**Work in Progress: Building the Undergraduate Chemical Engineering Community by Involving Capstone Design Students in Undergraduate Courses**

Dr. Ryan Anderson, Montana State University

Dr. Anderson received a BS in Chemical Engineering and a BA in History from Bucknell University in 2007. He obtained a PhD in Chemical and Biological Engineering at the University of British Columbia in 2012 before postdoctoral studies at City College of New York. He is currently an assistant professor at Montana State University.

Dr. Abigail M. Richards, Montana State University

Dr. Richards has been faculty at Montana State University in the Department of Chemical and Biological Engineering since 2007. She is particularly interested in retention of underrepresented groups in engineering and first-year engineering programs.
Abstract:
Motivated by efforts to retain, prepare, and create a sense of community among engineering students, aspects of a Senior Design Capstone course in the Department of Chemical and Biological Engineering at Montana State University were integrated into freshman- through junior-level courses over the course of two years. In the first year of integration, these efforts focused on technical analyses. In the second year of integration, the focus was on enhanced communication skills. In the technical analyses, students in a sophomore level Fluid Mechanics course worked in teams to analyze the material balance tables and pump sizing specifications produced by twenty Capstone Design groups. Each team was responsible for analyzing one unique design project. Also, in that year students in a junior level Heat Transfer course used the same design projects to validate the design specifications of heat transfer equipment pertinent to each project. Assignments were timed such that the sophomore and junior students had just learned relevant technical information pertaining to these tasks in their courses. To enhance communication skills, Seniors in the second year of this integration gave oral presentations about their design project twice to students in an introductory chemical and biological engineering course. The first presentations occurred at mid-semester when the design students had completed a process flow diagram for their project, but none of the material balance tables or technical sizing. Freshman students in the introductory course had just been exposed to process flow diagrams and material balances the week prior to these presentations. The second presentations occurred at the end of the semester when the technical design was complete along with analysis related to society, safety, and the environment. The benefit of this presentation exercise is two-fold: 1) Seniors gain experience presenting their design to a non-technical audience (with only a math and science background) and 2) the Freshmen, by learning about the design process through peers in their major, obtain a perception of connectivity with the major and the department. The connection may help Freshmen envision where they will be by senior year and strengthen their identity as engineers. This work in progress presents these approaches along with survey data from each cohort and additional insight from the instructors. Initial results from the second and third year students indicate they enjoyed the approach, recognize the applicability of their current coursework within the context of a larger design, and feel more connected to the major. Results from the first-year course and Capstone Design course collected at the end of the Fall 2017 semester indicate the Seniors wished they received a similar presentation in their first year, and the Freshmen look forward to completing upper division courses and feel connected to the department and field of engineering.

Introduction
The Chemical and Biological Engineering Department (ChBE) at Montana State University (MSU) currently has approximately 600 undergraduate students. Over the last three years, the Capstone Design instructor noticed, when assigning new groups at the start of the semester, that many students seemed to be meeting for the first time in the fourth year. This occurred despite most students moving through the same curriculum, as a cohort, over the past three years.
Simultaneously, the instructor of the introductory chemical and biological engineering course, which targets first semester freshmen, found through end of semester course reviews that many students remain uncertain of what career opportunities are afforded to them as chemical or biological engineers. To remedy this perceived problem, the authors were inspired by the work of Butterfield and Branch [1] where seniors ‘hired’ freshman students to assist in the laboratory component of the Capstone Design experience. In their work, freshman participants self-reported having learned important engineering concepts, and also gained insight into their future career trajectory.

Our approach, while inspired by the work of Butterfield and Branch [1] where freshman students were ‘hired’ by Capstone students, relied on integrating the Capstone Design course into chemical engineering courses occurring across the freshman-junior level. In the first iteration of the present work, technical aspects of the Capstone Design projects formed the basis for group problems that were assigned in two courses: Fluid Mechanics and Heat Transfer. In the second iteration, the Capstone Design students gave a series of presentations to a first-year, introductory chemical and biological engineering course. Presentations focused on both the technical components of their design and safety considerations and societal impacts pertaining to their process design. At this stage in the project, the authors’ objectives were threefold. The first objective was to assess if sophomore and junior students participating in the technical integrations of Capstone Design projects reported a better understanding of the technical aspects of their respective courses (i.e. Fluid Mechanics or Heat Transfer) and gained an appreciation of how this material fit into the context of a larger design within the field of chemical engineering. Second, pertaining to the delivery of presentations within the introductory chemical and biological engineering course, the authors wanted to determine if the presentations gave the freshman students a greater understanding of the breadth of the chemical engineering discipline. A third objective, was to provide Capstone Design students with additional opportunities to develop their communication skills by delivering presentations to a variety of audiences, which had historically been limited to the confines of the Capstone course itself. Finally, by creating more opportunities for students within our department to interact, particularly during the groupwork assigned at the sophomore and junior levels, the authors anticipated that a stronger sense of community would be reported by each cohort of students.

In addition to developing a more cohesive undergraduate chemical engineering student community by facilitating interactions with Capstone Design students, the approach employed by the authors touches upon several other facets that may increase student learning. These benefits could include more opportunities for teamwork, an avenue for collaborative learning in traditional lecture-based courses, development of professional skills by preparing and delivering technical presentations to diverse audiences, curricular integration, and engineering identity formation. The benefits of teamwork are well established and updated ABET criteria include specific language on teamwork as an outcome: ‘Establish goals, plan tasks, meet deadlines, manage risk and uncertainty, and function effectively on teams.’ [2]. Furthermore, a previous study focused on a single institution showed that their engineering graduates valued ABET criteria related to teamwork highly [3]. This teamwork facilitates a collaborative learning
environment where the groups work toward a goal together, which has been shown to be an effective implementation of active learning [4].

Finally, teams of the Capstone Design students were charged with creating and delivering presentations regarding their design projects to the Freshman students. Historically, Capstone students at our university only presented to their peers and faculty within the department. These additional presentations addresses another ABET outcome: ‘an ability to communicate effectively with a range of audiences through various media.’[2]. Capstone Design students were tasked with delivering presentations regarding their process design to an audience that was stated to have high school level math and science preparation and little engineering background. This contrasts with the presentations that Capstone students deliver within the confines of the Capstone Design course, where the audience consists of faculty and their fellow senior students.

As reviewed in [5], it is encouraged for students to see connections between subjects, as this aids in knowledge transfer between classes. This further motivated the authors because the integration of Capstone Design would allow students to investigate the application of subjects learned within a single course into the context of a larger design. Identity as an engineer also can form during undergraduate studies, and a tool is being developed by Godwin to measure engineering identity [6]. As shown by Meyers et al. [7], a sense of community is particularly important for first year students to aid in retention efforts, and professional persistence is related to one’s identity as an engineer. The formation of an engineering identity plays a part in both interest in engineering and contributes to perseverance in the major [7, 8, 9, 10]. Exposure to mentors and/or role models within the STEM discipline has a positive impact on an academic sense of belonging, as well as a positive impact of academic self-efficacy [11], while others have noted that poor faculty-student relationships negatively impact a sense of belonging and the persistence in the major [12, 13]. Curricular integration within various engineering departments combined with peer-peer interactions, specifically utilizing a course such as Capstone Design as a centerpiece, is shown to assist students in learning about engineering as a future career [1, 14] and provide context to the coursework taken outside the engineering rubric such as basic math and science courses [5, 15].

As a work in progress, the authors are motivated to increase the sense of community, both within an individual course and across cohorts, amongst the engineering students throughout their undergraduate experience. Via this increased sense of community, the authors hope to further study if these efforts better recruit, train, and retain more students. This paper presents the approach used to integrate the Capstone Design course and capstone teams into traditional, ‘unit operations’ courses in the Fall of 2016 and into a freshman-level introduction-to chemical and biological engineering type course in the Fall of 2017. Students in all classes were surveyed and provide insights into the strengths and weaknesses of the approach employed. The authors discuss future plans to make these efforts easier to implement while imparting more benefit to the students. Also discussed are future plans to employ a validated measure of engineering identity developed by A. Godwin [6] to examine how this curricular integration impacts student’s engineering identity as they advance through the chemical engineering curriculum.
Courses and Capstone Integration Approach

At MSU, the Capstone Design course for Chemical Engineering spans two semesters. The course is structured so each group receives an initial, vague deliverable from the mentor. Over the Fall semester, the students address a series of deliverables related to background research on the project, markets, material and energy balances, equipment sizing, safety, and impacts to the community and environment. Each deliverable is graded and returned to the groups to be updated and incorporated into a final semester report. The following Spring semester, the same student teams revisit their design, address any deficiencies identified in their Fall final report, and incorporate safety and engineering economic analyses to complete their design.

In the Fall 2016 semester, aspects of the Capstone Senior Design course were integrated into two unique chemical engineering classes: Fluid Mechanics and Heat Transfer. At that time, the Capstone course had 81 students with 20 unique design projects. The topic areas were generated by a faculty or outside mentor who oversaw each project. The 2016 projects were diverse and included breweries and distilleries, mining/mineral recovery, green building design, a power plant, chemical production from waste feedstocks, and biogas production among others.

In the Fall of 2017, the Capstone Design course was restructured to use fewer mentors and allow for more project overlap. Five theme areas were used with one mentor overseeing four groups consisting of four students each, within a given theme area (still 20 groups for 86 students). These theme areas were: mining, CO₂ conversion to fuel, biomass conversion to chemicals, brewing, and wastewater treatment/utilization. As will be discussed, utilizing theme areas better facilitated the group presentations by the Capstone Design teams to the introductory chemical and biological engineering class.

**Fall 2016: Technical Integration of Senior Design via Pump and Heat Exchanger Sizing in the Fluid Mechanics and Heat Transfer Courses**

At MSU, the Fluid Mechanics course can be taken in the sophomore or junior year and the Heat Transfer course is taken by students in their third year. The Fall 2016 Fluid Mechanics course had 46 students who were of either sophomore or junior standing. These students were put into twenty groups by the instructor and each was assigned one of the twenty corresponding Capstone Design project teams. Those students were given two group assignments based on deliverables submitted by Capstone Design students, (1) verify the material balance on the process design and (2) check the pump sizing completed by the Capstone Design team. In the Heat Transfer course, which had 110 students, students were put into a total of forty groups by the instructor, consisting of two or three students. Each of the twenty Capstone Design teams were assigned to two Heat Transfer groups. Heat Transfer groups were tasked with verify the sizing of heat exchange equipment within the Capstone Design team’s process.

Integration of Capstone projects into the other classes utilized “Technical Report 1”, the material and energy balance tables, and “Technical Report 3”, the equipment sizing. “Technical Report 2” focused on safety considerations and social and environmental impacts, and was left out of the technical integration. A schematic of the integration plan and specific timing is shown in Figure 1. The material balance was given to the Fluids class and they returned their assessment to the
Design students just after the “equipment” sizing deliverable. While this may seem ‘after the fact’, the workload in Design before Technical Report 3 is sufficiently high that it seemed best to incorporate feedback from the underclassman after the sizing was due. There was still sufficient time to make changes before the Final Report if errors were identified by the Heat Transfer and Fluid Mechanics students.

Figure 1: A timeline of the senior-level Capstone Design course, integration of Fluid Mechanics and Heat Transfer courses assignments and timing of student feedback to the Capstone Design teams.

**Fall 2016: Survey Questions to Fluids and Heat Transfer Students**

Fifteen survey questions were given to the students in the Fluid Mechanics and Heat Transfer course after completing the group projects. The questions fell into four broad theme areas: student self-reported learning, their sense of connection to the department and future courses, report quality, and desired level of engagement with the senior teams. The questions that are plotted in the results section are shown in Table 1.

Table 1: Survey questions for Heat Transfer and Fluid Mechanics students

<table>
<thead>
<tr>
<th>Number</th>
<th>Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The ‘Pump Sizing’ project helped me learn core content related to Fluid Mechanics (or Heat Transfer)</td>
</tr>
<tr>
<td>5</td>
<td>I feel more confident/comfortable ‘reading’ a process flow diagram (PFD)</td>
</tr>
<tr>
<td>8</td>
<td>I feel more connected to the department now</td>
</tr>
<tr>
<td>9</td>
<td>I feel more connected to the field of chemical engineering now</td>
</tr>
</tbody>
</table>

**Fall 2017: Integrating Senior Design Projects as Presentations into an Introduction to Chemical Engineering Course**

A group presentation typically accounts for 10% of the course grade in the Capstone Design class. Prior to Fall 2017, two people would represent their design group and would give a 10-12 minute presentation to the Capstone Design class and chemical engineering faculty mentors toward the end of the semester (see Figure 1). The remaining two group members were required to present in the following Spring semester. All twenty groups would deliver their own, unique presentation, and each individual student would present only once over the course of the year.

The Fall 2017 Capstone course contained 86 students, again divided into 20 individual groups. A change made for the Fall 2017 semester was to utilize the five theme areas as discussed above.
This allowed the formation of “thematic-teams” which combined two students from each group, drafted by the design instructor, to form a ‘super-group’ representing the theme area. This combined cohort presented to the design class. This led to 8-12 students presenting together for 40 minutes with an additional 10 minutes for questions. Similarly, the remaining members who did not present to the design class were tasked with presenting to the Freshman class. Of the remaining two members from each group, one person had to form a thematic-team to present to the Freshmen at the mid-semester and the other person joined a thematic-team to present to the Freshmen at the end of the semester. Figure 2 shows the process by which students were divided into these individual groups.

Figure 2: The Capstone Design course projects were focused into five theme areas. Each of the 86 students in the course were assigned to one of four groups within each theme. Within each theme-area, there were four distinct sub-groups consisting of four students each, labeled A-D as shown above in Theme Area 1: Wastewater, which serves as an example. Each group worked on a design project over the course of the semester. Two thematic teams were made by drafting 2-3 students from each of the four sub-groups in that theme area. These inter-group teams were responsible for crafting presentations tailored for either the Capstone Design or Intro to Chemical and Biological Engineering courses.

**Fall 2017: Survey Questions to Freshmen and Seniors**

The freshman students were surveyed mid-semester and end-of-semester, just after the delivery of each presentation. The Seniors involved in these presentations were surveyed at the end of the semester and asked to identify which presentation they participated in. For the Freshmen, questions focused on connection to the department, understanding of and connection to the field of chemical engineering and future courses, and the level of detail and quality of presentations. Questions to the Seniors focused on logistics pertaining to group performance, if they wanted a
similar experience in freshman year, level of presentation detail, and their own communication skills. A subset of these questions, which are plotted in the results, is included here in Table 2.

Table 2: Survey questions given to Freshman students after listening to Capstone Design presentations

<table>
<thead>
<tr>
<th>Freshmen – Both Semesters</th>
<th>Seniors End of Semester</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q4 - After listening to the presentations, I have a better idea of what chemical or biological engineers might do than when I started the semester</td>
<td>Q3 - I wish senior design groups spoke to my class when I was in CHBE 100.</td>
</tr>
<tr>
<td>Q10 - I am excited to take my upper division engineering courses</td>
<td>Q6 - Our presentation was appropriate for the CHBE100 audience (level of detail etc.).</td>
</tr>
<tr>
<td>Q11 - I can picture myself as a chemical or biological engineer</td>
<td>Q11 - I want more opportunities to give presentations.</td>
</tr>
<tr>
<td>Q12 - The presentations and design topics make me nervous about continuing in chemical engineering (the work looks too challenging and/or complex)</td>
<td>Q12 - I would like to give more presentations to develop my communication skills.</td>
</tr>
<tr>
<td>Q16 - I feel connected to the Chemical/Biological Engineering Department</td>
<td></td>
</tr>
<tr>
<td>Q17 - I feel connected to other Chemical/Biological Engineering students</td>
<td></td>
</tr>
</tbody>
</table>

Results and Discussion

This section includes three distinct areas, the Technical integration from Fall 2016, the Presentation integration from Fall 2017, and additional insights from the instructors.

**Fall 2016: Technical Integration**

In both the Fluid Mechanics and Heat Transfer courses, the students reported a better understanding of the course materials after completing the project as shown in Figure 3.

In the Fluid Mechanics class, 70% of the students agreed or strongly agreed with that statement, while the same was true for 60% of the students in Heat Transfer. Also reported in Figure 3, the students report gaining confidence in reading process flow diagrams (PFD), which were provided by each Capstone team. Developing a PFD is one of the major technical deliverables in
the Capstone class, though many students in the course have had limited interactions with them until that point.

Figure 4 focuses on students’ connectedness to the department and the field of chemical engineering. In the Fluid Mechanics class, an equal number of students agreed or were neutral to departmental connectedness, while in Heat Transfer a majority (52%) responded as neutral. This could be attributed to students in Heat Transfer being on average further in the curriculum, and thus having already forged more of a connection. Also, the larger number of students and more open-ended projects in the Heat Transfer course could have led to a perception of less connection. More study would be warranted to determine the cause. However, in both classes the students mostly agreed with increased connection to the field of chemical engineering. This may indicate that though a connection was not formed between students, they can more clearly see types of projects they may work on as engineers. Encouragingly, only a small fraction of students reported less overall connection.

![Figure 4 Fluid Mechanics and Heat Transfer Connection to department and field of chemical engineering](image)

Along this vein, several student comments indicated that they appreciated seeing how the material they were learning in Heat Transfer and Fluid Mechanics fit within the context of a larger design. Example comments about the best part of the assignment include:

- ‘The project was frustrating in that not all of the info was given, many assumptions had to be made, and a lot of the given info was incorrect. However, I think that was the best part of this assignment as it was more similar to real world problems. It took a lot more effort than traditional problems in which everything is given.
- ‘Being able to gain a little experience about what we will be doing in senior design (previewing of class).
- ‘Working with others and applying chemical engineering knowledge.’
- ‘The best part of this assignment was gaining exposure to a real-world process that I could encounter. I feel more prepared for senior design, knowing what I could encounter’

**Fall 2017: Presentation Integration**

The second integration approach focused on communication skills. The Seniors were aware this was the first implementation of the Capstone course into the first-year course, and interestingly 88% of the students (n = 24) strongly or somewhat agreed that they wished a group spoke to their
class in their first year (Figure 5). They also believe their presentation was appropriately detailed for the Freshmen, which is corroborated by the Freshman survey who report that the content was not excessively technical (88%). Only 16% of respondents agreed or strongly agreed that the presentations should have contained more detail.

Figure 5: Seniors’ responses to wishing Capstone Design had been integrated into their intro to engineering course and self-assessment of the appropriateness of their presentations.

The delivery of presentations to the introductory course required the Capstone Design students to work within the context of a new, larger team to design and deliver a presentation to a relatively non-technical audience. While teamwork and communication are ranked highly amongst graduates as valuable outcomes used in their work [3], it is unclear how this is perceived in the current senior class. The data in Figure 6 is scattered in terms of students wanting more opportunities to present and students hoping to develop their communication skills.

Figure 6 The apparent value that senior Capstone Design students place on opportunities for honing and developing communication skills.

It is possible that at a later point in their careers, these individuals will see the value in developing more effective communication skills, consistent with the post-graduate engineers who ranked communication skills fourth highest in terms of the pre-revision ABET criteria [3].
In terms of overall logistics, as experienced by the Seniors, Table 3 indicates that the students did not think it was too much effort to compile the presentation, even considering they were representing four design projects into one new presentation group. They also report being glad they could present to another class and 50% report agreeing somewhat or strongly to willingness to present outside the college of engineering. It is unclear if the 75% of students who were glad to present in another class were happy about presenting to the freshman-level students or glad to avoid a more technical, rigorous, and lengthy presentation to the senior design class.

Table 3: Perception of the Senior Capstone Design students on the effort and value of preparing and delivering presentations to the Introduction to Chemical and Biological Engineering course. Values shown are percentage of respondents with N = 24.

<table>
<thead>
<tr>
<th>Q7 – It was too much effort putting the presentation together.</th>
<th>Q8 – It was difficult to coordinate with teammates (other presenters in your theme area).</th>
<th>Q9 – I’m glad I could prepare a presentation for a class other than ECHM 411 Design.</th>
<th>Q10 – I would like to present a version of my Design to groups outside the college of engineering.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly agree</td>
<td>4.2</td>
<td>4.2</td>
<td>37.5</td>
</tr>
<tr>
<td>Somewhat agree</td>
<td>8.3</td>
<td>12.5</td>
<td>37.5</td>
</tr>
<tr>
<td>Neither</td>
<td>29.2</td>
<td>12.5</td>
<td>20.8</td>
</tr>
<tr>
<td>Somewhat disagree</td>
<td>25.0</td>
<td>29.2</td>
<td>0.0</td>
</tr>
<tr>
<td>Strongly disagree</td>
<td>33.3</td>
<td>41.7</td>
<td>4.2</td>
</tr>
</tbody>
</table>

Additional open-ended comments from the Seniors include:

- ‘The presentation itself was not very difficult to put together and present. The 7-minute length was just enough to get the information that needed to be covered out there but short enough to not lose the attention of the Freshman students.’
- ‘I hate presentations so presenting to the Freshman class was way less scarier (sic) than presenting to the design class.’
- ‘I think it was fun to take a step back and simplify our processes for presenting to the CHBE100 class. It is easy to get wrapped up in the details, and taking a big-picture look at our process was enjoyable. I think the way the system was set up was good. No more than 7 minutes should be needed for a simplified overview of the processes and 3 minutes of questions is adequate for most scenarios.’
- ‘Mostly enjoyed it. Really wish i (sic) could have been exposed to it when i was a Freshman! i liked presenting to ECHM 100 students more than i would have to ECHM 411 students.’

The integration of Capstone Design via presentations delivered by teams of senior chemical engineering students appeared to satisfy the first-year course’s goals of providing first-year students with the breadth of application within the field and the instructor’s goal to increase community and identity within the discipline. As shown in Figure 7, most of the Freshman students agree or strongly agree that they feel more connected to the department and other students, they are excited to proceed in the curriculum, and do not see the future work as too challenging. It is interesting to note that while only 25% of the Freshman students felt concerned about taking upper division courses after listening to the Capstone presentations, 54% of the Heat Transfer students were apprehensive about taking the Capstone Design course after completing their validation of the senior’s technical design pertaining to heat exchange equipment.
Figure 7 Freshman responses to questions pertaining to connection within the department and commitment to the major.

As shown in Figure 8, Freshmen can picture themselves as engineers and report a better understanding of what chemical and biological engineers do compared to their understanding earlier in the semester.

Figure 8 Freshman survey responses to mid-semester and end of semester survey questions on identification with engineering
It may be that the Freshman students can see themselves as that future design cohort, in effect ‘seeing the light at the end of the tunnel.’ Recognizing that these Seniors sat in the same seats only a few years prior and are now completing the degree may be encouraging to Freshmen. It is unclear if that outcome is due to the presentations or the course itself, as the course aims to introduce the students to what it is that chemical and biological engineers do.

While some comments specifically noted the presentations were helpful in shedding light on what is encompassed in the field of chemical engineering, others noted that they wanted more information and more opportunities for questions:

- ‘The presentations were great and very helpful. I think they will help students decide whether or not they really want to be chemical or biological engineers.’
- ‘Somehow present information like this to students on the first day of class so they can more clearly understand what they are getting into in terms of chemical and or biological engineering.’
- ‘I wished I gained more clarity on how the design projects work for senior year. How many people work together in a group? How are design projects selected/assigned? Do they have to meet specific weekly deadlines?’
- ‘More time for questions’

Additional Insights

Both the Fluid Mechanics and Heat Transfer instructors found the experience to be valuable. Student comments were mostly positive, and they seemed to enjoy seeing the PFDs. A fear of the instructors was that this would be perceived as ‘busy work’, but that sentiment was not observed in the student comments. Student comments in Heat Transfer indicate an appreciation for seeing a more “real-world” application of the material learned in class. Notably, the students in both classes commented on the lack of quality in overall presentation when receiving the PFD, material balance table, pump sizing specifications, and heat exchange requirements from the Seniors. This may be advantageous in that students might remember ‘poor presentation’ and aim for higher quality in their own design projects. The effectiveness of this ‘critique’ may be further investigated in future implementations of this process.

A high level of coordination between the Capstone and other course instructors is necessary. It was advantageous that the Capstone instructor was also the Fluid Mechanics instructor, reducing the level of coordination somewhat. The Heat Transfer instructor also taught the first-year course. Despite this overlap, regular communication and brainstorming between instructors was key. This was additional work, but based on the survey results, the effort seems justified and was not overly burdensome. However, it does not seem feasible to do both integration approaches in one Fall semester.

Beyond the coordination efforts, the quality of and level of detail within the Senior Design projects given to the Fluid Mechanics and Heat Transfer class varied. In particular, the quantitative data provided by Capstone Students within the Heat Transfer assignments was variable and spotty, often leaving the junior-level groups to estimate many parameters (e.g heat capacity of gas mixtures). While the open-endedness of this exercise could help one become a better engineer, the additional complexity was beyond what the instructors originally intended.
and was somewhat frustrating to the affected Heat Transfer students. It was simpler in the Fluid Mechanics class, where pump specifications included fewer required parameters (e.g. pump power, flow rate, pressure change). One design group did not turn in their Heat Transfer portion, which incurred only minimal penalty in terms of grading but left to additional effort on the Heat Transfer instructor’s part to reassign this group. In spite of this, several students volunteered via comments that discussing assumptions and results of their calculations with their group was enjoyable.

The teams interacted but did not need to form larger groups to accomplish the tasks. For instance, the groups in Fluid Mechanics or Heat Transfer had to work together, but minimal coordination/grouping was needed with the Design team. Questions for the Design team were asked via email. As mentioned by Butterfield and Branch [1], such interaction could lead to issues in poor communication and time management. Future efforts to encourage more collaboration between the groups of students in different years may be hindered by these obstacles, but it may be valuable to facilitate face-to-face interaction, as more than half (54%) of the Heat Transfer students responded to agreeing or strongly agreeing that they would have liked the opportunity to meet with the Capstone Design groups in person to ask questions and a large portion agreed or strongly agreed to wanting to meet with Capstone groups to discuss their findings (39%). Responses to these same questions by Fluid Mechanics students were not quite as strongly in favor and this may be due to the fact that the task of pump sizing was more straightforward and clearly defined. It is unclear how much group work occurred within an individual Fluid Mechanics or Heat Transfer team. For instance, one student in Fluid Mechanics wrote on what he or she would change: “Take out the group project. I didn’t work with my partner anyway.” This type of short project means little interaction may be required within a team, and the instructors did not include a peer-review process. In Heat Transfer, many students commented that the best part of the project was working on a team to solve a real-world problem. In this case, the less defined process variables supplied by the Capstone groups necessitated that students met and discussed assumptions to make. While several of the Heat Transfer students commented that they were happy they had a well-functioning team, some alluded to a few dysfunctional teams.

The scope and focus of the presentations to the Introductory class may also be improved. Comments from the Seniors on the presentations also provided informative, critical feedback:

- ‘I believe to present to a Freshman level class, the presentation needs to be interesting and stimulating. For most of the presentations, I wanted to fall asleep so I'm not surprised the Freshmen weren't super involved. I also think having more time for question and answer may lead to a more interesting and interactive conversation.’
- ‘Thought that overall it was fine but could have had a but more direction and stricter grading to encourage better work from the group members.’
- ‘I enjoyed presenting to ECHM 100 students. In their position, I would have really liked to see projects that the Seniors were working on so that I could understand exactly where my undergraduate degree was heading. The main issue with the presentations, though, was the length. It was incredibly difficult to present any sort of detailed information in the time allotted. For the future, maybe select 1 or two or three groups to present to ECHM 100, and if possible, find another similar setting for the other groups to present in. I think the length of the presentations made it difficult to
communicate information effectively, and longer presentations might be able to provide more engaging information to the class in a way that they understand and can connect with.’

The Seniors are relatively unprepared when it comes to delivering presentations (hence having course assignments to practice), but that pedagogical benefit is lost on the freshman audience. As the quality of presentations varied, student engagement of the freshman cohort ebbed and flowed, as observed by some of the presenting Seniors. To increase the level of interaction between the Freshman and Senior students, the Seniors indicated they would be willing to schedule meetings with the Freshmen. Survey results indicate that 87.5% of the Seniors surveyed on presentations said they would meet with the Freshmen to answer their questions and 79% indicated they would meet with the Freshmen in a mentoring role. This may lead to a solution to another issue noted by the Freshmen, where some first-year students expressed a concern that the Seniors’ presentations encompassed ‘all’ chemical engineering is and that only these theme areas were within the scope of the chemical engineering field. Facilitated interactions between Seniors and Freshmen could be one way to show more of the breadth of opportunities and to show students how the curriculum relates to broader engineering themes on the way to Senior Design. Linkages of first year and senior design teams has shown early academic career engineering students were able to effectively decide on whether engineering was an appropriate career path [14]. Future plans include organizing facilitated meetings between Freshmen and Senior students, which could accelerate the development of engineering identity through role acquisition and socialization [16, 17].

Conclusions

The Senior Design Capstone class in the Chemical and Biological Engineering department at Montana State University was integrated into three undergraduate classes at the freshman-junior level. In Fall 2016, these efforts focused on using technical aspects of the design reports to form the basis for group projects in Fluid Mechanics and Heat Transfer courses. Students in Fluid Mechanics assessed the material balances and pump sizing specifications while students in Heat Transfer verified the sizing calculations of heat transfer equipment. Students in general responded positively, and reported more understanding on both topics as they pertained to Fluid Mechanics and Heat Transfer. In addition, most students were either ‘Neutral’ or ‘Agreed’ to feeling more connected to the department and to the field of chemical engineering. In Fall 2017, the Capstone class was integrated into a Freshman level introductory course on chemical and biological engineering. The Seniors who gave those presentations reported wishing they had a similar set of presentations delivered to them as Freshmen. The Freshmen reported feeling more connection to the department and excitement about taking upper level classes. The instructors viewed both approaches positively. While a high level of coordination was required, the instructors are encouraged by the survey results. Future efforts to reduce the instructor workload during technical integration will focus on more specific and higher quality reports from the Seniors as to remove some of the ambiguity. The presentations can also be changed to focus on fewer projects while reminding the Freshmen that these are only examples of their future work. Considering this successful implementation, the framework presented here will be extended in future efforts to include validated survey instruments, such as the one by Godwin [6] to measure changes in engineering identity formation.
References


