Assessing teaming skills and major identity through collaborative sophomore design projects across disciplines.

Dr. Jennifer R Amos, University of Illinois, Urbana-Champaign

Dr Amos joined the Bioengineering Department at the University of Illinois in 2009 and is currently a Sr Lecturer and Director of Undergraduate programs. She received her B.S. in Chemical Engineering at Texas Tech and Ph.D. in Chemical Engineering from University of South Carolina. She has developed and offered more than 5 courses since joining the faculty and has taken the lead roll in curriculum development for the department.

Dr. Troy J. Vogel, University of Illinois, Urbana-Champaign

Dr. Troy J. Vogel is a lecturer in the Department of Chemical & Biomolecular Engineering at the University of Illinois at Urbana-Champaign. He primarily teaches Chemical Process Design, a senior level course. In addition to formal teaching, Dr. Vogel acts as the advisor for the Illinois Chapter of AIChE and AIChE's Chem-ECar Competition. Dr. Vogel also plays an active role in various summer camps fostering a desire to learn science and engineering in all of today's youth.

Prof. Princess Imoukhuede, University of Illinois Urbana Champaign

Dr. Princess Imoukhuede is an Assistant Professor of Bioengineering at the University of Illinois at Urbana Champaign. She received her S.B. in Chemical Engineering with a minor in Biomedical Engineering from the Massachusetts Institute of Technology, and she received her Ph.D. in Bioengineering from the California Institute of Technology. Prior to joining Illinois, Dr. Imoukhuede completed a postdoctoral fellowship in Biomedical Engineering at Johns Hopkins University School of Medicine. Her research interests are at the interface of Systems Biology and Angiogenesis with applications to Breast Cancer and Cardiovascular Disease.

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Abstract

Collaboration and student projects than span multiple departments are often seen as too difficult to pursue due to administrative, topical, or other logistics related barriers. This project demonstrates an approach at introducing true interdisciplinary design projects within a sophomore level materials and energy balances courses in both Bioengineering and Chemical Engineering programs at the University of Illinois at Urbana-Champaign. Engineering curricula have been focused on integrating design in the freshman and senior years but often fail to integrate projects into the sophomore and junior year courses. The study consists of one section of bioengineering students paired with a section of chemical engineering students. Teams are made up of equal proportions of each major. The project consists of an exploration of energy balance in the body revolving around economic resources available to meet nutritional needs. Preliminary findings show that each program of students genuinely brings different skills and emphases to the project. Survey and focus group results combined with outcomes-based assessment are used to determine direct and indirect assessment of skills.

Introduction

Undergraduate curricula are challenged to provide sufficient depth within the breadth of interdisciplinary technical content. Tom Kelley proposed the idea of "T-shaped Person" as one who has empathy across disciplines coupled with deep knowledge in specific areas[1]. One key aspect of the T-shaped individual is the ability to see opportunity and bring it into their own discipline[2]. Facilitating an environment where students studying different disciplines can work together should enhance cross-discipline thinking later as well as a greater sense of their own strengths in the common career paths of the two disciplines[3, 4].

The fields of Chemical Engineering and Bioengineering have historically worked together[5, 6]. The US Bureau of Labor Statistics classifies these disciplines as similar, and some overlapping employment opportunities include: biosciences equipment and supplies manufacturing; scientific research and development services; pharmaceutical and medicine manufacturing; colleges, universities, and professional schools; general medical and surgical hospitals[6]. Due to these similarities in training and professional outcome, cross-discipline teaming at the undergraduate-level is a valuable training experience for the students.

Engineering curricula have been focused on integrating design in the freshman and senior years but often fail to integrate projects into the sophomore and junior year courses. These years are crucial and present an ideal opportunity for experimentation[4]. Traditional engineering textbook problems, which are typically used in lower level courses, are disconnected from the complex, socially-situated problems that engineers must face[7-9].

Both disciplines have a sophomore level course focused on conservation principles in the fall of the sophomore year, making this an ideal course as a test bed for cross-disciplinary collaboration. Each discipline of students enter with background in calculus I-III, physics mechanics and electricity and magnetism, chemistry through or concurrent with organic chemistry, and basic programming skills. The students differ in their biological background knowledge and introductory courses, which are discipline specific overviews of their respective fields. Thus, interests and skills at the sophomore level are similar and make for a complimentary pairing.

This paper demonstrates an approach at introducing true interdisciplinary design projects within a sophomore level materials and energy balances courses in both Bioengineering, herein referred to as BIOE, and Chemical and Biomolecular Engineering, herein referred to as CHBE, programs at a large public institution. The project is a societal, health-focused challenge, which compliments the content and skills of each major. We hypothesize that projects completed by students of the crossdisciplinary teams will have higher performance in interpreting data and working within real-world constraints, making recommendations to include social and economic concerns, interacting within a team, and having an appreciation for other engineering disciplines[10-13].

Methods

Team formation: The study consists of two sections of BIOE students and one, self-selected, subsection of CHBE students. One BIOE section is designated as the control: these students follow the previously established, unidisciplinary team curriculum. The second BIOE section is paired with a CHBE, subsection (crossdisciplinary teams). It is important to note that CHBE students self-select into this project, choosing between the grand challenge project and a traditional chemical engineering project in the area of ethylene production. Teams are formed using the Comprehensive Assessment of Team Member Effectiveness (CATME) Team Maker using indicators for GPA, race, gender, leadership style, schedule, major and class[14]. The BIOE teams were formed in the first two weeks of the semester and the CHBE teams were formed 2 weeks later. The crossdisciplinary teams combined preexisting BIOE teams and newly formed CHBE teams at week 2 of the project timeline.

The CATME Team Maker allows for automated assigning of crossdisciplinary teams with an even composition of each discipline as well as race and gender balance across the teams. Prior studies have validated its utility in team formation[14].

Teams are given little guidance beyond a charge to work together on the project and they are told that their projects would be team graded to make sure that grade distribution is fair between the two majors. Student sample sizes are as follows: BIOE crossdisciplinary (n=31), CHBE crossdisciplinary (n=36), BIOE unidisciplinary (n=32), CHBE unidisciplinary (n=194).

Table 1. Project Timeline

Week	BIOE Crossdisciplinary	CHBE Crossdisciplinary	BIOE Unidisciplinary	CHBE Unidisciplinary
1	Receive project & begin Phase I		Receive project & begin Phase I	Receive project & begin Phase I
2	Complete Phase I, meet with CHBE peers & share Phase I write-up	Meet with BIOE peers & review Phase I write-up	Complete Phase I	Complete Phase I
3	BIOEs support CHBE efforts	CHBE begin Phase II	Begin Phase II	Begin Phase II
4	BIOEs support CHBE efforts & integrate findings	Continue Phase II	Continue Phase II	Continue Phase II
5	Joint poster presentations		Poster presentations	Written Report

The project timeline is detailed in Table 1 and consists of an exploration of energy balance in the body revolving around economic resources available to meet nutritional needs[15]. We expanded upon the previously published project description by separating into two phases. Phase I consists of the following: (1) reading primary research on the intersection of obesity, energy, and food cost[16]; (2) researching nutrition in various foods via exploring the grocery store to gather nutritional content; (3) integrating their understanding of energy balances by planning a menu for a day with constraints of varying budgets, $5, $10, and unlimited budget, and (4) meeting a nutritional caloric intake for an individual in that budget constraint. Given the course schedule, the BIOE students start the project 1 week earlier than the CHBE students. As a result, we expect the BIOE team to lead the first phase and act as data gatherers and establish the framework for nutritional/biology needs and absorption models. The CHBE students begin to collaborate and learn from the bioengineering teams and then take over for the next phase, optimization. Phase II is the design/optimization phase where students have multiple design scenarios to apply the new knowledge and models such as increasing caloric intake for nursing mothers, excluding food items for allergy, or dieting. Students must design and optimize a process for ideal caloric needs. Unidisciplinary BIOE teams complete the entire project on their own, similar to previous years. CHBE unidisciplinary teams complete a similar project as previous years, an optimization of commodity chemical production, specifically an ethylene production plant during this offering. Students presented their findings in a public poster session. Combined teams present together and unidisciplinary teams present in a separate poster session. Posters were group graded for consistency and no distinguishable differences in graders were observed between those participating in crossdisciplinary projects versus those in unidisciplinary projects. For teaming skills assessment, the CATME Peer Evaluation tool was administered to all teams. In addition, a post-experience survey was administered where students were asked "How did your project experiences influence the following skills and abilities? The 10 skills accessed are listed in Table 2. A power analysis indicates that a representative sample was reached for both groups.

Statistics: Significance tests were conducted using student t-tests with a one tail algorithm.

Table 2. Skills and abilities assessed via Post Experience Survey

Skills and abilities	1 No Impact	2 →	3 Moderate Impact	4 →	5 Extremely large impact
1. Coping with conflict					
2. Applying math and formulas					
3. Applying creativity					
4. Understanding ethics					
5. Leadership ability					
6. Solving problems independently					
7. Appreciating other cultures					
8. Understanding scientific findings					
9. Openness to new ideas					
10. Understanding major					

Significant findings are presented in this paper where * indicates $p < 0.05$, ** indicates $p < 0.01$, and *** indicates $p < 0.001$.

Results and Discussion

BIOE cross- vs. uni-disciplinary teams report significant differences in conflict coping: BIOE students self-reported a significant difference in ability to cope with conflict in the crossdisciplinary teams versus the unidisciplinary teams (Fig. 1). This result was also supported by focus groups and CATME Peer Evaluation feedback comments. Here, crossdisciplinary BIOE students described conflicts that can be generalized, as follows: (1) Task conflict: Management of work expectations across the disciplines and (2) Relationship conflict: Exhibition of clique behavior within disciplines. Since the unidisciplinary BIOE students would not have to manage work expectations or have new students introduced to their established groups, similar conflicts were not reported. While unmanaged conflict is not a goal of teaming, coping with conflict can lead to more enduring solutions and use of more resources when creating a solution[17, 18]. Therefore, it is noteworthy that the crossdisciplinary BIOE students reported growth in their ability to cope with conflict.

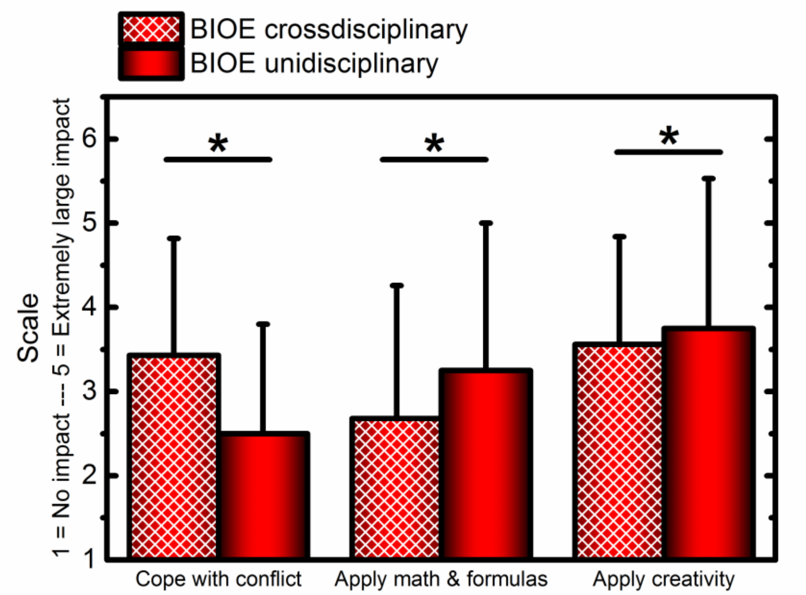

Figure 1. Bioengineering cross- vs. uni-disciplinary team comparison.

BIOE cross- vs. uni-disciplinary teams report significant differences in creativity: Another significant finding in this comparison group was the lower abilities of crossdisciplinary BIOE students to apply creativity (Fig. 1). We were unable to determine the cause for this difference; however, studies at the intersection of conflict and creativity may provide insight into this difference. Organizational conflict is often described as task-conflict, which generally comprises differences in opinion on task performance versus relationship-conflict, which generally involves "interpersonal incompatibility"[19]. Recent findings indicate positive correlations between task conflict and creativity and negative correlations between relationship conflict and creativity[18]. These data indicate a need to offer future crossdisciplinary teams tools to minimize relationship-conflict towards possible increases in team creativity.

BIOE cross- vs. uni-disciplinary teams report significant differences in math application: BIOE crossdisciplinary teams also reported lower application of math and formulas (Fig. 1). We were unable to determine the cause for these differences. However, we speculate that, the larger size of the crossdisciplinary teams (Average size = 6) relative to the unidisciplinary teams (Average size = 3) would lead to decreased work-load for an individual student, resulting in fewer opportunities to perform calculations and fewer opportunities to offer creative solutions to problems. In addition, team size theory suggests that when team sizes are greater than 8, individuals may lose a sense of self, conflicts may be greater and conflict avoidance may appear[17]. Furthermore, as described in our introduction, CHBE training, at this stage, focuses on optimization, an applied mathematics technique; while the BIOE training also relies heavily on mathematics, at this stage, the focus is on understanding systems. The data, the larger team size, and the CHBE applied skillset, suggests that the BIOE crossdisciplinary teams relied more heavily on their CHBE crossdisciplinary team members for mathematical calculations.

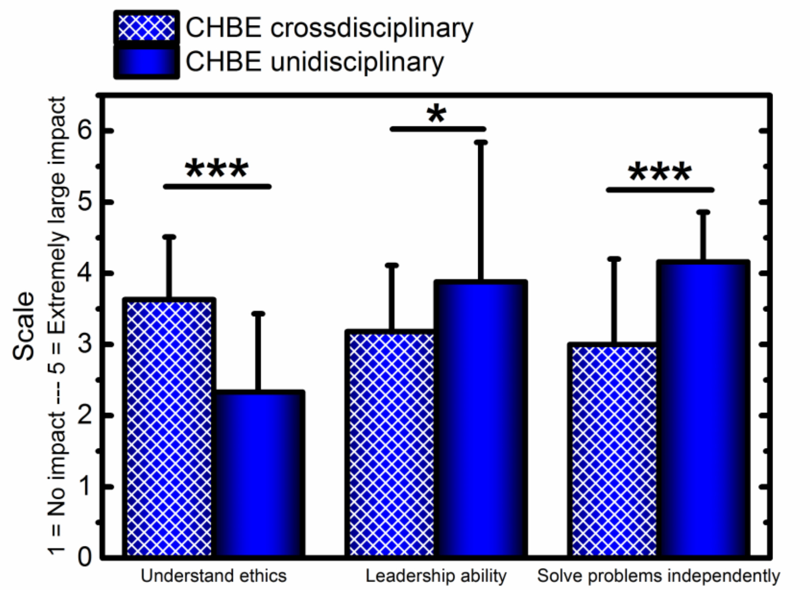

Figure 2. Chemical and Biomolecular Engineering cross- vs. uni-disciplinary team comparison.

CHBE cross- vs. uni-disciplinary teams report significant differences in ethics: CHBE students who participated in the crossdisciplinary teams reported a significant increase in ability to understand ethics (Fig. 2). Comments received in the focus group addressed the increase due to the "social" and "personal well-being" aspect of the combined project compared to the unidisciplinary project (Supplement). Crossdisciplinary CHBE students also reported changes in their thinking of poverty and wealth distribution. This finding can be better understood when considering the possible BIOE contribution to the crossdisciplinary team. At this stage in student training the BIOE students would have greater training in biology and its effect on society. Indeed, 100% of BIOE students take ENG100 in their frosh year: this is a course that aims to introduce the students to ethical considerations in BIOE along with general aspects of the BIOE profession. Thus, the BIOE ethics skillset may have offered opportunities for crossdisciplinary CHBE student growth.

CHBE cross- vs. uni-disciplinary teams report significant differences in leadership & independence: CHBE majors who worked on the unidisciplinary teams self-reported both increased leadership abilities and an increased ability to solve problems independently (Fig. 2). As with the BIOE cross- vs. uni-disciplinary teams, there was a significant disparity in CHBE cross- vs. uni-disciplinary team size, with average team sizes of 6 and 4, respectively. Again, team-size theory may hold here, where creative skills and conceptual decision making skills may suffer as team size increases; whereas, smaller teams offer increased opportunities for leadership and independence[17].

BIOE and CHBE crossdisiplinary team results: Though this group of students both worked on the same project, they gained different understanding and abilities. The self-reported understanding and abilities were higher across ethical understanding, ability to understand scientific findings, cultural awareness, openness to new ideas, creativity and understanding of major for the CHBE students compared to the BIOE students (Fig. 3). It is striking that one major (CHBE) had a more impactful experience across these six skill areas, when working on the same task. One possible explanation may be that CHBE students had the opportunity to select from two different projects. The CHBE focus groups reported their rationale for selecting this project as: personal interest in the project, interest in the social aspects, and interest in understanding of how "mass balances and thermodynamics are relevant and can be applied to different engineering [majors]". Organizational psychology offers insight into self-selection and how this impacts experience. Recent studies show that students in the self-selected groups reported lower assessments of their group's efficiency and slightly higher degrees of conflict but report a more positive work attitude and better outcomes in performance[21]. Although we did not see a difference in technical performance of the project, the higher perceived ability in we did see a higher perceived ability level in several categories.

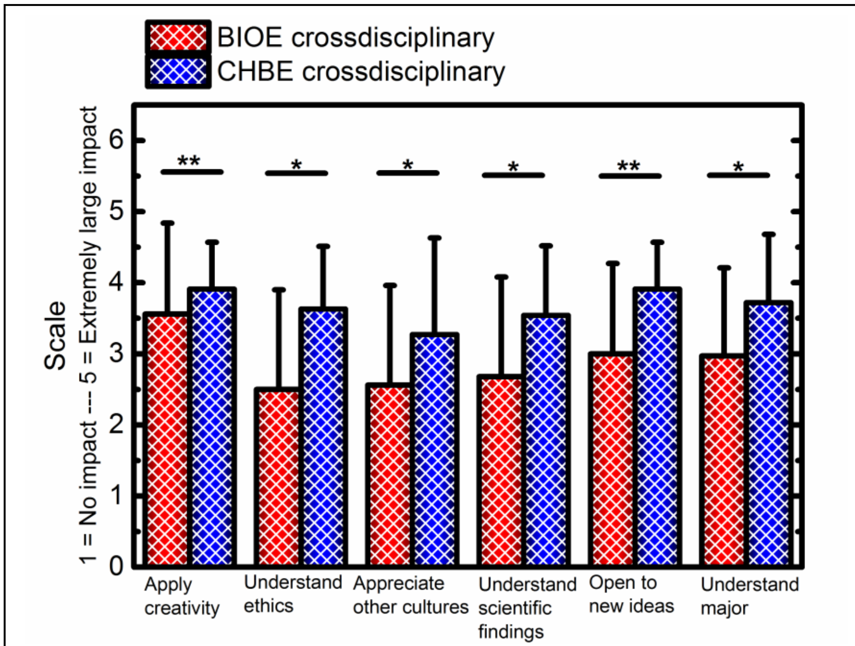

Figure 3. Crossdisciplinary team comparison.

BIOE and CHBE unidisciplinary team results: CHBE students in the unidisciplinary project reported a higher impact on their ability to cope with conflict and solve problems independently (Fig. 4). This may also be due to the fact that BIOE teams were formed first. Additionally, while the BIOE students reported higher understanding of ethics, which as previously described, is a skillset stressed in BIOE.

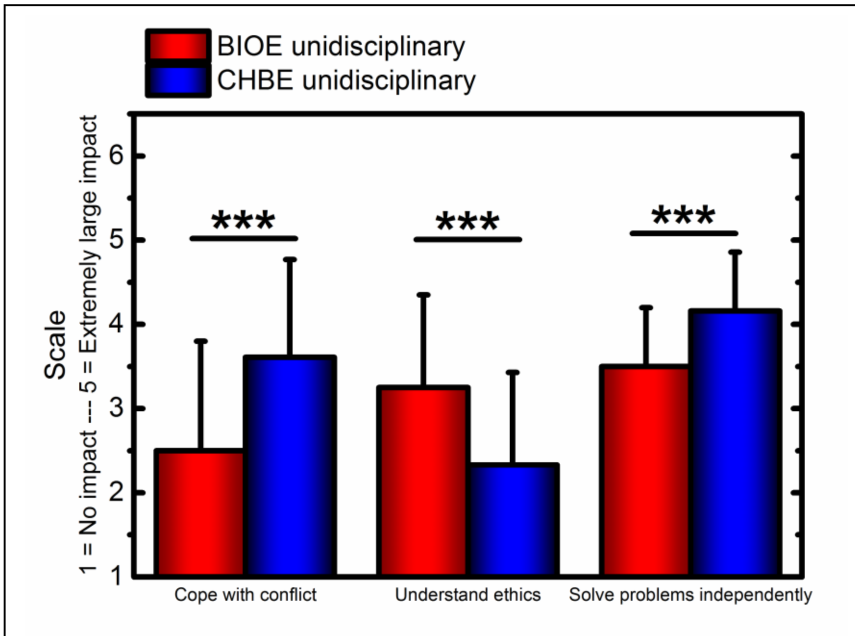

Figure 4. Unidisciplinary team comparison.

Instructor comments: Instructor based observations of group dynamics within the cross-disciplinary teams closely mirror those of unidisciplinary groups. Those groups which worked together had a more cohesive final projects. Groups sometimes had an imbalance of workload between group members. Groups divided project tasks based on knowledge and skill which led to disjointed final projects. The instructors reported that observed challenges in crossdisciplinary teams are identical to unidisciplinary groups, indicating that the crossdisciplinary experience does not appreciably ad additional challenges to the students above what is already expected of them from group work.

Summary

Overall, feedback was positive from each group for both projects and both majors. Findings were not always intuitive, but were insightful into the differences in experiences and project content, which is not apparent otherwise.

When comparing experiences and perceptions from both participating teams, we found that the CHBE students reported more impactful experiences from the combined projects than their BIOE counterparts. When comparing unidisciplinary teams in both majors, BIOEs reported higher ethical understanding and CHBEs reported higher independent problem solving ability, which, again, is likely due to the lack of explicit socio-economic principles in the CHBE specific project and feeling of diminished control in the combined projects. An interesting finding was that the students in CHBE unidisciplinary teams reported a higher impact on coping with conflict, where unidisciplinary BIOE teams did not report conflict as often. The authors speculate that this is due to the smaller number of BIOE majors compared to the large CHBE major class, so BIOE teams were already familiar with their classmates.

Abilities related to applying creativity and ability to use and understand math were higher in the unidisciplinary teams for BIOE students but no significant difference in CHBE majors was reported. This was quite surprising since we thought that having different viewpoints might enhance these skills. CHBE students reported a higher ability to understand ethical implications in the combined teams. This was likely due to the nature of the projects assigned, since the combined project had a strong socio-economical component to the design constraints compared with the unidisciplinary project related to commodity chemical optimization with no explicit socio-economical design constraint.

Conclusion

21st century engineering problems routinely require tools from several disciplines. Indeed, a sampling of three research papers in Bioengineering and Chemical Engineering displays the enlistment of specialized methods from biology, chemistry, physics, mathematics, computation, medicine, and several sub-disciplines[22-24]. As educators, we must meet these multidisciplinary challenges by training engineers that are adept at combining their own expertise with those of experts from other disciplines. Several educational researchers have recognized the need for interdisciplinary, crossdisciplinary, and multidisciplinary training. Indeed, there are reviews outlining their importance[25], presenting case studies and challenges in crossdisciplinary teaming, and offering recommendations for supporting these collaborations at the foundational, institutional, and faculty levels[26]. Recent, crossdisciplinary team research has outlined some structural elements needed for implementation[27], identified effective methods for learning[28] and teaming skill characterization[29], and offered self-efficacy measurement[30]. While applied and observational studies have examined cross-disciplinary interaction between engineering and more removed disciplines, such as: arts, social sciences, and business[31-33]. This growing body of literature offers significant insight into the needs and opportunities in the crossdisciplinary space; however, more insight is needed into crossdisciplinary engineering education, teaming, and its impact on students.

Our study sought to examine these questions, and we found that the project led to significant growth for all students surveyed, and our study offered unique insight into growth-areas and challenges to crossdisciplinary team success. In particular, some crossdiscplinary teams saw growth in conflict coping and others saw growth in ethics. These are skills that are important in the training of engineers. The crossdisciplinary teams also revealed problematic areas that should be observed when training engineering students through crossdisciplinary teams. In particular, leadership ability, independent problem solving ability, math and formula application, and creativity may lag. These areas where we observed decreased proficiency for cross-disciplinary students offer opportunities for crossdisciplinary team improvements. The instructors of the pilot course have already set up to repeat with another cohort of students and have been contacted by other majors interested in participating in the crossdisciplinary teams. The authors will continue to implement cross-major projects in an effort to study major identity and effect on crossdisciplinary experiences early in the curriculum. We have designed further surveys and will repeat the administered survey on self-reported understanding and abilities in the senior year of the curriculum to see if the experience had any lasting effects compared to peers who worked in unidisciplinary teams throughout the curriculum. Overall, this project offers a useful model for collaborative learning across majors at a large institution and our future work will offer insight into improving crossdisciplinary team outcomes.

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Supplement: Feedback from the Focus Groups

Many students had a new perspective on food and relation of engineering to one's personal well-being

Groups which met the most were most well-aligned and thorough

The project made students think about a project in a different manner to incorporate all viewpoints

- One group had chemical engineers focused on providing nutrition while the bioengineers wanted to make sure that person eating the food would enjoy it
- One group wanted looked beyond nutrition and made sure their backpacker could carry the food in the proposed diet
- "Subjects such as mass balances and thermodynamics are relevant to different types of engineers"

Students learned how subjects such as mass balances and thermodynamics are relevant to different types of engineers

- Thermodynamics in terms of nutrition
- "The body is a steady state system."

Strong critical thought relating engineering to social issues

Enjoyed seeing the "human aspect" of engineering

- "Strong critical thought relating engineering to social issues"

Some groups did not meet together as a whole due to different schedules and lack of communication

The design component was not a major focus of the group, despite its intensity

Observed imbalanced workload between group members and different majors

- A division of tasks based on knowledge led to disjointed poster and/or presentation
- This led to uninformed team members with little understanding of final result