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Collaboration between Seniors and Freshmen on Senior Capstone Projects

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Abstract

Learning through teaching is well-recognized as a tool of pedagogy, which, if implemented effectively, may result in significant gains for both the mentor and mentee student. Furthermore, developing social connections to a department, and forming the engineering identity of incoming students have both been repeatedly demonstrated to improve student retention. To benefit by such teaching and retention potential, we have introduced collaborative projects for inter-cohort teams of freshmen and senior students in the University of Utah's Department of Chemical Engineering.

Freshmen develop their resumes over their first year in our program. Towards the end of our spring semester they use their resumes to apply for positions on the senior capstone projects on which they are most interested in working. Senior teams then use the resumes to make hiring decisions. Once teams are assembled, the inter-cohort groups work together for approximately three weeks to complete a capstone laboratory project. Significant logistical hurdles were encountered due to the divergent expectations, schedules, and priorities of the two groups. However, effective management methods were developed to address these issues, and mitigate interpersonal conflicts.

Survey results were collected for over 300 students involved in this program. Peer, mentor, and mentee evaluations were also collected, along with faculty evaluations of the senior team's management and use of their freshmen employees. Results reveal significant freshman and senior satisfaction with this collaborative project, but this satisfaction is greatly dependent upon the senior team's use of project tools made available to them to overcome logistical barriers. Free response answers and direct observations show that freshmen gained valuable insights into their academic and professional trajectory from the seniors. Seniors gained an appreciation for how an employer might regard their resume, and for methods of management of "employees", whereas, up to this point in their academic careers, they had only experienced team dynamics on teams of equals. This method of inter-cohort project development has led to significant returns for seniors and freshmen alike.

Introduction

In general, developing a connected, communicative, and active society of students and faculty within a department is an important aim for college educators. Several lines of evidence indicate that gains in student satisfaction and retention may be realized through increasing and improving social connections between students[1,2]. Students in underrepresented groups may particularly benefit by the development of social links to peers and mentors[3].

A very common means to promote such connectedness among students has been through the use of projects that require the involvement of multiple students. Team working experiences and collaborative learning have been found to be generally beneficial to student learning and satisfaction[4–7], and students generally recognize the importance of collecting and using various forms of social capital within their departments[8]. Collaborative learning has been implemented in many models, most of which involve students in the same discipline and cohort; however, success has also been demonstrated in using interdisciplinary collaborative learning[9].

Peer tutoring and instruction has also been long used to improve student outcomes[10–13] and has been suggested as an important means to improve student connectedness[14]. In this model, the interactions involve the promotion of a teacher-student model among students. Such methods not only benefit the tutee, but the tutor has also been found to experience positive results in the form of increased perceived employability and understanding of engineering concepts[15], providing support for the adage that there is no better way to learn a subject than to teach a subject.

Projects involving multiple students, however, can often suffer from the hurdles typically associated with team work: poor time management, imbalanced division of labor, ineffective communication, and so on. These hurdles are often exacerbated in student team projects by their inexperience with the tools of collaborations which most professionals commonly use. Such obstacles have been shown to be addressable with the use of various supports, such as computer-based communication tools, which may raise the quality of team working interactions[16]. Interactional conflicts may also easily arise, depending upon the personalities and capabilities of the students involved. Therefor it is important to provide students with tools and methods to remedy interpersonal conflicts in order to create successful collaborations within an educational environment[17].

In this work, we use traditional models of collaborative learning, with students working in teams made up of peers from their academic cohorts. We then implement collaborative and peer tutoring projects that mimic more closely an employee/employer relationship between our freshmen and senior students.

Methods

Collaborative Project Implementation:

In the final semester of our students' senior year, our seniors enroll in their final chemical engineering laboratory course. In this course, seniors pitch proposal ideas. These proposals must respond to a "Request for Proposals" and promise to deliver real value to an industrial partner or to our department through research, education, or service. Each proposal must involve core chemical engineering theory and use that theory to predict and quantify project success. Approximately a third of these proposals are funded and senior teams are formed around these proposals, which then continue on to become senior capstone laboratory projects. Seniors who do not pitch a proposal that is ultimately funded join their peers on funded proposals, making teams of three seniors.

During the same semester our freshmen take an introductory chemical engineering design laboratory which has been described in prior work[18,19]. In this course student accomplish five design projects and a final project of their own design. Additionally, just prior to their final project, they must complete the collaborative project which is the focus of this work.

After senior proposals are selected and senior teams have been assembled (approximately three weeks into the semester), the list of successful senior projects is shared with the freshman class. Freshmen are instructed to read the winning senior proposals and select several projects on which they are most interested in working.

In the previous semester, freshmen are instructed on how to appropriately assemble a resume, and, in the design laboratory's semester, they are required to update their resume and resubmit it. They are instructed to hone their resume to target senior projects of the greatest interest to them. In an objective statement in their resume, freshmen are asked to list, in order of preference, the senior projects onto which they most wish to be hired. These resumes are then sent to the senior class. To be in compliance with FERPA, freshmen who have reservations about sharing their information with the seniors are allowed special accommodations, although, no student in our program has ever chosen this option.

Seniors are instructed to assess each resume and choose which freshmen they would like to hire onto their team. After one week, seniors deliver to the instructor of the freshman laboratory an ordered list of freshman candidates. Hiring occurs in rounds, with the senior teams with the highest proposal scores being given priority in hiring over lower scoring teams. The instructor then builds teams based primarily on senior "employee" requests and secondarily on freshmen project requests. Teams are typically made up of three seniors and five freshmen.

Over the years, several key requirements have been added to this process to mitigate problems observed in the program's first iteration. Both senior project pitches and proposals must clearly detail the role of freshmen employees, to avoid a situation in which freshmen are left undermanaged and confused about their assignment requirements. Seniors and freshmen are given lectures on time management, and instructed on how to use online scheduling tools used to find appropriate meeting times for their team. Both groups are instructed on team working strategies and seniors are specifically instructed on management methods; for many of them this experience is the first in their careers where they have been given the task of managing others.

Assessing an Employer/Employee-Type Collaboration among Students:

Added consequences are an important means to improve the chance of creating successful collaboration between freshmen and seniors. All involved students are held to several rubric items as part of their course grades. These rubric requirements have been honed over several iterations to address common problems in senior-freshmen projects.

In their project elevator pitches and single-page proposals, seniors are required to demonstration the following.

> *"Roles of freshmen team members are extant, reasonable, and clear (and humane). The estimated time expected for each task is listed and does not exceed limits. Major project tasks are reasonably assigned and team members could reasonably be assumed to be qualified for their given task."*

Once projects are selected to move forward the senior teams must complete a long-form proposal. In their "Statement of Work" they must demonstrate that:

> *"…It is clear for which tasks freshmen students will be responsible and the time requirements on each."*

In their "Capabilities" section the seniors must also demonstrate that:

> *"Team management structure and roles are clearly identified. A senior team member is clearly indicated as the person primarily responsible for managing the freshmen student. The roles of all freshmen student team members are clearly explained."*

Seniors must show they have given clear thought as to how they will use their "employees" and indicate a clear point-of-contact for the freshmen, so that it is apparent who is ultimately responsible for coordinating with the freshmen and that task is not assumed by the each senior on the team to be another's responsibility, as was common in the first iteration of this collaboration model.

Once the collaboration is at an end, seniors assess their freshmen team members and that assessment affects the freshmen's grade on their collaborative assignment. The following rubric items are used by the seniors to grade their freshmen:

> *"Time - This freshman team member was always on time. They were reasonably accommodating when scheduling meetings, lab work, and writing tasks. They consistently met the deadlines agreed to by the team."*
>
> *"Effort - This freshman team member is a hard worker. They put in their fair share of effort and took on an appropriate percentage of the tasks needed to complete the lab work and written reports. When working on the project, they took our work seriously and remained focused on the tasks at hand."*
>
> *"Temperament - This freshman team member was pleasant to work with. They were a source of encouragement and accommodating to the legitimate needs of the group without a negative attitude. They resolved differences professionally and diplomatically and were concerned about the consensus of the group."*
>
> *"Overall - Your general evaluation of your freshman team member. Given a broad selection of the different types of coworkers that you may encounter in your professional life, you would personally choose to hire this team member onto your team over most others."*

Freshmen are also able to assess their senior team leaders. They use the following rubric, which focusses more on the seniors' effectiveness as management.

> *"Project managers clearly and accurately explained to freshmen team members what was expected of them and a clear schedule of work was given."*
>
> *"Team managers gave adequate training to freshmen team members regarding the operation of equipment, analysis of data, or any other task assigned to them. Team*

managers imparted adequate understanding of the purpose for and basic science behind the tasks assigned to the freshmen team members.”

“*Team managers were good supervisors. They maintained a respectful, encouraging, and professional working environment. They displayed concern for the development of the skills of freshmen team members and helped them better understand their academic futures.”*

The grade on these items affect approximately a quarter of the seniors’ “Capstone Project Success” score (10% of total course points) and about the same fraction of the freshmen’s total class points.

In addition to the assessments gathered from the associated grading rubrics, success of this project was also evaluated using end-of-semester surveys including Likert-style questions and free-form responses to prompts about the collaboration. The full survey is available in prior published work[19]; several survey questions pertained directly to this collaborative project that is the focus of this work. Two questions were standard 5-point Likert-style questions asking if the freshmen perceived they “learned important engineering concepts from…” and if they “enjoyed…” the collaborative project. Lastly, we also asked how many hours the freshmen would approximate they worked in the lab with their seniors.

Results

Survey and peer assessment data were gathered from 192 freshmen and 118 seniors who participated in the intra-cohort team working projects that are the focus of this work. Data were collected over the spring semester for the years of 2013, 2014 and 2015. All confidence intervals reported in the following results are determined for a 95% confidence level.

Freshman Evaluation of Senior Managers:

Freshmen have been consistently positive about their senior employers. In the first year of this program the average freshman evaluation of their seniors was $92.33 \pm 0.09\%$ (95% confidence level) of the total available points. As improvements were made in our methods and training, this average rose by a slight but statistically significant degree to $94.73 \pm 0.06\%$ over all three years. These percentages may seem high, but it is common for students to be exceedingly forgiving of their fellow students in their peer evaluations. In cases where a less-than-perfect score was given there typically existed a significant deficiency in the senior teams’ management strategies, which came up in freshmen student comments. Most all of the freshmen freeform comments have been positive. The most common problems freshmen have vocalized about their senior managers over the years have been related to senior teams being unresponsive or resistant to involving the freshmen in their projects in a meaningful way. To address this problem after the first year, we now specifically assess the plans of senior teams’ for freshman workers in their proposal rubrics, before they are ever assigned freshman employees. This added scrutiny and accountability has apparently improved senior planning and the freshman experiences on these team, as seen in the upward trend in freshman evaluations of their mentors.

Senior Evaluation of Freshman Employees and the Collaboration:

Senior evaluations of their freshman employees are generally positive, though less so. The average score given to freshmen was 89 ± 5% of the total available points. Much more variation exists in the seniors' evaluation of their freshman team members due to the fact that individual freshmen were more likely to simply ignore the assignment. Some would not return senior emails and consequently would receive a zero on the collaborative project, whereas most (over 60%) of the freshmen who did participate received 100% of the possible points from their senior managers. Generally, seniors were satisfied with their freshman team members and their contributions to their project and their experiences in the collaboration. Seniors have also anecdotally reported finding value in reading over freshman resumes, in that it gave them a new perspective on how a potential employer may regard their resume. They have also expressed appreciation for having been given a managerial experience, which many of them have never encountered, and they have found the experience helpful in answering interviewer questions about managerial experiences they have had on teams.

Freshman Survey Results:

As part of their freshman laboratory, students fill out a detailed survey about their design lab experience (including perceptions of their collaborative project), perception of their academic capabilities, demographics, and more. This survey covers just under 100 separate items and the broad results from this work are discussed elsewhere[18,19]. In this work, we have analyzed the correlation between freshmen's perception of their collaborative project experience with the seniors and various other student characteristics.

Unsurprisingly, there is a strong correlation between students' enjoyment of all modules in this laboratory and their perception that they learned something important from the module. Simply, engineering students enjoy activities they perceive as valuable to their careers as engineers; this is also the finding for the collaborative project. Freshmen's perception that they "learned important engineering concepts from the collaborative project" had a correlation coefficient of 0.75 ($p = 6e\text{-}8$) with their expressed enjoyment of the project.

This freshman design lab has received course evaluations which are significantly above average and all the modules were evaluated highly by students. However, the collaborative project received below-average student assessments of both their enjoyment and perceived learning from this module, both questions receiving an average score of 3.6 ± 0.2 on a 5-point Likert scale (5 being the highest possible). The average score for all learning and enjoyment modules was 4.0 ± 0.05 and 4.2 ± 0.05, respectively. First, it is clear more variance exists in students' regard for the collaborative project than any other in this same course (there is a standard deviation of 0.9 for all modules, verses 1.2 for the collaboration). Student opinions were more polarized.

One clear reason the collaborative project worked for some students and not for others was simply whether or not the senior students successfully used the freshman students in their project. Figure 1 shows the average hours which freshmen report working with seniors sorted by the Likert-score the freshmen gave to the collaborative project. Freshmen who spent more time with their senior teams, enjoyed their project more. Of course, freshmen may be spending more time on the project because they enjoy working with their senior team, but freshmen were required to spend at least four hours working with the seniors; many teams were simply unable to schedule even the required amount of time. Some senior teams demonstrated poor scheduling and time management when interfacing with their freshmen. Additionally, very often freshmen complained that their senior teams would not engage them or even return emails. If the freshmen actually participated in the collaboration, they tended to have high regard for it, and many students were spending far more time than they were required. When asked why freshmen were working past the requirement, they would typically express that they felt a personal investment in the seniors' project goals, or that they just enjoyed working with their team. The students who most enjoyed the collaboration spent, on average, twice the required amount of time in the collaboration. These findings suggest that logistic hurdles were the primary problem in executing inter-cohort collaborations. We found that seniors were not using any scheduling tools and have since instructed them on how to use online polls and shared online calendars. Perhaps consequently, in the most recent semester of this lab, freshmen regard for the collaboration project has risen to an average of approximately 4.0 (up from an average of 3.4 in the first semester).

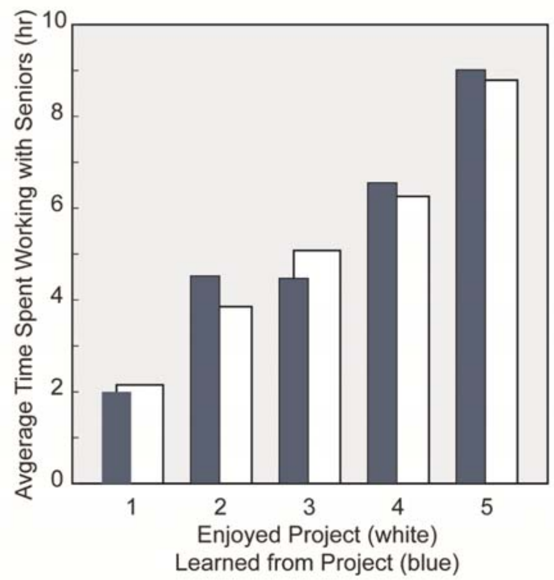

Figure 1: Relationship between time spent working with seniors and the freshmen's enjoyment of the experience and perception of how much they learned from the project.

The effect of this inter-cohort collaboration on underrepresented students was also of great concern. No statistically significant difference was found in the enjoyment, perceived learning, or time spent on the collaboration with regards to gender. Furthermore, there was no statistically significant correlation found between student regard for the collaboration and being a student who identifies as having non-Hispanic Caucasian or Asian ethnicity (neither of these groups are underrepresented in our department). However, students who identify as having underrepresented ethnicities do show a slight but significant correlation with enjoying the collaborative project more than other students, $r = 0.15$ ($p = 0.04$).

Peer tutoring was a central aim of adding a collaborative project between seniors and freshmen. It is difficult to quantify what the freshmen learned, exactly, as each senior team was working on a capstone lab project which involved different core chemical engineering theory and concepts. However, freshmen's perception of the educational value of the project did correlate with their perception that "*This course has helped me understand the modern societal issues addressable by chemical engineering*" ($r = 0.2$, $p = 0.007$) and "This course has made me more aware of the various areas of chemical engineering in which I may specialize" ($r = 0.2$, $p = 0.01$). These students also felt more strongly that the course improved their understanding of "*laboratory procedures*" ($r = 0.35$, $p = 1e-7$). In general, those students who "*enjoyed*" the collaborative project were more likely to claim their understanding of “*mathematics*”, “*team working*” and “*written communication*” skills were improved by the course ($r \approx 0.2$, $p \approx 0.01$).

To us, as instructors, some of the most valuable peer tutoring outcomes of this project where witnessed when nothing was happening in their collaborative project. Anecdotally, conversations between seniors and freshmen in the lulls of a lab period (for example, as equipment came to steady state) were as important as the active training on engineering concepts that the seniors imparted to their freshmen. Conversations centered on internships, job opportunities, and courses (and faculty) to take or avoid. The data bear out these eavesdropping observations. Freshmen who had a high regard for the collaboration project, were more likely to have confidence, at the end of the semester, that they “*understand the steps needed to graduate from the chemical engineering program*” ($r = 0.4$, $p = 0.003$). Those who enjoyed their collaborative experience also left the course feeling more confident that they will have an engineering internship ($r = 0.2$, $p = 0.02$), and that they are “*an active part of the community in [their] college*” ($r = 0.4$, $p = 0.001$).

Conclusions & Recommendations

In summary, this collaborative project has been well-received. Senior mentors appreciate gaining managerial experience and having the added help in the laboratory for their capstone projects. Freshmen who took full advantage of the collaboration tended to feel they had a better understanding of their academic trajectory and options, and evidence exists that they leave the associated course feeling a greater sense of connectedness to their department.

Recognition of such projects’ value has also come from external assessors. Our Industrial Advisory Board has expressed significant appreciation for the ways in which this project mimics an authentic work environment for an engineer, and our ABET program evaluator highlighted the associated courses as particularly strong in educating our students. Furthermore, this program has, in part, contributed to the conferring of two university awards, one for improving our student’s employability and another for “providing transformational experiences to undergraduate students”.

However, organizing such an expansive peer tutoring program is not without its costs. Any sort of collaborative learning or peer tutoring program can be fraught with logistical problems. When the involved students are not in the same class, or even in the same academic year, these hurdles grow. We have, though, found such difficulties are manageable using several tools.

Recommendations:

Rubrics – We have found that these collaborations tend to go more smoothly if seniors are asked to plan out how they will use their freshman employees long before their team is even assembled. In a project which is initiated by seniors’ proposals, the proposals should be assessed on how well they plan to use their freshmen in accomplishing specific project tasks. Then, once the project has come to an end, accountability should be enforced by allowing freshmen to evaluate their seniors and vice versa.

Management Structure – A single point-of-contact on the senior team should be designated to assure the tasks of employee management do not become tasks each senior is falsely assuming another senior is satisfying. The contact information for the single senior point-of-contact may then be given to the freshmen and thereby head off confusion. Furthermore, seniors should be instructed on basic managerial strategies, in contrast to the team working and conflict resolution information they typically receive in regards to teamwork where all members have similar power and competencies.

Organizational Tools – Online scheduling tools do not yet seem to be commonly used among even our senior students. In these projects we are asking students who may have wildly different schedules to find times to meet and work together. We have found seniors and freshmen need to be instructed on how to use online calendars and polling services in order to get teams to use these tools and thereby overcome many of the logistical hurdles.

Safety – We have not had any accident associated with these collaborations, but this collaborative project brings together inexperienced students to work in a laboratory environment under senior managers who are more experienced, but who are not yet experts in laboratory safety. As such, we believe it is important that such projects be executed towards the end of a freshmen's chemical engineering laboratory course, well after they have had safety training and at least two months of experience in the laboratory. Furthermore, we require senior teams to detail the safety concerns with their project and how those may involve our freshmen, both in writing and in-person during a lab meeting with the instructor before work may commence. If a task carries with it substantial risk, freshmen may not be assigned that task.

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