content and concepts. The types of feedback given to students included affirmative and corrective feedback with specific techniques of elaboration and revoicing. In addition, some discussion was found to be neutral. When student teams were given directive feedback regarding their written work products, this feedback was taken up by the teams almost immediately.

Introduction

While few studies have actually examined “everyday” engineering practice, professional skills (e.g., teamwork and communication) are believed to be a critical aspect of an engineer’s job. Providing students with feedback is necessary to help students further develop these skills and it has been suggested such feedback is best when situated in the context of authentic engineering tasks. We hypothesize that in such a context, students are more likely to take up feedback on professional skills because these skills will be viewed as an integral part of what an engineer does. There are two parts to providing students with feedback on these skills: (a) we first must have a firm understanding of what it means to have professional skills in engineering, and (b) we need to know how to effectively provide students with feedback on these skills.

The case study described in this paper focuses on discourse as students receive feedback while they engage in an industrially-situated, ill-structured engineering task, previously described. Throughout this task student teams receive feedback on a variety of topics (e.g., experimental design and strategy, modeling, reaction kinetics, teamwork, and communication) from a faculty member who acts as their supervisor and mentor; we call the faculty member the coach. We believe that an in-depth focus on feedback provided with respect to professional skills will afford a more nuanced understanding of what it means to have professional skills in this project and, by extension, in engineering. We also begin to explore feedback techniques used by the coach to
help students develop professional skills and the influence of that feedback on the subsequent use of professional skills in the project. In this context, we begin to explore our hypothesis with the following research questions:

1. What proportion of the coaching sessions attends to professional skills?
2. What types of feedback does the coach provide on professional skills and why?
3. How do interactions in this project between a coach and student teams allow for a better understanding of what it means to have professional skills in engineering and influence student development with respect to those professional skills?

This research contributes to the long term goal of the authors to understand how engaging engineering students in industrially-situated, ill-structured engineering tasks facilitates the development of their engineering skills, including professional skills.

Background

Professional Skills

Professional skills, sometimes called “soft” or “generic” skills, are generally believed to be very important aspects of engineering practice. This belief is emphasized by industry representatives and some engineering educators. In some cases, practicing engineers spend nearly two thirds of their time interacting with people. Critical drivers such as “rapidly changing technology, particularly information technology, corporate downsizing, outsourcing, and globalization (p. 3)” provide the continually increasing need for engineers to be proficient in professional skills. Therefore, it is imperative such skills are intentionally developed in engineering students. In this section we present a description of professional skills in engineering education. We start with a discussion of which skills are commonly described as “professional skills.” Next we discuss the inclusion of these skills in accreditation outcomes, commonly cited issues with teaching these skills, and strategies educators have used to include these skills in engineering curricula through program-wide initiatives, individual courses, tools and methods. Finally we summarize the recommendations from the literature for teaching professional skills.

While the importance of professional skills is generally recognized, the way educators and industry representatives define what “professional skills” means and which skills fit into that category, varies widely. When it comes to clearly defining the term “professional skills,” most researchers provide a list of included skills rather than defining the category. Even the lists of skills that fit into the category of professional skills vary. As noted by Colwell, “if one were to ask educators in…engineering…what is meant by the term ‘soft skills’, there would likely be some consensus on the list, but each educator asked would probably have a different list (p. 3)”.

Despite the variation, many authors representing practicing engineers, alumni of engineering programs, and engineering educators agree that the following skills are professional skills:

- Teamwork
- Communication (both written and oral)
- Project management
• Leadership
• Self-awareness

Additional skills often described as professional skills include social skills, cultural sensitivity, dealing with diversity, adaptability, decision making, documentation, ethical responsibility, knowledge of contemporary issues, and an ability to understand the impact of engineering solutions in a global, economic, environmental, and societal context. Like the category of professional skills each of the skills that fit within the category of professional skills also has a vague and fairly broad definition.

With growing attention from industry and in the literature given to professional skills, accreditation organizations began to include these skills in their outcomes. The Accreditation Board for Engineering and Technology (ABET) engineering criteria began to explicitly require professional skills as student outcomes in 2001 and has continued to include them in revisions since. ABET came to see these skills as needed by all engineering graduates. The following six of the eleven outcomes specified in the ABET engineering criteria fit within the literature list of professional skills:

- an ability to function on multi-disciplinary teams (3.d)
- an understanding of professional and ethical responsibility (3.f)
- an ability to communicate effectively (3.g)
- the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context (3.h)
- a recognition of the need for, and an ability to engage in lifelong learning (3.i)
- a knowledge of contemporary issues (3.j)

These criteria have spread globally through the International Engineering Alliance, a joint alliance among the Washington Accord, the Sydney Accord, and the Dublin Accord. In this alliance, the ABET professional skills have been explicitly included, described, and expanded upon as attributes and competencies that a graduate of a sanctioned program must possess.

While ABET criteria and industry demands mandate that engineering educators teach professional skills, helping students develop these skills is more difficult than it may seem. Many educators view professional skills as important aspects of practice. However, there is sometimes resistance from engineering students and educators to emphasize these skills in the curriculum. There are many reasons engineering faculty still struggle with teaching these skills. Cajander et al. suggest “that many educators have an intuitive grasp of what professional skills are, but struggle to give a clear definition of them and to define rubrics for their assessment. (p. 1)” Other reported reasons from computer science include limited room in the curriculum, lack of experience or familiarity with professional skills, and a view that professional skills are not core to the discipline being taught.

Despite the challenges, educators have made an effort to incorporate professional skills in undergraduate and graduate education. Changes have been made in curricula ranging from the program level, to entire standalone courses, to integrating professional skills as part of “integrative” courses, to offering professional skills modules. In addition, professional
skills have simply been integrated as a part of design courses with a variety of focus on professional skills and integrated into cooperative learning experiences. A recent study surveying 444 programs from 232 institutions about the nature of engineering design courses showed that these courses increasingly attend to professional skills, with professional skills comprising a majority of the most frequently taught topics.

The ABET accreditation process has also served as the basis for several development of tools and methods targeted at assessing the proficiency of students with professional skills. For example, researchers reported on the College of Engineering at Virginia Tech using ePortfolio to document and assess the ABET professional skills criteria. In their use of ePortfolio, faculty specified definitions of the criteria, along with three levels of expectations that represent a progression from factual knowledge at level 1 to level 3 which aligns “with contextual knowing and with synthetic and evaluative tasks. (p. 4)” Another tool, originally termed the curricular debrief and now termed the Engineering Professional Skills Assessment (EPSA), was developed at Washington State University to measure all of the ABET professional skills criteria simultaneously. This assessment places students on teams and tasks them with a complex, real-world scenario, giving them merely 45 minutes to “determine the most important problem/s and to discuss stakeholders, impacts, unknowns, and possible solutions. (p. 2)” Other more commonly used tools such as performance reviews and peer assessments have also been reported.

In order to help engineering students acquire proficiency in professional skills, Shuman et al. echo the words of John Prados in advocating for a new engineering education paradigm “built around active, project based learning; horizontal and vertical integration of subject matter; introduction of mathematical and scientific concepts in the context of application; close interaction with industry; broad use of information technology; and a faculty devoted to developing emerging professionals as mentors and coaches rather than all-knowing dispensers of information (p. 1)”.

**Situated Learning**

Considering the development of professional skills through the lens of situated learning theory, authentic engineering tasks should serve as the context within which professional skills are learned. Johri and Olds, referencing Engle, describe a situativist reasoning for this perspective, “arguing that we apply what we know in a new activity based on features common to that activity and previous activities and by reframing the learning context. (p. 156)” Paretti reinforces this idea with specific attention to written communication, stating that it is “a situated activity rather than an independent, abstract mechanical skill. (p. 492)” The same is likely true of other professional skills.

Lave and Wenger discuss how novices develop through situated learning which occurs due to participation in a community of practice, “a set of relations among persons, activity, and world, over time and in relation with other tangential and overlapping communities of practice (p. 98)” For example, chemical engineering could be considered to be a community of practice. In addition, a particular industry, such as the semiconductor industry could also be considered to be a community of practice. While each of these examples can be defined as individual
communities, they also may overlap, i.e., chemical engineers can also work in the semiconductor industry. Particular discourse and practices can be specific to communities of practice. In this paper, we refer to discourse of chemical engineering (the discipline of our participants) as **disciplinary discourse** and discourse specific to the semiconductor industry (the context for our engineering task) as **industry-specific discourse**. Lave and Wenger 37 call novices legitimate peripheral participants, who engage in community activity at the periphery of the community initially. As novices engage in community activities over time, and become more familiar with the community, its social structure, power relations, and conditions for legitimacy, they may progress to be considered full participants. We describe instances where attention is paid to conditions for legitimacy, and term them **symbols of legitimacy**. Symbols of legitimacy are symbols that indicate a community participant’s legitimate belonging to the community. Situated learning theory provides a useful perspective with which to consider how engineering students develop professional skills.

Along with the situated context, providing students with feedback is one way to help students develop proficiency with professional skills. Feedback has been shown to be one of the most important tools used by faculty to close the gap between actual and desired performance. However, a few studies have examined the influence of feedback on professional skill development of engineering students. In this paper we focus on the influence of feedback provided by a faculty member, termed the coach, on individual student teams in an authentic, ill-structured engineering task.

**Feedback**

Feedback has been shown to be one of the most important tools used by instructors to help students close the gap between actual and desired performance 38. Feedback can be broadly defined as “information provided by an agent (e.g., teacher, peer, book, parent, self, experience) regarding aspects of one’s performance or understanding” 38. Based on an assessment of hundreds of meta-analyses from 180,000 studies, Hattie concluded that “the most powerful single moderator that enhances achievement is feedback” 39. While feedback has been shown to strongly influence student performance and learning, explicit research on the effect of feedback in engineering education is sparse. Findings from studies of first-year engineering students 40, 41 show that feedback is positively related to learning gains. These results are consistent with studies in other disciplines 42.

In general, there is limited agreement on what characterizes “effective” feedback, especially in ill-structured, open-ended projects. Hattie and Timperley 38 suggest that feedback is more effective when the feedback is related to the achievement of and progress towards specific goals and that less complex feedback may be more effective than more complex feedback. They also suggest that feedback focused on the individual rather than the task and goal is not effective. Elaborated feedback, feedback in which an explanation is provided rather than a simple “right” or “wrong,” may be more effective than a simple mark or grade. Shute contributed a literature review on formative feedback which supports these suggestions and provides tabulated lists of “things to do,” “things to avoid,” timing related issues, and learner characteristics to consider when providing feedback 43. Feedback has previously been grouped as either reinforcing feedback or corrective feedback 44. Reinforcing feedback, which we call affirmative feedback 45,
acknowledges a correct response and may include praise. Corrective feedback has been
described by Black and Wiliam to have two main functions: (1) to direct, and (2) to facilitate.
Directive feedback tells the recipient what must be corrected whereas facilitative feedback,
which may be more effective, provides suggestions to guide the recipient toward his/her own
revisions.

**Theoretical Framework**

The industrially-situated, ill-structured engineering task described in this paper offers students an
opportunity to “participate in realistic adaptations of actual engineering practice within a
controlled environment that removes some of the commercial, physical, and social constraints of
industry,” much like the systems described by Svarovsky and Shaffer. Literature suggests that
as students engage in these types of tasks, they are more likely to value the tasks, be motivated,
develop transferable skills, and develop self-awareness. We believe that providing students
with feedback from an experienced coach on professional skills within the context of such
industrially-situated, ill-structured engineering tasks is likely to help students develop
professional skills and be able to apply those skills in future engineering tasks.

In this paper we focus on development of professional skills in the coaching sessions rather than
their transfer to other tasks. This perspective provides the basis for our investigation. To explore
the intricacies of the feedback process and the influence of feedback on professional skills in-
depth, we apply a case study methodology. We combine the case study methodology with
discourse analysis, which allows us to identify and follow the themes in both written and
verbal discourse related to professional skills. Specifically, we extend our use of episodes as a
discourse analysis framework to chunk discourse between student teams and the coach into
thematic units. Each episode in this work has a central theme that has been found to fit into one
of three general categories, a clear beginning and end, and contains up to four stages:
surveying, probing, guiding and confirmation. Some smaller episodes have also been found to be
nested within larger episodes, i.e., one themed discussion takes place in the context of a larger
themed discussion.

We draw upon the summarized list of professional skills from the literature to identify the
episodes of discourse related to professional skills. Acknowledging that different types of
feedback will likely result in different types of skill development activities, we also incorporate
types of feedback, labeling episodes as including affirmative or corrective feedback. In some
cases, discussion includes neither corrective nor affirmative feedback; we label these episodes
“neutral discussion.” Finally, we examine the influence of feedback on student teams’ use of
professional skills throughout the task by following themes throughout the project during intra-
team discourse.

**Methodology**

The methodology for this paper is comprised of a case study of four student teams and a single
coach. Discourse analysis was used as a way to explore the data. The data collection includes
field notes and audio recordings of teams throughout the project anytime two or more members
met. Such fine grain data allows the researchers to study the teams in detail throughout the entire
project, providing a project wide picture of the influence of feedback. The case study of the four teams afforded an exploration of the way in which the feedback was tailored to individual teams, while providing information about the aspects of the feedback process that appear to be common, at least between the four teams investigated. Discourse analysis through episodes provided a method to examine the transcripts, starting with the interactions between the student teams and the coach and, through keyword searches, branching outward both forward and backward in time to trace the influence of feedback in the discourse. Student work products were also considered.

**Setting**

The authors have designed and studied an innovative learning system. Central to the learning system are two virtual reactors, the Virtual Bioreactor and the Virtual Chemical Vapor Deposition (CVD) Reactor that provide a context for teams of students to practice engineering design. This study is a subset of a larger investigation of student learning industrially-situated, ill-structured engineering tasks and took place at a large public university. The task described in this paper, the Virtual Chemical Vapor Deposition (CVD) Process Development Task, was the second of three tasks in a capstone laboratory course, typically taken by students in their final year of an undergraduate chemical, biological or environmental engineering program. Students in the course were organized into teams of three and maintained their team composition throughout the course. The other two tasks in the course were more traditional laboratory projects. In contrast to the more traditional projects, the Virtual CVD Process Development Task, places students in the role of semiconductor process engineers tasked with optimizing an industrially sized reactor for high volume manufacturing. A typical student team devotes 15 - 25 hours to this complex, three-week project. To optimize the reactor, they must engage in activities and apply concepts introduced in previous courses. The majority of their previous courses are technically focused, but some include oral and written communication, teamwork and other professional skills related components. The course in which this task was delivered is designated as part of the “writing intensive curriculum.” A few courses, such as technical writing, are

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<thead>
<tr>
<th>Timeline</th>
<th>Key Task Information &amp; Milestones</th>
<th>Student-Coach Opportunity for Feedback</th>
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<tbody>
<tr>
<td>Task Begins</td>
<td>• Task context is framed&lt;br&gt;• Task goals and performance metrics are introduced&lt;br&gt;• Issued laboratory notebook</td>
<td>The coach delivers an introductory presentation on the industrial context, engineering science background, the Virtual CVD Reactor software, and task objectives and deliverables. Feedback is limited to in-class interaction.</td>
</tr>
<tr>
<td>~End of Week 1</td>
<td>• Design coaching session&lt;br&gt;  o Memorandum with values for initial experiment, experimental strategy, budget</td>
<td>During a 20-minute coaching session, feedback occurs as the coach and student teams ask questions of each other and discuss. If initial experimental values, strategy, and budget are acceptable, student teams are granted access the Virtual CVD Reactor software.</td>
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<tr>
<td>~End of Week 2</td>
<td>• Update coaching session&lt;br&gt;  o Memorandum with progress to date</td>
<td>Feedback is given by the coach in this second 20-minute meeting in which student teams and coach discuss progress to date, issues, and path forward.</td>
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<tr>
<td>~End of Week 3</td>
<td>• Final recommendation for high volume manufacturing&lt;br&gt;• Final written report&lt;br&gt;• Final oral presentation&lt;br&gt;• Laboratory notebook</td>
<td>Teams give a 10-15 min oral presentation to the coach, other instructors, and other students. Teams then entertain a 10-15 minute questions and answer session that affords additional feedback. Final task feedback consists of grades and written comments on final deliverables.</td>
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entirely focused on professional skills. The desired learning objectives for the project include both the development of professional skills (e.g., teamwork, communication) and the integration of core engineering science concepts (e.g., material balances, reaction kinetics, diffusion). Key project milestones and corresponding opportunities for feedback are summarized in Table 1.

The feedback analyzed in this paper occurred during the first 20-30 minute meeting, referred to as the design coaching session and shaded in blue in Table 1, between the student teams and a faculty member, who we call the coach. During the coaching sessions the coach acts as a mentor or supervisor in industry. In the design coaching session, students deliver a memorandum that details values for their initial experiment, a strategy for subsequent experiments, and an entire project budget (in virtual dollars). Feedback is intended to be tailored to engage students in identifying gaps in their current approach and directing attention to methods for addressing those gaps.

Participants

The twelve undergraduate student participants came from two cohorts of approximately 80 students each. Two teams were selected to participate in this study from each cohort. The process for choosing teams to participate addressed several factors, the most fundamental of which was simply schedule; teams were only chosen if a researcher was available during the team’s laboratory section and projected work times. The perceived willingness of a team to participate was also a contributing factor to team selection. This included perceived willingness for both informing the researcher of all team meetings as well as verbalizing thoughts during meetings. A team’s perceived willingness was a major criterion for selection because of the limited window of data collection associated with the task. It should be noted that students’ academic performance (e.g. GPA, class standing, test scores) was not a contributing factor to team selection. Three of the teams were mixed-gender teams and the fourth team consisted of all female students. A total of eight female students and four male students participated in this study. The gender distribution in the participants for this study is not typical of engineering students as a population, which is a limitation of this study. In addition, the sample size and sampling strategy are limitations. However, we are not intending to provide generalizable data. Instead, we focus our qualitative efforts to afford transferable findings. Also, more than half of the students had previous experience in engineering internships or laboratory research positions.

One coach provided feedback to all student teams. This coach has coached over 60 teams in the same capstone course over several years and has many years of thin films processing experience. The coach has also published research papers and developed courses on the subject.

Data Collection & Analysis

Data sources include audio recordings and transcripts of student teams, researcher field notes, student work products, and post-project, semi-structured student interviews. Every time two or more members of a team met, they were audio recorded and those audio recordings were transcribed for the four student teams (Team A, Team B, Team C, and Team D) as they worked throughout the entire project. Researcher field notes include the researchers account of the student team as they worked and may include what team members were actively doing (e.g.,
team member 1 was searching the internet for sources while team member 2 constructed an excel spreadsheet, information not otherwise captured on audio (e.g., website addresses), and notes of particular interest to the researcher. Student work products include the following items: laboratory notebooks in which students were instructed to detail their thoughts, calculations, and work throughout the project; all memoranda; final reports; final presentations; and electronic files, such as spreadsheets in which students developed mathematical models. Semi-structured interviews were completed with all participants up to 6 months after project completion.

Discourse analysis using the episodes framework was performed on transcripts of meetings between the coach and the student teams to identify episodes with feedback focused on professional skills. In episodes analysis, feedback in the coaching sessions is characterized by parsing transcripts into a series of episodes.

Episodes were classified as either professional skill related or not professional skill related. The episodes that related to professional skills were characterized as including affirmative feedback, corrective feedback or neutral discussion. The episodes were then grouped based on common professional skills related themes. For each of the episodes, a list of keywords was created based on the discourse present in the grouped episodes. This list of keywords was then used to search throughout the entire transcript of the corresponding team. The list of keywords was iteratively modified as sections of the transcript that appeared to be connected with the feedback episodes were found. Once an exhaustive search was completed the researcher compiled all instances that referenced the overarching topic in chronological order. From these instances, the story of what happened pre, during, and post feedback with regards to each of the professional skills related topics was compiled.

Results and Discussion

Feedback on Professional Skills: A Survey of Four Teams

In order to examine the degree to which feedback on professional skills is integrated into the coaching sessions of this project (research question 1), we examined the episode themes in the first coaching session for all four teams. Initially episodes were assessed as either related to professional skills or not related to professional skills. Out of an average of 29 episodes, approximately 40% of the episodes contained some discussion of professional skills. In most cases these episodes were nested within a technical context. For example, the coach and a team might be discussing the strategy the team used to determine one of the input parameters. Within that discussion the coach might ask what literature references they used to determine the value and if the team hadn’t cited any sources in their memorandum, the coach would likely emphasize the importance of providing citations in written communication because the citations serve as a way to establish or reinforce credibility. We also used word count as an indicator of the degree to which feedback was given on professional skills. Figure 1 shows the percent of professional skill related discourse out of the total discourse for each team, as measured by word count and episode count.
Next, the subset of episodes related to professional skills was further divided into professional skills subcategories. We used the literature list of professional skills combined with our observed professional skills to guide this grouping. The specific professional skills that were identified in the first coaching session for the participant teams are as follows:

- Teamwork
- Communication (written and verbal)
- Project Management
- Impact of Engineering Solutions on the Economic and Societal Context
- Symbols of Legitimacy
- Written Documentation

The most common professional skill addressed was written communication. This is not surprising since student teams are expected to deliver a written memorandum to the coach at the beginning of the meeting. In addition, documentation was prevalent as the coach emphasizes the need for keeping a laboratory notebook. One category that emerged from the data, and was not readily described in most of the professional skills literature is the symbols of legitimacy category. However in hindsight, it is clear that enculturating students into the disciplinary community of practice should include feedback on symbols of the students’ legitimate belonging to the community.

In addition to professional skills categorization, episodes were also grouped by type of feedback or discussion, including the following groups: neutral discussion, corrective feedback, and affirmative feedback. The results of this grouping are illustrated in Figure 3.
Figure 2. Distribution of professional skill subcategories within the discourse related to professional skills - percentage of word count and percent of episodes that relate to each professional skills subcategory.

Figure 3. Distribution of episodes categorized by type of discussion/feedback within the professional skills episodes.
Interestingly, all of the feedback related to the impact of engineering solutions on the economic and societal context was facilitative. The coach guided students to consider the impact without directing action. The same was true of teamwork. It is likely that the coach considers these two skills to be flexible and adaptable. In addition, neither of these skills are easily monitored or assessed in the task, so directive feedback is not particularly warranted. However, the writing skills and verbal communication were commonly directive. One reason for the directedness in the written communication is that the coach required two teams to modify their memoranda before they could proceed with the project, before they had demonstrated their competency to gain access to the virtual equipment.

We continue to integrate discussion of the type of feedback throughout the more in-depth description of each of the professional skills subcategories, presented in the following sections. Like the term “professional skills,” each of the subcategories also has a vague and fairly broad definition. While literature discusses the need for these types of skills, it is rarely clear as to what exactly these skills look like and how an engineering educator can craft feedback to help students develop them. In the following subsections we describe instance of one coach providing four student teams with feedback on these skills. We hope that with these illustrations, we can help clarify how some aspects of each of these skills are embodied through coaching.

**Communication and Symbols of Legitimacy**

Written communication was the most prevalent theme for the professional skills related episodes. These episodes included feedback on the teams’ memoranda, specifically formatting, typos, and the lack of communication with industry discourse or disciplinary discourse. Verbal communication episodes were also commonly associated with lack of communication with industry discourse or disciplinary discourse. One verbal example of the lack of communication with industry-specific discourse can be seen in coaching session from Team C. This professional skills episode is nested within a larger discussion of modeling and reaction kinetics. The students had referenced a journal article and the coach began to ask some clarifying questions. A question about wafer size, shown below, initiated subtle corrective feedback on disciplinary discourse.

>*Coach:* And their size are?
>*Student 3:* 200, or sorry, 20 centimeters
>*Coach:* 200 mm
>*Student 3:* Yeah, 200 mm, so it’s 200 mm size

The task is situated in the semiconductor industry. In this industry, engineers refer to wafer sizes in units of either millimeters or inches. There are also common, standard wafer sizes (e.g., 300 mm, 200 mm, 150 mm, etc). The student responded in centimeters. If the student had been discussing a journal article with a boss or colleague in the semiconductor industry, s/he would be perceived as a novice, not aware of or fluent in the discourse of the industry. This mistake would have symbolized the student’s lack of experience, and possibly lack of credibility. The coach subtly corrected the student and the student took up that correction, perhaps even subconsciously adopting the discourse of the coach and thereby the semiconductor industry. Because the lack of
industry-specific discourse often translates to the perception of a lack of legitimacy in the community, this episode was coded as a “symbols of legitimacy” professional skill as well.

While the previous example illustrates lack of fluency in industry-specific discourse, other episodes illustrate lack of fluency in the more general disciplinary discourse. For example, another episode from Team C has much less subtle feedback. This episode is nested within discourse about calculating a mass balance (also known as a material balance), a core chemical engineering concept, for the purpose of determining one of the input parameters.

 Student 3: the minimum [material needed for our system] would be, um, the total deposition divided by the, the total mass deposited and then convert that to moles deposited divided by the time.
 Coach: So what do you call what you just did? Conceptually?
 Student 3: The average depositing...
 Student 1: Mass balance
 Coach: A mass balance

In this mass balance episode, the student again shows a lack of fluency in discourse, but in the broader discourse of the discipline rather than the specific discourse of a particular industry. The coach offered clear corrective feedback, first asking a leading question. Then when two students offered answers, the coach revoiced the correct answer given. Revoicing is a feedback technique that was commonly observed in the professional skills discourse examined in this study. A similar mass balance episode occurred with Team D. However with Team D, the coach elaborated on one of the purposes for using disciplinary discourse. This episode, like the previous example, takes place within the context of using a mass balance to determine one of the input parameters. After asking a leading question and revoicing the correct answer given by the student in Team D, the coach added:

 Coach: Alright, so if you tell me that we performed a mass balance ... to determine the input flow rate [one of the input parameters], then I would say ok.

In this statement, the coach is emphasizing that the single phrase “mass balance” has meaning in the discipline of chemical engineering. This phrase represents a concept, and a procedure that can be executed by a series of equations. In addition, had the student described this series of steps to an expert practicing chemical engineer, the engineer would have likely perceived the student to be a novice, obviously not fluent in the disciplinary discourse. A core concept like mass balance should be understood by experts in chemical engineering. Certainly calculations can be the topic of discussion, but they are better communicated when they are introduced with disciplinary discourse. In both mass balance episodes, the coach offered clear corrective feedback to help the students identify, and apply disciplinary discourse, unlike the episode about industry-specific discourse. It is likely that the coach realizes that the industry specific discourse was set somewhat arbitrarily and that students will eventually practice in wide variety of industries. While student use of the industry-specific discourse is important, it is likely viewed as less critical than student use of disciplinary discourse that will be likely applicable regardless of the industry the students end up practicing in.
Other types of symbols of legitimacy episodes focused on credibility. In one episode from Team B the coach questions whether the students would retain credibility if they presented input parameters with an excessive number of significant figures to an operator in industry. The coach hypothesizes that the students would lose “floor credibility,” referencing the manufacturing facility floor, and that the students would be perceived as novices, as “someone who did a calculation” without considering the practical implications. In other cases credibility is related to references. In some cases the focus was on the credibility that is established through citing appropriate references. In other cases the evaluation of the credibility of different members and types of members in the community was the central theme. For example, in one case the coach and the students from Team A discuss the potential bias inherent to an industry website reference and compared to that of peer-reviewed journal references. A final episode themed around symbols of legitimacy included one in which a written communication error in one team’s memorandum prompted the coach to probe the students, asking if they understood the difference between what they had written and what they should have written.

**Documentation**

Episodes related to documentation were almost exclusively related to documenting progress in the team’s laboratory notebook. Episodes related to documentation were also only present for the two teams that were part of the later cohort, Team C and Team D. A coach strategy changed between years, which lead to more of an emphasis on the importance of keeping an updated and inclusive laboratory notebook. In both cases, the teams spent multiple episodes and approximately 40% of their professional skills word count on discussion related to documenting work in laboratory notebook and using the notebook as a “palette” which should contain “any thoughts, ideas, analysis” as stated by the coach when talking with Team D. For Team C, the coach related the usefulness of the laboratory notebook to professional practice with the following discussion with the team:

*Coach:* This is like a 3 week thing ‘cause that’s how we do it in the school year, but in practice, you know, you can imagine this type of project might be 8 months.

*Student 1:* kind of forget what you did

*Coach:* And you have other projects going on. So if you…can get in the habit of recording not just what you did, but why you did it

*Student 1:* mmmhm [indicating yes]

*Coach:* As you revisit it, as your thoughts change, that can be helpful.

Documentation was also discussed in the context of a team strategy to document work.

**Teamwork**

Episodes themed around teamwork were also fairly common and encouraged team strategies that are often used in industry, but less common in the academic setting to which the students are accustomed. In the teamwork example built upon documentation, the coach and Team D discussed a team strategy for documenting progress. Another teamwork example is the emphasis on team level monitoring, which was seen in an episode from Team A. Distribution of labor was a strategy discussed in episodes from three of the teams. A common team practice in school is to
divide work to such a degree that individuals on a team are solely responsible for a somewhat isolated part of a team project. While distribution of labor is also common in industry and was even suggested in one very short episode as a strategy Team C could use while making changes to their design memorandum, practicing engineers will frequently engage in peer review, asking colleagues to double check the accuracy of calculations, experimental designs, and other plans. This peer-review type of team strategy was focused on in two teamwork episodes, in the coaching sessions of Team A and Team B. In the case of Team A, this episode occurs at the end of their coaching session, as they were about to go perform some calculations as a required action before they could proceed with experimentation. The coach asked the team how they would verify that the numbers they would calculate were accurate. One student suggested that each member of the team could review the calculations or that they could all perform the calculation independently. The coach responded with vague facilitative feedback, prompting the students to consider what the best strategy would be. Team B had already performed a calculation and the coach asked how confident the members of Team B were in their values. The student who had performed the calculation was confident. The other two students, however, were not. After commenting positively on the skill of the student who had performed the calculation, the coach asked how the other two members could be more confident in their value. The student that had done the calculation responded. The coach revoiced the student’s recommendation and elaborated with an emphasis on the economic implications of their calculation with the following statement.

Coach: You could have independent checks on that, ‘cause it’s, you know, you don’t want to spend seven thousand dollars to learn that, oh, I forgot to carry a zero or something. Um, I’m not saying it’s wrong or right, I’m just suggesting that it’s just more of a team strategy type thing.

With the above statement, the coach emphasized that engineering solutions have an economic impact. Further, inaccurate engineering solutions as simple as a fundamental calculation, can have a significant economic consequence. Luckily for students, in this task the economic consequence is in virtual dollars, rather than sacrificing real company money. While the distinction between virtual dollars and real currency may slightly decrease the authenticity of this task, it also provides students with scaffolding and a safer environment in which to make mistakes and learn and grow from those mistakes.

Impact of Engineering Solutions on the Economic and Societal Context

Three of the four teams had an episode themed around the impact of engineering solutions on the economic and societal context. One case is discussed above in the “Teamwork” section and the second case is very similar. However, in the third case the coach connected engineering solutions more explicitly to industry. This third case occurred in Team A’s coaching session. Prior to this episode the students and coach were discussing reaction rates and the influence of input parameters on reaction rate. Through the discussion the students came to realize that decreasing the value for one parameter would cause the reaction rate to decrease. The coach related the implications of a slow reaction rate in industry in the following interaction.

Coach: Right, and what’s the problem with that in a high volume manufacturing facility?
Student1: You have waste
Student3: You can’t get things done very fast
Coach: You can’t get things done very fast
Student1: Oh, okay
Coach: And so you...
Student3: ‘Cause it’ll, I mean it’ll still get deposited, it’ll still get there
Coach: right
Student3: it will take a lot longer
Coach: right
Student3: and it’s not ideal for
Coach: so that you’re making less product than your competitor is
Student3: So you might be uniform, you know,
Coach: you might be uniform
Student3: you might have high utilization but you know, oh we take 4 hours.
Coach: yeah
Student3: Wait 4 hours? Why are you taking 4 hours?
Coach: Yeah.

This episode appeared to be especially engaging for Student 3, who at end of the episode verbalized an imagined conversation with perhaps an unhappy industry supervisor.

**Project Management**

Like the theme, impact of engineering solutions on the economic and societal context, project management episodes occurred in three of the four coaching sessions as well. These episodes were primarily concerned with meeting scheduling. Two of the four teams, Team A and Team C, were required to make changes to their memoranda prior to gaining access to run experiments. Their episodes dealt with rescheduling for a follow-up meeting and discussing the timing of the initial meeting as a way to get feedback early in the project. Team D, however, was not required to make changes to their memorandum, but instead initiated a conversation about the overall project timeline and milestone expectations. In this episode one student questions if they have a minimum or maximum requirement for their update meeting, which occurs one week later. The coach, somewhat hyperbolically, states that the maximum is they will have their project complete. The coach then elaborates on more realistic expectations with the following monologue.

Coach: I would expect that you would be able to have some reflection on where you are at now, so that you’ll be at some different point a week from now and that you can touch in on say where you were...Really, where you go between here and the final, is going to probably be different than any other group based on, you know, what your creative and uh, analytical thought[s] are on that. So it’s really hard to say exactly what next week will look like, alright...it’s another opportunity for feedback for you. You might want to consider that, so, where is reasonable to get, where you know. If there’s kind of like a note you want to brainstorm about or something.
In the above statement, the coach elaborates on the why there are no concrete expectations in saying that each team will take a unique path. However, the coach prompts the students to reflect on what they believe is reasonable and to come to the update meeting with questions, ready for feedback.

During the coaching sessions, the coach also provided feedback in the form of written notes on the design memorandum artifact that each team brought to the meeting. The notes highlighted formatting errors and included a list of the changes required of a team before the team could move forward with the project.

**Influence of Feedback on Professional Skills: An In-depth Investigation**

To investigate the influence of feedback, we chose to follow one professional skill throughout the project for each team. Team A had the second highest amount of feedback given on teamwork, so we investigated this team’s use of the specific teamwork strategies mentioned in their coaching session. Team B had the most feedback given on written communication, so we examined the development of their written communication skills throughout the project. Team C had the highest percent of episodes themed around project management. To investigate their project management skills, we investigate their preparedness for the first coaching session and draw from student reflections from the post-project interviews. Team D had the highest percent of episodes themed around documentation. To examine Team D’s documentation skill development, we examine their notebook and their post-project interviews.

**Team A - Teamwork**

In their initial coaching session, Team A had two episodes in which they discussed teamwork with the coach. These two episodes made up 21% of their word count associated with professional skills and about 8% of the entire coaching session. One of their teamwork episodes, previously discussed in the teamwork subsection of this paper, happened prior to the team performing a critical calculation. In this episode, the coach prompted the students to think about a team strategy that would ensure accuracy in their calculations. One of the students suggested two options, in the following statement.

*Student 3: we can hand it to each other and have everybody review it or we could do it individually and see how the numbers match up*

This theme was explored in the rest of Team A’s project transcript with keywords of check, calculate, update, and memo. Directly following the coaching session, the team met to address requirements the coach had put forth before they would be allowed to begin experimentation. One requirement was the calculation of a mass balance to verify their value for one of the input parameters. During their meeting, two members simultaneously and independently performed the calculation. The two members compared their answers and iterated until they got the same results. Then the third member of the team performed the calculation and confirmed the result.

Later as they work on calculating a particular model parameter, an instance arises in which they get and recognize erroneous data. The erroneous data leads the students to question the
calculations for the parameter and the team checks the calculations. Unfortunately, the coach was trying to guide them to use this as a team strategy throughout to prevent such obvious errors.

The only other instance of the team using this type of intragroup validation strategy is when they are creating and revising their written communication, including the update memorandum and their final report. In those cases the each member starts by working on individual sections of the memorandum and report. Then each team member reads and edits the sections completed by the other two team members. However, prior to the initial coaching session, the team had employed a similar strategy.

The second episode in Team A’s coaching session that dealt with teamwork was a different sort of team strategy. The coach provided the team with technical feedback regarding their initial ideas for modeling the reactor. This feedback included a nudge to take a “jump back” and “real simply” consider the system. The coach was trying to help the team avoid making errors due to a needlessly, overly complicated model. Recognizing that Student 1 was the champion for the complexity, the coach provided team strategy feedback to Student 3 to help lessen Student 1’s propensity for complexity. The exchange of discourse is presented below.

\[\text{Student3: 'cause if you add too many things, if you add in too many things and you consider absolutely everything important, then you’re gonna end up having something that changes so many variables that you won’t be able to design a reasonable experiment [indiscernible].} \]

\[\text{Coach: So, so that’s a good check for you to do, Student3, is to say hey, you know, um Student1 likes to think about things on really high levels. Is this getting too complex? Okay, because the higher level you think on things, if you can get it working that’s great, but the more likely that you might have a little thing that’s not working. Alright, so that’s kind of a useful thing about a team and team dynamics. Everybody brings these inclinations and strengths and, you know the, your ability to negotiate through those is also gonna be important in addition to making those decisions. Right?} \]

\[\text{Students: Yeah} \]

\[\text{Coach: Okay} \]

This team strategy was explored in the Team A’s entire project transcript with the keywords of complex, complicate, in depth (and its variations), and difficult. This strategy appears later in the project when the team is discussing their path forward for the last approximate week of the project. In the discussion, Student 1 adopts the strategy suggested by the coach, monitors himself/herself and expresses, “this sounds really in-depth, and we don’t have that much time before next week.” A little later in the same meeting, Student 1 and Student 3 are engaged in a “philosophical debate” about how to get one of their model parameters. Student 1 advocates for calculating from their data, while Student 3 advocates for using a published value. After going back and forth a few times, Student 3 says, “my argument kind of coincides with the argument of doing the entire thing too in-depth, you are going to add more layers of work to this.” While we can’t be positive that these students are referencing the episode in the coaching session, they do appear to be employing the team strategy suggested by the coach, as where they hadn’t done so prior to the first coaching session.
**Team B – Communication**

Team B had four episodes related to written communication and nearly 300 words in their coaching session. In addition, they had 1 episode related to verbal communication. Most of the written communication episodes were affirmative. They either reinforced the idea of citing relevant literature or gave the students praise for their “thoughtful job” and good communication. One episode related to making minor changes in the memorandum. The final communication related episode situated the project in industry. In this episode the coach, in reference to two of their specified input parameters, challenged their number of significant figures in the following exchange.

*Coach:* Alright um, okay, so if you were to present this to an operator. What do you think the operator would think about 427.5 for the first run and and 2439?

*Student3:* It would be absolutely accurate [indiscernible].

*Student1:* I actually did think about changing those and I didn’t [indiscernible].

*Coach:* okay

*Student1:* but, yeah

*Coach:* Okay, so we probably want to, you probably want to round these to some you know, I don’t know if you want to do 430 and 2400 or 2500, or, or, um... And, you know, that, that, that, so these numbers are right from an engineering standpoint, but probably as you go to the floor, and make that transition, nice round numbers...There’s 2 things, one is just your floor cred, right, you want the operators to say you know what you’re doing and if they see numbers like this, it’s oh, here’s someone who did a calculation. And the other thing is just a practical thing, with these type of numbers it’s easier to have input errors? Right?

As previously mentioned, the coach is highlighting the students’ novice behavior and connecting their use of excessive significant figures to their appearance as new engineers, “someone who did a calculation” without considering practicality. After the coaching session the team began to run experiments. Only 6 of their 30 experimental runs contained parameter specifications with more than three significant figures and these six runs were part of a Design of Experiments. None of these occurred in the week directly following their design coaching session. Their entire project transcript was also examined using keywords of round, significant, figures, flow, and rate. There appears to be no indication in their transcript that they verbally discussed rounding values.

**Team C – Project Management**

In the design coaching session for this team we find half of total project management episodes from all teams. However, the majority of discourse related to project management is neutral. This team appears to have struggled with project management. They arrived at their design coaching session late and stressed, as illustrated by the initial discussion about an intra-team “communication breakdown,” and through one student’s reflection about the initial coaching session described in a post-project interview. The first episode related to project management was early in the design coaching session when the coach and students discussed whether the
students were prepared enough to even have the meeting. They proceeded with the meeting and it lasted the longest of the four design coaching sessions studied. In the meeting, they also expressed distress because of the large amount of time the project had taken them to get to their seemingly ill-prepared state. At the end of the meeting they discuss the multitude of changes they need to make to their memorandum and reschedule for a follow-up meeting. The follow-up meeting, where they again submit a memorandum and try to gain authorization to start experimentation, is approximately the same length as the initial design coaching session. In one post-project interview, one member of the team expressed the overwhelming amount of time this project required and discussed having difficulty planning time to work on project deliverables (e.g., the final presentation preparation) because of the amount of work perceived to be required in the reactor optimization process. This type of note regarding time management, a project management subskill, possibly indicates a deficiency throughout the project. This team could possibly have benefited from more corrective feedback on project management. In future work, we plan to further investigate examples like this and develop potential specific feedback strategies to identify these types of deficiencies and to provide feedback to help students develop better project management skills.

**Team D - Documentation**

Team D had the largest number of episodes dedicated to documentation. Their word count dedicated to documentation was also the highest. This team received feedback on the importance of documenting their work in their laboratory notebook. From examination of their laboratory notebook, it was clear that the team consistently made an effort to document their thoughts. In the design coaching session, the majority of documentation related discussion was about the purpose of their laboratory notebook. In the largest documentation episode, the coach described the notebook as a place to document their thoughts, ideas, and analysis. In addition, the coach stated:

*Coach1: So when we look at this at the end, if it’s like this real clean logical stuff, that’s not, that’s kind of...the, then we say this is, this wasn’t, this wasn’t u-. So, the laboratory notebook is a tool in the lab, and it is a tool to help you brainstorm and record and reflect. Okay so it’s not like a fine, a memo or a written report where, where, you know, where you want things to be edited and precise, but rather it’s you know, anything’s okay to have.*

The statement emphasized the idea that the notebook is a personal space to capture everything. Another episode in the coaching session described a team strategy for writing in the notebook which included the coach recommending passing the book around between team members as each member got ideas s/he wanted to write down. There were also two small sections of text that guide the students towards printing copies of their calculations and data to tape into the notebook. These two sections make up about 35% of the discussion related to documentation. Their verbal references to the laboratory notebook increase after the design coaching session. The team also wrote reflections in their laboratory notebook. However, the team did not include printed copies of data or calculations until after the update coaching session, in which documentation was further reinforced. In a post-project interview, one of the members of Team D discussed their use of the notebook in response to a question inquiring as to whether the team
members had defined roles. S/he noted in the following reflection that everyone wrote in the notebook every meeting.

\[
\text{Student 1: For example, I don’t really like writing in the lab notebook because I am kind of a slow writer and I get behind and everything, but we would pass around the lab notebook every meeting to make sure that everyone wrote in it.}
\]

The other two students did not reference the laboratory notebook in their interviews. It’s possible that because 65% of documentation discourse related to capturing thoughts, the team perceived this aspect of documentation to be more valued or more important. They did appear to have made a concerted effort to capture their thoughts and reasoning in the laboratory notebook. Perhaps they assessed the decreased attention paid to documenting calculations and equations as meaning that portion was less important.

**Conclusions and Implications for the Future**

Professional skills were found to be commonly incorporated in coaching sessions, with attention paid to teamwork, communication (written and verbal), project management, impact of engineering solutions on the economic and societal context, symbols of legitimacy, and written documentation. On average about 40% of the total coaching episodes related to professional skills. Most of these episodes were nested within the context of core disciplinary content and concepts. The types of feedback given to students were found to vary and include affirmative and corrective feedback with specific techniques of elaboration and revoicing. In addition, some discussion was found to be neutral.

We have presented detailed examples of discourse related to professional skills. In doing so, we provided additional information about how each of these skills is defined within engineering. For example, one purpose of communication is to express and convey ideas such that another individual can understand. However, another purpose of communication, as seen in these examples, can also be to symbolize legitimate participation in a community of practice. Proper choice of wording and references illustrates that a peripheral member of a community is becoming fluent in the discourse of the community and signals their progression towards full participation. Lack of doing so, symbolizes that an individual is a novice in the community. If educators want to enculturate students into a disciplinary or industry-specific community of practice, their feedback should include feedback on these conditions of legitimacy and the ways students can symbolize their belonging. In our case, most of the episodes regarding symbols of legitimacy provided students with corrective feedback to help them properly apply and interpret symbols of legitimacy.

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