Board 3: Chemical Engineering Division: Supporting Diversity in Teams through Asset Mapping

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Supporting diversity in teams through asset mapping

Abstract

While industry values teamwork and research suggests that diverse teams are more creative [1], there is limited understanding of how to support students to learn to work in such teams. We conducted a design-based research study to investigate how an asset-mapping activity could help team members to value each other's contributions in chemical engineering design projects. As part of our ongoing effort to redesign the curriculum to better support diverse students to persist in chemical engineering, we have been guided by the notion of building on students' assets and seeing their potential, rather than focusing on their deficits [2], [3]. We extended this notion by investigating how to help students see the assets they and their teammates bring.

We report on student progress in a sophomore-level material and energy balance course (n= 63 in 10 teams) and a capstone chemical engineering design course (n= 53 in 12 teams) at a large, Hispanic-serving research university in the Southwest. The sophomores had prior design experience, as they were in a cohort that began after the curriculum had been redesigned to incorporate design challenges throughout the core chemical engineering coursework. The seniors did not have prior design experience within the curriculum. Both courses stressed the importance of teamwork and engaged students in working on design challenges.

Students completed a two-part activity: They first identified their own assets and the assets of their teammates. They were then guided to map the assets across their team members and critically evaluate areas of strength and weakness. To aid them on the second portion, we provided a list of specific skills valued in professional engineering practice. In this paper, we focus on professional communication, project management, and interpersonal / teamwork skills. We collected all student work related to the activity. We developed a coding scheme to analyze the qualitative data and conducted basic statistics (correlations and t-tests) to analyze quantitative data.

The two areas that fewer students reported having skills were in project management and communication, particularly communicating outside of engineering. Overall, the sophomores tended to report similar numbers of team members with each professional skill as the seniors. Whereas the seniors could clearly distinguish between the professional skill areas, the sophomores were not adept at this.

To understand the impact of the team asset-mapping activity, we compared the sophomores' scores on items from a peer evaluation conducted twice during the semester. Early in the semester, students tended to report some difficulty managing conflicts related to team tasks, but by the end of the semester, significantly fewer teams did so.

We also describe an asset-based modification we made to the teams in the senior capstone class.

Introduction

Professional skills like communication, teamwork, creative problem solving, and project management are valued in both academia and industry. However, supporting our chemical engineering undergraduates to develop these skills is not straightforward and is often treated as a much lower priority than technical content, even though industry increasingly cites such skills as the most needed [4].

We report on a design-based research study in which we sought to leverage diverse chemical engineering undergraduate students' assets as a means to support these students to value professional skills.

Literature review

Following the design-based research method [5], [6], we formed a theory and conjectures about how to support chemical engineering undergraduate students to value professional skills. Because there is somewhat limited research in chemical engineering education related to the formation of professional skills, we also incorporate research from engineering education and education research more broadly. Specifically, we sought to build on research showing that diverse teams tend to be more creative; this strengths-based view of diversity aligned to our particular context and our efforts—as part of an NSF *REvolutionizing engineering and computer science Departments (RED)* project—to better support diverse student success. We therefore conjectured that providing students with an opportunity to reflect on their own and their teammates strengths, and then to critically assess their team's collective gaps would support them to value both professional skills and their teammates' contributions in these areas. Because the teams in our study were in design teams, we specifically considered research on how to develop students' professional skills in design teams.

Teamwork is an increasingly important critical skill of professional work [7]. Globalization has influenced workforce trends, with increased diversity of teams, with some researchers arguing for a more diverse view of diversity [8]. Harrison and colleagues [9] advanced previous work on diversity [10], [11] which proposed two levels of diversity, surface-level and deep-level diversity. They cast visible differences, such as demographics, as surface level diversity, and the accumulation of values, attitudes, and experiences as deep-level diversity. Using measures of surface and deep diversity, including a 24-item conscientiousness [12] measure, they found that over time, successful teamwork tended to lessen the effects of surface diversity, while enhancing the role of psychological diversity. In other words, teams that are able to integrate and build upon their attitudinal and experiential diversity tend to have better outcomes.

We want our students to approach surface diversity as the tip of the iceberg, leading them to seek and build upon deep diversity. However, collaborating with team members who are different from you, whether at a surface or deep level, takes effort and can be enhanced through instructional interventions [13], [14]. For instance, in a study of undergraduate drama majors, students drew concept maps of what they viewed as a successful team and engaged in reflective self- and peer evaluations as part of their team project; their team skills showed improvement [15]. Likewise, in marketing courses, Lancellotti and Boyd investigated team exercises [16]. Just as engineers may question the value of sacrificing class time to team skill development over disciplinary content, they sought to understand if such sessions had value. They found that team exercises increased students' satisfaction and acceptance of differences, and ultimately improved team performance.

Commonly, students are called upon to work in teams, but given little guidance on how to do so effectively [17]. In engineering, faculty frequently use interventions unsupported by relevant theories to direct students to manage their time, work together well and contribute their fair share of effort [18]. According to Lancellotti and Boyd, "Students are often placed in teams for a class project where it is optimistically assumed that the experience of teamwork itself will make students better at working in teams" [16]. Teamwork is an integral part of capstone design courses that provides "many opportunities to participate in team projects, but they do little to help students develop or improve specific teamwork skills" [19].

However, some research suggests that engaging in longer term, authentic team design can also result in improved team skills; research on design projects in chemical engineering, conducted using surveys and focus groups, showed that students perceived improvement in their teamwork skills [20]. Although traditional views of design ignored the social and psychological factors that influence team dynamics [21], team design is clearly a social process [22]. Edmondson, Dillon, & Roloff argue that team processes—behaviors, actions, and interactions—are more important to focus on, compared to the products or outcomes [23]. This is foregrounded by findings that poorly functioning teams can sometimes produce effective products by finding workarounds and excluding members [24]. Much research attention has been given to forming design teams and peer assessment. Many faculty use these assessments at the end of courses to adjust individual grades [25]. Having students engage in peer assessment supports them to develop a better understanding of team skills and their own strengths and weaknesses [25]. To support first-year undergraduates to develop improved design team skills, faculty assigned students to review and reflect on a video of one of their design team meetings [26]. They coded students' reflections based on Mezirow's theory of transformative learning [27], findings that over 60% of students were able to reach higher levels of reflection.

In addition to serving as a space to develop team skills, design projects also offer opportunities to practice other professional skills, including an area that engineering graduates notably tend to be weak: project management [28]. Qualitative analysis of students' work in project management tools related to a design project shows that they can learn to use such tools appropriately [29]. Likewise learning project management skills can support students to take ownership of their design work [30], resulting in improved overall design quality, and students tend to see it as valuable part of design work [31], [32]. In the present study, we consider how student teams view and value various professional skills, including project management and team skills.

Given our setting, which is very diverse, we sought to build on this diversity to help students develop and value professional skills. Diverse teams tend to be more creative [1]. However, without support, students in culturally-diverse teams sometimes experience conflict or act in exclusionary ways [33], [34]. To realize the potential of diverse teams, the members must do more than simply be open to diversity; even valuing diversity does not appear to be sufficient in long term design project. Rather, researchers have found that teams must also connect this value to engineering, meaning they must understand that the professional skills are linked to diversity and to technical competence [35]. When members of engineering teams have knowledge of and value the characteristics their teammates, they tend to be more creative [36] [37]. Researchers have argued that teams should include members who have complementary skills [38], or as we frame them, *assets*.

Others employ the term *funds of knowledge* to describe the everyday and cultural resources that students have, and that faculty can build upon [39], [40], [3]. Rather than stereotypical caricatures or broad but vague notions of culture, funds of knowledge are specific [3]. For instance, as engineers consider the funds of knowledge Latinx (an inclusive term that avoids gender binaries) students might and that faculty might build upon, we should avoid making assumptions that such students have identical, monolithic experiences of their culture. Instead, we might consider specific experiences that are relevant, such as knowing that a few students grew up near and had family members who worked in a factory that processed chemicals to make dye, or that others grew up using a multi-stage cooking process, not unlike distillation. By understanding these specific experiences, we can make chemical engineering more relatable to the students who are least likely to persist.

This approach has been shown to be effective in engineering education. For instance, Mejia identified Latinx high school students' funds of knowledge tied to the engineering design process [2], [41], [42], [43]. He found that students were able to build on their everyday experiences to address community problems. He also showed that students used professional skills, such as communication, collaboration and project management to reach design solutions. This approach also enhanced students' self-efficacy [44]. Our own work has built on this approach, finding that diverse undergraduate students bring engineering assets from their everyday experiences [1-3]. Like funds of knowledge, asset-based approaches aim to meet students where they are, valuing their experiences and engaging them as co-constructors of their expertise [45].

In this study, we extend prior research on asset-based approaches by investigating how to help students see professional skills as assets they and their teammates bring.

Methods

We used the design-based research (DBR) approach to developing and testing our theory that having students view their teammates from a strengths-based stance and critically consider their collective team strengths and gaps would help them develop stronger teams with more awareness of the importance of professional skills for engineers. DBR is a method that was developed to address the limitations of laboratory experiments in the social and behavioral sciences. Finding that very few, even well-tested laboratory studies had impact on actual teaching and learning, researchers developed DBR as a way to test theories about how learning can be supported. DBR involves building a theory that takes context seriously and *instantiating* the theory into a design for learning [46]. Iterative testing of the design under real world conditions provides an opportunity to assess both the design and the theory [5], [6].

We were guided by the following research questions:

RQ 1: How do sophomores' and seniors' assessments of their collective team's professional skills differ?

RQ 2: Do sophomores show evidence of developing team skills over the course of a semester-long design project?

RQ 3: How might we reinforce an assets-based view of students on dysfunctional teams in senior capstone design?

Setting and participants

Participants include students enrolled in two chemical engineering courses at a Hispanic-serving research university in the Southwest US. We sought consent from students to participate in the university's Institutional Review Board-approved study. The sophomore course focused on chemical process calculations (n=63) and the senior course focused on chemical engineering design (n=53). In both classes, students worked in teams of 5 to 7 students to address a design challenge. In the sophomore class, teams were formed using the CATME tool (www.CATME.org), which forms teams based on research about optimal teams using students' responses on a survey. In the senior class, the students formed their own teams. The design challenge was threaded through the entire semester in the sophomore class, and spanned two semesters for the seniors, with a focus on economics and problem definition in the first semester.

Study materials and data sources

In the sophomore class, the design challenge focused on the growth, harvest, and extraction of algal biofuels. They completed homework assignments that guided them to apply course content to specific issues related to biofuel production. They participated in "parley sessions" where they were scaffolded to do independent research and then bring their ideas together using a decision matrix.

Seniors were provided a list of possible design projects based on the AIChE list of past design challenges. From this, they could choose a project, modify a project, or suggest another related design challenge.

In both courses, students completed two assignments that we developed to help them value their team experience. The first assignment was completed individually about one month into the semester. Students evaluated themselves and their teammates in terms of the skills and contributions each member brought that would help the team be successful. They were told that they would share these with their teammates during class. We viewed this as a way to focus students on their teammates' strengths, rather than focusing on deficits. We additionally asked them to explain what interests and experiences drove them to become an engineer.

In the following class session, they conducted a team gap analysis, placing a tick mark for each person who had each specific professional skill (additional areas focused on lifelong learning, ethics, problem solving, and technical competence). Students self-assessed whether they possessed each skill, making this a binary choice (present/absent) for each member. For our purposes in this paper, we narrow our scope to the areas below, which were well covered by sub-topics:

Professional Communications Skills

- Technical writing (technical summaries, technical descriptions, reports)
- Professional writing (emails, memos)
- Oral communication (technical, formal presentations in front of an audience)
- Oral communication (communicating ideas to other engineers)
- Oral communication (communicating ideas to stakeholders or the public)

Project Management Skills

- Planning a schedule to meet deadlines
- Prioritizing tasks
- Delegating tasks across team members
- Organizing resources and information
- Making decisions collectively and effectively

Interpersonal and Teamwork Skills

- Dealing with difficulties effectively
- Listening and being open-minded and respectful when disagreeing
- Encouraging everyone to contribute ideas
- Showing concern for the feelings of other team members
- Making sure team members understand each other
- Adapting to new ideas
- Giving constructive feedback

Following this, they identified areas of weakness in their team and described strategies for how they could collectively resolve areas of weakness.

Students in the sophomore class additionally completed the CATME peer evaluation survey about one month into the semester and at the end of the semester [47]–[49]. We selected specific questions from this instrument that were aligned with our work. Specifically, of the task conflict, we selected an item that focused on disagreements. We excluded task conflict items that focused on having different ideas, because these can be beneficial to team creativity. We also selected an item from process conflict focused on work across team members:

- Task conflict: How frequently do you have disagreements within your work group about the task of the project you are working on?
- Process conflict: How often are there disagreements about who should do what in your work group?

These items are Likert scaled (1 = None or Not at all, 5 = Very Much or Very Often).

Analysis

We analyzed student work to compare the sophomore and senior students' team assessment across a range of professional skills. We first calculated the percent of team members reporting competence in each skill, and then drew comparisons across skills and across the two groups. We calculated average scores in three professional skill areas by taking the average across related questions: professional communication, project management, and interpersonal teamwork skills. We calculated correlation coefficients between these for each group of students.

We summed the students' responses on the selected items from the CATME peer evaluation instrument and conducted a paired samples t-test to compare students' responses at an early time point and at the end of the semester.

Results & Discussion

Students' assessments of their teams' professional skills

Our first research question investigated differences between the two courses in terms of the professional skills teams reported having. We present data for each of the professional skill areas: professional communication, project management, and interpersonal / teamwork skills. We then present results from correlation analysis, which provide insight into students' understanding of these skills.

We found that teams generally reported few gaps in professional communication. Only one senior team reported no members with one of the specific communication skills (orally communicating ideas to stakeholders or the public), a skill with which few students reported competency. Overall, the seniors reported higher numbers of teammates who felt competent presenting technical findings.

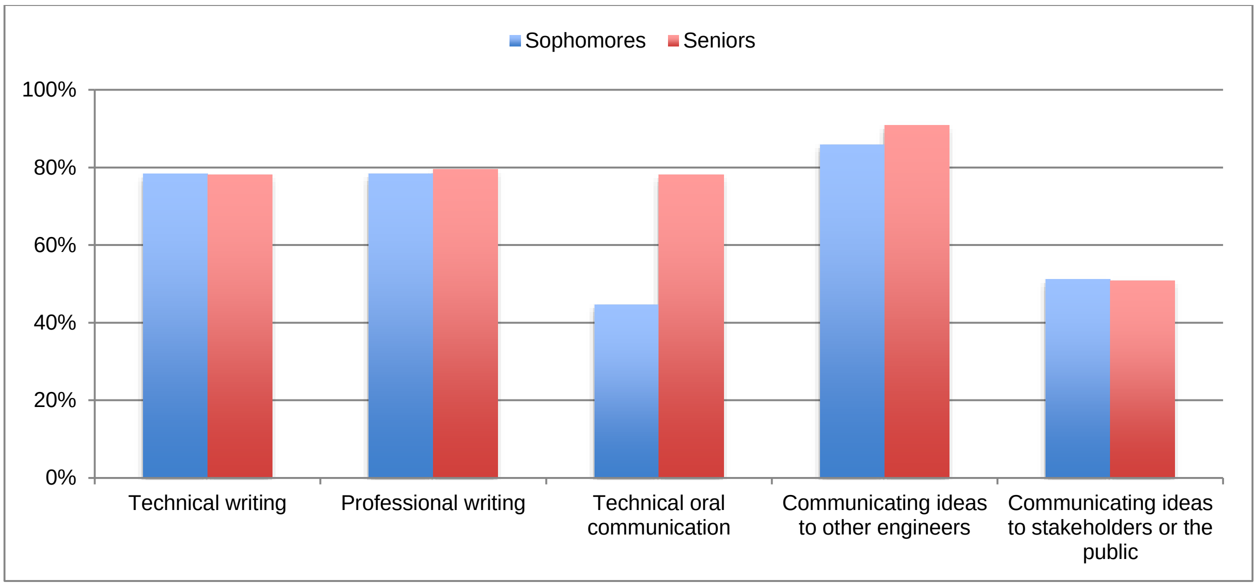

Figure 1. Teams' self-assessment of the percent of team members who have specific communication skills (sophomores, n=63; seniors, n= 53)

Overall, teams reported fewer members with project management competencies. Although they generally agreed they could make team decisions, one senior team reported no members who were competent in this area. One sophomore and one senior team reported no members who were competent at delegating tasks. Our findings align to findings elsewhere at show that engineering students typically feel weak in the area of project management [28].

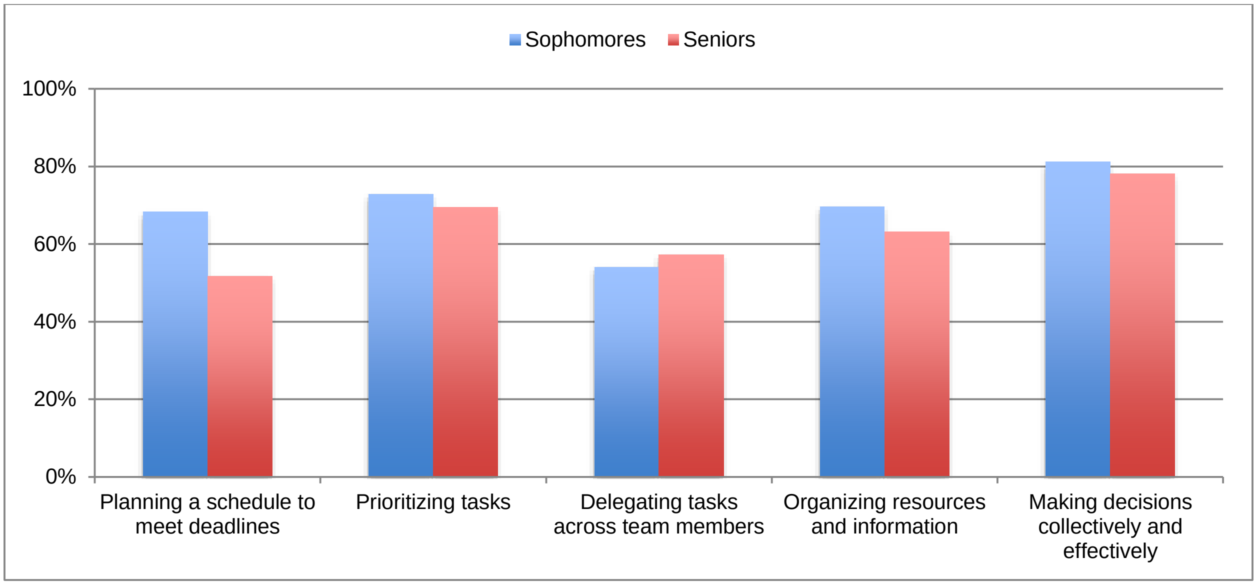

Figure 2. Teams' self-assessment of the percent of team members who have specific project management skills (sophomores, n=63; seniors, n= 53)

Three sophomore teams identified gaps related to interpersonal teamwork skills (showing concern for team members' feelings, giving constructive feedback, and adapting to new ideas). Although none of the seniors found such gaps, many teams had only one person who reported competency in giving constructive feedback. While these findings seem promising, we question the degree to which students were able to accurately self-assess some of the se competencies. Our purpose was not to evaluate whether students actually possess these skills, however, but rather to help students value these professional skills and connect the skills to engineering, as recommended by past research [35].

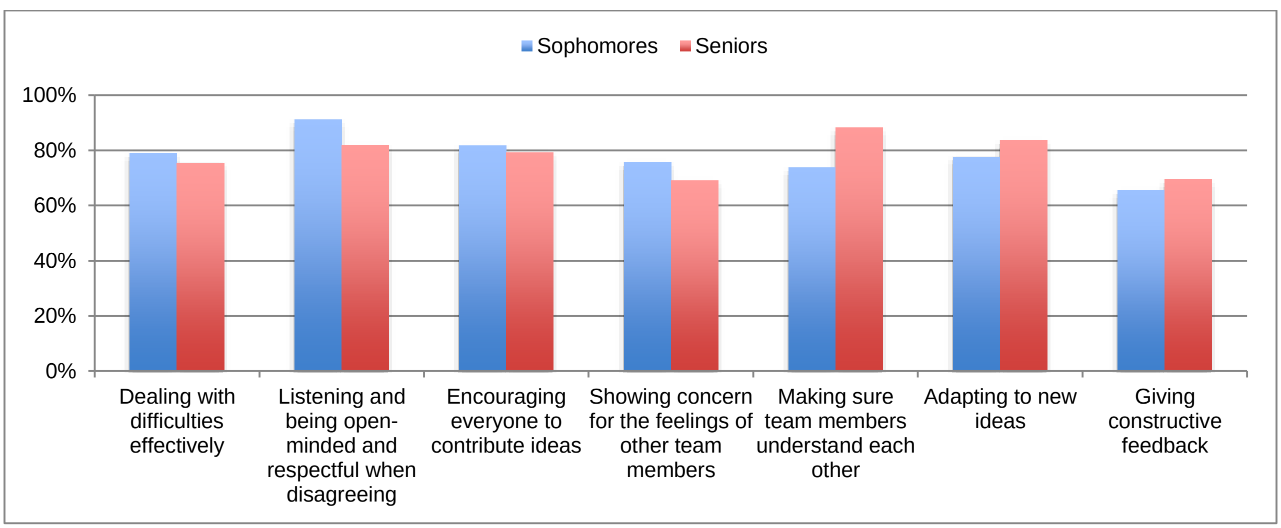

Figure 3. Teams' self-assessment of the percent of team members who have specific team skills (sophomores, n=63; seniors, n= 53)

To better understand student perceptions of these professional skills, we sought correlations between their scores, conjecturing that the professional skills should not correlate with one another because they represent different and distinct skills. We found positive correlations between each of these three professional skill areas for the sophomore class. The correlation between professional communication and project management skills was 0.55, $p > 0.05$. This is a moderate positive correlation, which means there is a tendency for teams who rated themselves as having many members with communication skills to also report having many members with project management skills, $R^2 = 0.31$. The correlation between professional communication and interpersonal skills is 0.68, $p < 0.05$. This is a significant moderate positive correlation, which means there is a tendency for teams who rated themselves as having many members with communication skills to also report having many members with interpersonal skills, $R^2 = 0.46$. The correlation between project management and interpersonal skills is 0.54, $p > 0.05$. This is a moderate positive correlation, which means there is a tendency for who rated themselves as having many members with project management skills to also report having many members with interpersonal skills, $R^2 = 0.29$.

In contrast, we found no significant correlations between each of these professional skill areas for the senior class. The correlation between professional communication and project management skills was 0.08, $p > 0.05$. This means there was essentially no relationship between having many members with communication skills and having many members with project management skills, $R^2 = 0.01$. The correlation between professional communication and interpersonal skills was -0.45, $p > .05$. This is a moderate negative correlation, which means there is a tendency for teams who rated themselves as having many members with communication skills to also report having few members with interpersonal skills, $R^2 = 0.20$. The correlation between project management and interpersonal skills is 0.19, $p > 0.05$. This means there was essentially no relationship between having many members with project management skills and having many members with interpersonal skills, $R^2 = 0.04$.

We see this difference between the two classes as revealing information about the sophistication of students' understanding of these specific skills. Other than in the area of technical oral communication, the sophomores tended to report similar numbers of team members with each professional skill as the seniors. We found that their responses were positively correlated, suggesting that the sophomores had not yet learned to distinguish between these different professional skills, whereas the seniors recognized that each professional area required different abilities. This is not surprising given the limited exposure most sophomores have had in project management in particular. We next consider the impact of this activity on the sophomores in terms of interpersonal and teamwork skills in particular.

Developing interpersonal and team skills at the sophomore level

A paired-samples t-test was conducted to compare scores on the selected CATME peer evaluation questions early in the semester and at the end of the semester. The early scores (M = 2.41, SD = 1.40) were significantly higher than the end of semester scores (M = 1.97, SD = 1.23), $t(62) = 2.146$, $p < .05$, with a small effect size, (d = 0.33). This means that early in the semester, students tended to report some difficulty managing conflicts related to team tasks, but by the end of the semester, significantly fewer teams did so.

As part of our asset-based team intervention, these students had identified strategies for resolving areas of weakness. Five of the ten teams planned to work on within-team communication skills. Six of the ten teams mentioned helping each other, especially in light of the diverse strengths they brought. For instance, they planned:

- to put themselves "in other people's shoes for empathy"
- to "help each other in areas of need and periodically reevaluating and assessing ourselves" and
- to "support each other and we compensate for those w/ weaknesses n one area by having someone with a strength in that area help them."

Reinforcing an asset-based approach to teams in senior capstone design

In the senior capstone design class, the students formed their own teams. This resulted in one "default" team made of members that were not chosen to join any team. A few weeks after completing the team asset-mapping activity, the instructor became concerned about the progress the default team was making, compared to the other teams. We met as a design-based research team to brainstorm further interventions that aligned to our asset-based approach. This was not part of our original planned design, but is a facet of the design-based research approach, in which emergent issues are viewed from the theoretical lens guiding the design. We considered the potential experiences of these students should we simply dissolve this team and assign them to new teams, fearing their new teams would focus on their deficits. Instead, we *invited* the members of the default team to assemble anonymous applications to join a new team, showcasing their strengths. We scaffolded this process by listing the design projects the teams were focused on, and asked the applicants to choose one or more possible design projects, as well as detailing why they were interested in the project and how they hoped to contribute, including their attitude and attributes.

We analyzed these seven applications using qualitative methods focused specifically on the professional skills they highlighted. Most of the students identified specific contributions, such as willingness to help others, skills at listening to others' ideas, and supporting the development of shared team understanding of problems. Several specifically noted that as outsiders, they could bring new ideas to the team. This positioning aligns to research on the value of diversity in teams [1]. The other teams reviewed these applications and "hired" a new team member. This approach has been successful, with teams that hired new members continuing to make good progress and not raising concerns about their new members.

Conclusions

Using a design-based approach, we aimed to test our conjecture that an asset-based self- and team-assessment activity could support students to value their team members' professional skills, especially related to communication, project management, and teamwork.

We found that students identified gaps in their professional skills specifically in the areas of technical oral communication (sophomores only), communicating to stakeholders, planning schedules (especially the seniors), delegating tasks, showing concern for the feelings of others, and giving constructive feedback. We also found that while seniors could clearly differentiate between the three professional skill areas of communication, project management, and teamwork, the sophomore students tended to conflate these.

The sophomore students showed significant improvement in the area of interpersonal skills, as measured by the CATME Peer Evaluation instrument. While there are many factors that may have played into this change, and we cannot directly attribute this change solely to our intervention, we note that many of the strategies the sophomores identified during our intervention as ways to improve related to these interpersonal skills.

While we cannot draw strong conclusions about the effects of our approach with the senior capstone design, in which we supported students on dysfunctional teams to "apply" to join other teams, we draw attention to this as a key component of the design-based research approach. This particular change emerged from concerns we observed, and was not part of our planned intervention, yet aligned to it. Students were open to the approach, and the new team members have been able to productively contribute.

As with the design-based research approach, we will continue to iterate on our design, to better test ways to help team members value each other's assets.

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