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Use of an Undergraduate, Interdisciplinary Design Team to Address the Remediation of Fracking Water and Acid Mine Drainage

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An NSF Scholarship program was used to assist in the development of an interdisciplinary team of 15 students spanning five different engineering disciplines, chemistry, biology and mathematics. The scholarship enabled the team to be comprised of the same students from their freshmen to senior year to facilitate the learning of effective team building skills, as well as serve as a longitudinal study. This paper will discuss the approach and activities used over two years: pre-junior and junior year for the engineering students that participate in co-op and the junior and senior for the non-engineers.

At the beginning of the two-year project, students were provided four different potential problems to evaluate that required an interdisciplinary approach to solve and had direct relevance to issues in Ohio. After conducting an initial literature search, each student selected two topics as a project that they would like to work on. Based on their interest, the students were subdivided into two teams: one to address the remediation of an acid mine drainage site and one to evaluate possible handling methods of flow-back water from fracking sites. The activities included in the projects were an in depth literature review, prototype design, laboratory assessment, economic analysis, environmental regulation evaluation, community action plan development and submission of a final design report. The objective was to assess if these activities could enable the students' to develop into an effective interdisciplinary team and to address the potential lack of interest in core STEM classes. In addition to describing the students' key activities, we will describe issues faced by the students and faculty mentor in completing the project, as well as provide possible solutions for future team activities.

Introduction

Less than half the freshmen students entering college to pursue a STEM discipline actually graduate with a STEM degree.[1,2] Numerous studies have examined why students fail to matriculate in STEM fields. The reasons included lack of preparation for first year science and math courses,[3,4] inability to balance coursework and external commitments,[5,6] satisfaction with discipline,[7] self efficacy,[8,9] and rising cost of tuition.[1,2,10] As a result, many of these students simply give up on STEM and look to other majors. First generation college students and underrepresented minorities are at-risk groups that do not persist in STEM fields due to financial issues, parenting practices and perceived social gaps.[11,12]

Scholarships can be used to alleviate some, if not all, of the financial issues. Financial assistance alone will not eliminate attrition. Surveys have found that academically capable students receiving scholarships still leave STEM fields. For instance, Carpi et al.[4] presented survey results showing that STEM students receiving financial assistance left due to a belief that non-STEM majors offer greater intrinsic value, a loss of interest, or a career-associated lifestyle. The results of Carpi et al. are similar to our findings where three of our initial scholarship recipients left the program to pursue non-STEM majors where they could help others and four left for that they perceived to be less time consuming undergraduate programs so that they could spend more time working or on social activities.

In this program, NSF S-STEM scholarships were awarded to 15 students. The requirements for students to maintain their NSF scholarship were continuous enrollment in courses leading toward a STEM degree, 3.0 GPA, and active participation in the one-credit course associated with the scholarship each semester. The course was used to enable more one-on-one interactions between students and faculty as well as with their teammates from different disciplines. Interacting with faculty, whether in the classroom, the laboratory, office hours, or other venues, is one of the key college experiences associated with student development.[13] In the two years prior to the project timeline described here, the students participated in team building activities and research experiences that prepared them for the final project. The preliminary activities, particularly the team building skills, described in Cutright et al.[14] were used to enable the students' to develop into an effective interdisciplinary team as well as address the potential lack of interest in core STEM classes. This is in line with Wilson et al.[2,15] who reported that mentoring, education, and research were all critical for college and post-college persistence in STEM. Students that participate in well structured research (theoretical or lab based) enhance knowledge, develop self efficacy, may consider science important aspect of self-identity.[16] This is critically important for underrepresented students who are more likely to persist in STEM when they interact more with fellow student.[17] The activities that formed the final project describe in this paper gave the student the opportunity to apply what they had learned about research, project planning and teamwork.

Undergraduate Cohort

The activities used to initially develop the team building skills were fully described in our paper that focused on the freshmen and sophomore year.[14] At the start of the two year project described in this paper, the students were starting their junior year. At this time, the student cohort consisted of one biomedical engineering, two chemical engineering, two civil engineering, two electrical engineering, two computer engineering, three biology, two mathematics and one chemistry undergraduate student. Seven of the students were male and 8 were female. After the first semester, the biomedical engineering student (female) was no longer academically eligible. One of the mathematics undergraduates (male) graduated the following semester, leaving thirteen students to complete the final three semesters of the selected project.

Initial topics for selection

Students were provided four environmental topics with specific relevance to Ohio to select from. Current problems with direct relevance to the student's hometowns were used in order to specifically address the issue that some students leave STEM to pursue a discipline that "helps" others. Hiellbronner[18] found that one of the key reasons women left STEM programs was because they did not see the potential to help others. Likewise, if students work on something they selected and utilize their specific skill set, they are less likely to loose interest.[19] Direct interaction with peers on an academic related task has also been found increase retention of underrepresented students.[20] Therefore, students were allowed to select their own project and assign who would be responsible for completing specific tasks to address potential lack of interest.

In addition to a general description of the issue, the problem statement included the specific questions the students would have to address during their project. The topics included:

i) Wastewater issues: release of raw municipal wastewater, toxic materials from industry and non-tracked materials such as pharmaceuticals and agricultural runoff.
ii) Radioactive groundwater: design an innovative treatment technology to remediate an aquifer contaminated with radionuclides.
iii) Acid mine drainage (AMD): design remediation method to treat soil and water contaminated with heavy metals from an AMD site.
iv) Addressing flowback water from hydraulic fracking.

A full description of all activities completed by each team cannot be included. Highlights of each semester will be provided in order to enable a comparison across the teams. As shown in Table 1, during the first semester students conducted an in-depth literature review of each of the topics. Based on their findings and interest, two topics were selected for use: Acid Mine Drainage (AMD) and Flowback water from hydraulic fracking (Fracking). The AMD team was comprised of two biology, one mathematic, one civil engineering, two chemical engineering, and two electrical engineering students. The fracking team contained: one biology, one chemistry, one civil engineering, two computer engineering, and one mathematics undergraduate. Both teams had all of the requisite skills and background to complete the projects.

Preliminary design

During the spring semester, the engineering students were on co-op. The Arts & Sciences majors of both teams continued to conduct a literature review and, by the end of the semester, developed their preliminary treatment design. For the AMD team, their preliminary treatment steps were based on the initial contaminant levels obtained after analyzing samples collected from the contaminated site. The steps involved a series of pH adjustments to precipitate out the target metals (iron, manganese, and aluminum). Potential flocculants were also selected for precipitant removal.

Table 1. Overview of key activities during the two year project

	Summer	Fall	Spring
Year 1	Not applicable	All students Lit. review 4 topics Project selection Develop initial 2 year timeline Assign tasks	Arts & Sci. Students -Field sampling to assess initial levels (AMD) -Select compounds for synthetic solution (Fracking) - Prelim design -Literature review - Adjust 2 year timeline - Hand off plan
Year 2	Engineering Students Test initial treatments Prelim. Economics Modify design Adjust timeline Handoff plan	Arts & Sci. Students Finalize design/testing Env. Regulations Start community action plan Adjust timeline	All students Finalize economics, env. Regulations, and community action plan Complete report Poster presentation

The fracking team developed a synthetic contaminant solution based on their literature results. The pH and conductivity measurements of the synthetic fracking solution were measured. The preliminary process steps selected for further investigation over the summer included reverse osmosis (for salt removal) and liquid-liquid extraction (LLE) to address target organics. The use of a knock out tank as a first step was also suggested by the faculty mentor to settle out ~60% of the salts.

Both teams also identified the preliminary environmental regulations that pertained to their project. At the end of the spring semester, both teams wrote a status report and handed off their findings to the engineering students who would be working on the project over the summer session. This was the first team activity that neither the Arts & Sciences or Engineering students had any experience with: how to develop a concise yet informative statement of completed activities, proposed summer tasks and deliverables to give to the returning students before leaving for three months. Neither team completing as many tasks as identified at the start of semester complicated the development of the 'hand off plan'. At this stage, the fracking team had not made as much progress as the AMD team. A key concern was the fracking team had not completed half of the items on their own timeline. The faculty mentor spoke to each fracking team member individually. For those students who were completing their tasks, suggestions as to how to develop a "Plan B" for non-responsive teammates, time management strategies, etc. were discussed. Team members that were not fulfilling their responsibilities were informed what grade he/she earned and how his/her inactions impacted the rest of the team.

Design modifications and summer activities

The first task of the summer session for the engineering students was the evaluation of the tasks completed during the previous spring, the proposed summer timeline, and the 'condition' of the hand off plan. It is interesting to note, that although the engineering students wished that their teammates had provided more details in the hand off plan, they failed to increase the amount of detail/organization when they generated their own status report at the end of the summer.

At the beginning of the summer, the AMD team decided to collect another sample from the AMD site. This sample was used to assess potential seasonal variations in contaminant levels, as well as to provide samples to further optimize the design. A chemical engineering student led the laboratory assessment used to optimize the preliminary design. This student was very motivated and organized; much of the AMD teams advancement was attributed to her leadership. In addition to selecting the final flocculant, the initial economic evaluation and equipment sizing was started.

Based on the suggestions from the Arts and Sciences students, the fracking team spent a large portion of the summer activities trying to get the reverse osmosis (RO) system to work. At this point, one of the faculty mentors helped to reconfigure the RO unit so that it could be used at the elevated salt levels contained in the fracking solution. Specifically the fine suspended solids filter and activated carbon section of the RO system were removed.

Design modifications and activities during the second year

As in the summer, the students took the first week of the fall semester to evaluate what was completed during the summer, the proposed timeline for fall, and the 'condition' of the hand off plan. Both teams spent some time in the lab in an attempt to optimize their design. It was particularly difficult for the fracking team to make progress because they were waiting on a teammate to analyze the results from their LLE experiments. Although faculty tried to steer the team into having a backup plan, they were sure that he would 'analyze the solution this week.'

During the first week of the fall semester the faculty mentor had reminded both teams to reread the problem statements to make sure all requirements were being met. Unfortunately it took several reminders. It was not until the last two weeks of the semester that both teams realized that they had missed key elements. For instance, the AMD team had forgotten to address soil contamination (one of the elements of the project statement). Of the four tasks in the fracking problem statement, the team had only addressed the fourth one (how to remediate the existing flowback water).

In the final spring semester both the Engineering and Arts & Sciences students worked to complete their report and poster presentation. The main focus was to find at least partial solutions for their missing tasks. The AMD final design for the treatment of the contaminated water is shown in Figure 1 with the stream compositions given in Table 2. Using this approach, 99% of each target metal was removed from the water. The proposed approach for treating the soil was phytoextraction with *Phragmites australis*. The advantage of phytoextraction is that it is naturally occurring on the site. There is also the potential to recover the extracted metals for reuse. The capital investment for both phases of remediation was estimated at \$2.6 million, with annual costs of \$350,000 (labor and raw materials).

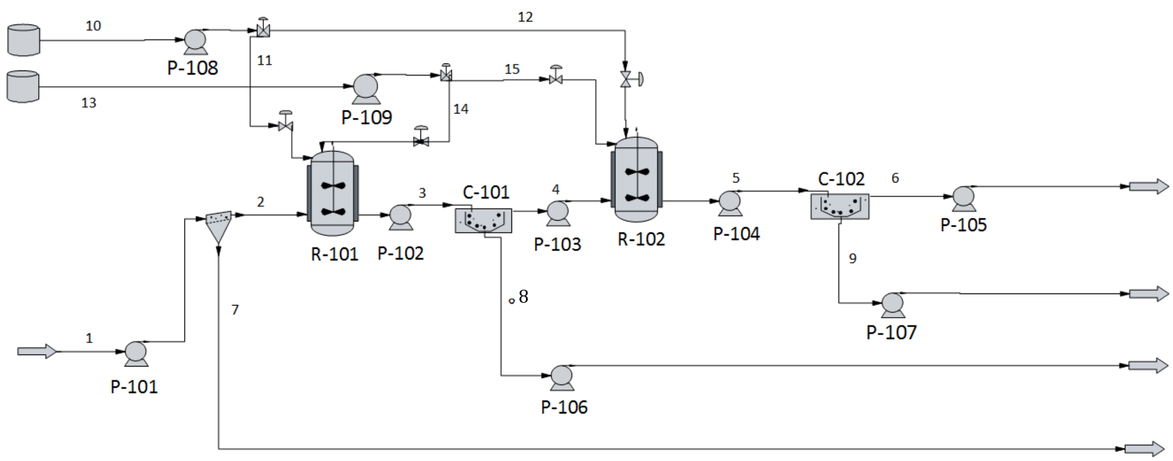

Figure 1. Process for remediation of contaminated water at AMD site

The fracking team experienced more difficulties during the final semester. Their struggles were partially attributed to the fact that they had three missing tasks to address instead of just one. In addition, the chemistry undergraduate continued to delay completing his portion of this tasks and one computer engineering student did not complete his sections of the poster. The missing analysis of the LLE product was addressed by i) the faculty mentor providing guidance as to where the rest of the team needed to look to complete the task and ii) one of the students

Table 2. Process stream table (based on batch process of 2 m^3 of process water)

Stream	Process Water (m^3)	NaOH (m^3)	Polyacrylamide (m3)	Aluminum (kg)	Iron (kg)	Manganese (kg)
1	2	0	0	0.10	0.24	0.18
2	2	0	0	0.10	0.24	0.18
3	2	0.09	0.02	0.10	0.24	0.18
4	1.789	0	0	0.001	0.0002	0.18
5	1.789	0.03	0.02	0.001	0.0002	0.18
6	1.61	0	0	0.001	0.0002	0.0018
7	0	0	0	Unidentified	Unidentified	Unidentified
8	0.211	0.09	0.02	0.099	0.2398	0
9	0.1789	0.03	0.02	0	0	0.1782
10	0	0.12	0	0	0	0
11	0	0.09	0	0	0	0
12	0	0.03	0	0	0	0
13	0	0	0.04	0	0	0
14	0	0	0.02	0	0	0
15	0	0	0.02	0	0	0

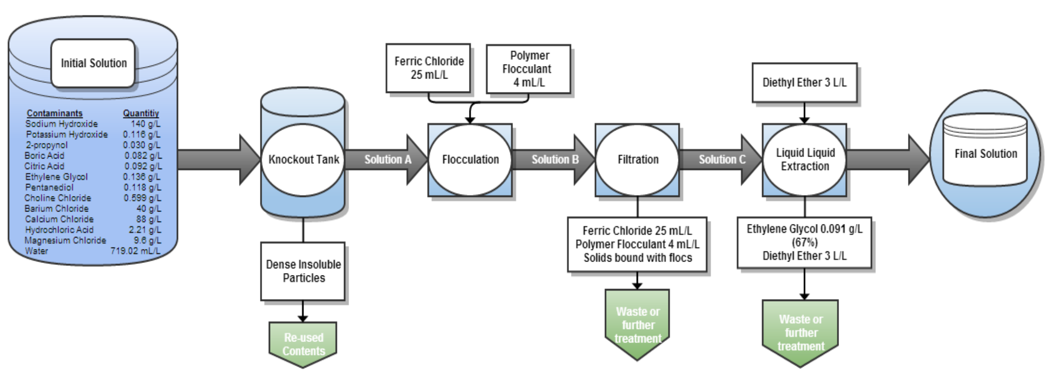

Figure 2. Process flow diagram for proposed remediation of fracking flowback water

who was pursuing a Master's degree after he graduated in the fall offered to help. With the help of the graduated mathematics student, the team was able to have a proposed design (Figure 2) to include in their poster. The poster issue was rectified by other team member correcting the missing items. To prove a point, the team had two posters printed for their presentation. The incomplete version was displayed until the team member in question arrived. He was then given the option by his teammates to display the first version (with him listed as coauthor) or the second, complete version. He opted for the second version without his name. The use of 'two posters' let the computer engineering teammate know that the rest of the team did his work (as it impacted their poster and grade), but the team was not going to let him 'earn' full credit.

Student feedback

Students completed surveys to assess what they learned from working on the two year project. Several students felt that it " *provided opportunities to see how other people from other disciplines can benefit from you and vice versa. It provided a chance to see how people with careers in those disciplines work together in the real world and what some of the things that they have to face when working on a project."* They also felt that they "*learned a lot about project management and how to efficiently use time instead of just doing busy work*." When conducting a team-based project it is important to "*always have a specific objective for each person and if a person cannot handle this task alone, then others can lend a hand. I also learned how to determine potential problems in the group and find ways to solve the problem*." The Arts & Sciences undergraduates found the project to be very beneficial as this was their only opportunity to participate in a team project.

When specifically asked if the work/experience in the STEM class impacted their approach to other classes several of the students found the STEM classes "*impacted how I worked in the lab because we were able to have some lab experience with the STEM class that made some of the labs for other classes easier to understand*." For some students (mathematics and computer engineering) it was the only exposure to a chemistry lab. Several students stated that this class helped them in their other courses as it "*taught me how to think from many angles"* and knew "*how to research independently*."

Biggest obstacles faced by students

Developing an interdisciplinary team comprised of undergraduates with vastly different backgrounds posed some unique issues. Traditional team building skills, and the time to practice those skills, were incorporated during the freshman and sophomore years.[14] One of the areas that was emphasized during the previous two years was the use of common terms instead of jargon unique to his/her discipline. By the time the student cohort was entering their junior year, they were comfortable enough with each other to ask a teammate to explain a term. For instance, an electrical engineering student asked their chemical engineering teammate about the importance of flocculants. Unfortunately as will be described below, the trust in explaining a concept did not always extend to trust in completing a task.

Over the two years that the students had to complete their projects, there were several other issues that they faced. For instance, initial task assignments had duplication of efforts (i.e., more than one team member researching the same topic). Unfortunately two people did not yield "twice as much new or useful information". It was not until students received repeated low grades on assignments that the duplication of effort stopped for the semester. A second key issue occurred when a teammate 'dropped the ball' it fell to one student to pick up the slack. This is not a new issue and often ties in with how young scientists/engineers properly manage a team and what to do to make someone do their assigned task. For the fracking team, the person that tried to pick up the slack did not have the background to run the analytical equipment. Similarly another team member tried to take a leadership role to motivate the rest of the fracking team. However the team members in question did not take her concerns or suggestions seriously. One of the biology students brought a team building activity (based on motivating K-12 biology students) for the class to try and demonstrate the importance of team participation, listening to other people's skills and completing tasks. Although the entire class enjoyed the activity, it did not did not have the desired effect on the team member in question. The only way this person was motivated to finalize his tasks was when he was informed his lack of performance was going to result in a failing grade.

A surprising issue was the lack of trust/faith in fellow team members. This was evident when assignments were handed off to engineering students in the summer. Initially, the AMD team started to repeat the experiments completed in the spring. Here one of the primary issues was that the team did not seek advice from the faculty mentor when needed. The team was told that they "have to trust your teammates and cannot repeat everything done during previous semester. Some some verification of data is okay, but not a complete duplication of activities." It was brought to light during this discussion that a few of engineering students did not trust the knowledge base of the non-engineering disciplines, and vice-versa. Two different approaches were used to address this issue. The first was to have each subset of the team 'solve' a problem specific to the other team member's discipline. For instance, the engineering students had to solve either an advanced biology, chemistry or math models problem while their counterparts solved an engineering-based problem. The following week each subset of the team was provided a 'solution' to the problem that identified how the other discipline specifically contributed to the answer. The second approach was each student research typical job descriptions and activities for another discipline, which was then shared with the entire class. By the end of both approaches, the students had realized that participating on an interdisciplinary team was like '*working without a* *net'* as one individual does not have all of the knowledge to solve the project. If one member does not complete his/her task, it may not be possible to simply do their work for them. If you have several years to work together, *learn each other's capabilities and earn respect*, the team will work more cohesively.

The most critical issue for the projects was that students forgot to address all items in problem statement(s), even with multiple reminders. Both teams made requests for the instructor to alter the project statements so that the tasks would not have to be completed. The rationale given was that it was 'too difficult to find time outside of class to work on it or remember who was supposed to do each task.' Altering the problem statements would have been the simplest approach for both the students and instructor. However it would not have prepared them for similar situations in the future. Thus the problem statements were not altered. Instead the faculty mentor provided several suggestions as to how each could be completed within the remaining time. Other potential obstacles and their solutions will be discussed during the presentation.

Obstacles faced by faculty mentor

One of the biggest obstacles faced by the faculty mentor was that not all students took the course seriously as it was only one credit. The less serious students often overlooked the fact that course participation was tied to their scholarship. Nor did they seem to care how their lack of participation impacted the rest of their team.

A key issue for any open-ended design problem is not to guide students too much. As with any form of mentoring, some struggle is needed for the student to grow. For two teams, it was also important to ensure that consistent information was provided to each. Finding time to provide guidance in the laboratory was daunting. Another issue was not to step in immediately with management issues. This may seen as an issue common to any team project, however having teams comprised of different disciplines prevented one student from completing a someone else's task as he/she may not have necessary skill set. And, if that task(s) was not completed, the project could not be finished. Although the reminder of lack of participation would result in a failing grade was used for the undependable fracking team member, it was a last resort. After the course, the faculty mentor met with student who became the team leader to discuss what could have been differently.

Another obstacle unique to a multidisciplinary team spanning engineering, chemistry, mathematics and biology, was finding a common time to offer the one credit course each semester. Although a time was found during the week each semester, it was often at non-traditional time slots so that it did not adversely impact any of the students' core classes. This was not an insurmountable obstacle; just one that required special permission from the Provost each semester.

Conclusions

Overall, the AMD team performed at a much higher level than the fracking team. This was due to a much stronger leadership within the team, as well as the willingness of team members to work outside their comfort zone (i.e., math helping with 'chemistry' based lab work). The fracking team did contain competent students. The primary reason they did not fully realize their capability was attributed to two members that did not complete their assignments. Although two other team members tried to 'assist him', he stated he would complete it, but never did. This particular student was an example of someone who did not take the course seriously as it was outside his major. Unfortunately only the threat of failing the course prompted his participation.

There are two ways that the 'threat' of failing grade may have been avoided. The first would be to demand detailed timelines at the beginning of each semester that included contingencies. For instance, if there was not NMR data (student did not complete his assignment, equipment breaks down, etc.) by a specified date, the team will assume a percent removal by LLE based on literature reports. A second way would be to make sure that teams have some strong leadership and reorganize teams if necessary.

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