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Utilizing Assistive Technology Design Projects and Interdisciplinary Teams to Foster Inquiry and Learning in Engineering Design*

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In industry, successful products and systems usually require a collaborative design process with a multitude of participating stakeholders (customers, sales/marketing, industrial designers, engineering designers from various engineering disciplines, manufacturing, distribution, etc.). Addressing this future work environment, interdisciplinary teaming has become an important element of student design projects. For the last several years at Virginia Tech, interdisciplinary design projects have been created with teams of students from the first year Exploration of Engineering Design course in the College of Engineering and students from the second year Industrial Design Program in the College of Architecture and Urban Studies. While students and faculty alike have appeared to enjoy the exchange of different perspectives and insights that interdisciplinary collaboration appears to offer, there has heretofore been no effort to assess the effectiveness of this experience. This paper describes the experiment currently in progress that investigates student learning with interdisciplinary teams taking on assistive technology (AT) design projects. Two of the three major milestones of the project have occurred thus far, and the leap from the conceptual presentations to the first working prototypes has been surprisingly astute and successful. To date, observations and analysis of assessment data indicate there is a discernable difference between the quality of the projects of interdisciplinary teams of engineering and industrial design students and engineering only teams. Data also indicate that interdisciplinary teams value and are more amenable to projects that are more complex due to being open ended, human centered, and collaborative more than engineering only teams.

Keywords: assistive; design; interdisciplinary; teams.

INTRODUCTION

REAL WORLD DESIGN is most often a collaboration of individuals from more than one discipline. To address this important future work environment, interdisciplinary design projects were created. For the last seven years, teams of students from the first year Exploration of Engineering Design course in the College of Engineering and the second year Industrial Design Program in the College of Architecture and Urban Studies have been teamed together to pursue design–build projects [1, 2]. In the initial years, push–pull toys were designed and constructed. Then LEGO Programmable RCX bricks were chosen as a medium for the interdisciplinary design projects. Last year, the students were charged with designing and building a 'Walkmobile' walking device using a rechargeable electric screwdriver as the power source. The assessment of the projects has been based on the elegance of the design, whether the design achieved the teams' stated goals, whether it worked at the final demonstration, teamwork and team interaction, and the final reports. The quality of the final reports and presentations has increased over the years as we have learned how better to administer, guide and mentor student teams. Further, students and faculty alike have appeared to enjoy this experience.

The inclusion of real-world problems in undergraduate education reinforces concepts and improves learning in ways not available through traditional methods of lecture or predefined case problems [3]. Students develop problem solving skills, project management skills, communication and teaming skills, and a sense of professionalism through such experiences. We have previously utilized open-ended real problems in the area of assistive technology (designing solutions for the disabled), for design projects at the senior level [4].

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Through these projects, students expanded and reinforced concepts learned about engineering design process. At the conclusion of the AT design project, each student had conceived, modeled, analyzed, and built a functional prototype of a mechanical and/or electromechanical device that satisfies an assistive need. Students welcomed both the hands-on and personal contribution aspects of their projects. In many cases, projects lead to research extensions, connections within the community, and for some students, inspiration to pursue graduate studies. We also believe that using human-centric design projects such as those focusing on assistive technology may have a significant impact on the interest and learning of women students [5]. There is a growing body of research that suggests that by addressing gender differences in learning style and perceptions of technology and interests, a more equitable environment in engineering classes could be created by changing the primary activities used to introduce or reinforce concepts [6–11]. For instance, traditionally class projects in engineering/technology often focus on the artifacts of design such as engines, gears, robots, etc. rather than the motivation behind such devices such as the benefits to humankind. While their male counterparts may find the artifacts alone exciting, females often require a more holistic approach.

This paper describes the experiment that is currently underway to investigate student learning with interdisciplinary teams taking on assistive technology (AT) design projects. While antidotal evidence suggests that both interdisciplinary collaborative projects and human-centered open-ended projects are beneficial, to date, we have not formally assessed the impact on student learning of engineering design. The section that follows describes the details of the collaborative assistive technology design–build projects. Assessment is then provided with a focus on project results and student perceptions for industrial design/engineering teams and for engineering only teams. As the experiment is currently underway, analysis of the experiment will be limited to preliminary results captured in student and faculty surveys and performance results based on overall perception of project presentations and design concepts. Conclusions and future plans include discussion on the continuing challenges and possible approaches to the rigorous evaluation for desired learning outcomes of interdisciplinary teams and for open-ended human-centric projects.

COLLABORATIVE ASSISTIVE TECHNOLOGY DESIGN-BUILD PROJECTS

Students were provided with a project brief that framed the context and charges of the term project. They were to assume the problem they solved was for third-world conditions. This implied the needs had to be addressed through low-technology, affordable materials and fundamental processes. Student teams were to consider daily living situations where humans need assistance due to disabilities of some sort, especially where people need to get materials from 'point A to point B.' The push–pull assistance problem could be a shopping situation, such as moving groceries from one location to another. Or, it could be an access situation where people need to reach for something, low or high. People may need assistance moving their bodies from one situation to another, such as in and out of a bathtub. The context could also be recreational or outdoors: garden hauling, weeding, moving building materials, backpacking, or hiking. Ultimately, each team was to develop a working prototype of an object that addresses a simple human need of getting materials or themselves from one point to another. At the conclusion of the project, each team would demonstrate their product by having it run/operate/function through two cycles.

An overview of the schedule and deliverables of the project follows:

F, MAR 18, noon–1:00 p.m.
- Question and answer on the Project and Assistive Technology Project Presentations from industrial design seniors

M, APR 5, 7:00–9:00 p.m.
- Projects concepts (should be a digital presentation of sketches, context, etc)
- Project management strategy: How does your team breakout—Who is the faculty liaison (Project Manager)? What are the sub-teams? What is the name of the project, product or team?

M-W, APR 11–13
- Each team meets with faculty for feedback and Q&A

F, APR 15, 1:00–2:30 p.m.
- Rough (functioning) prototypes

M, MAY 2, 2:00–6:00 p.m.
- FINAL DEMONSTRATIONS (including PowerPoint or other digital presentation)
- Project report due
- Project Development Notebook due (includes any research, sketch and concept development, CAD drawings, and photographs of the final project)

A project web site was established to provide a focal point resource for student teams [12]. The site contains all project assignments and deliverables, supporting guidance, project calendar, student teams with contact information, and documentation on the evaluation process.

Overall, the 17 student teams, experimental and control, selected a wide mix of assistive technology problems for their projects. The common element of satisfying those in need in a third world context of some push–pull problem tended to direct most student teams to farming, gardening, or basic transport sorts of problems. Of particular concern for many students were people who suffer from

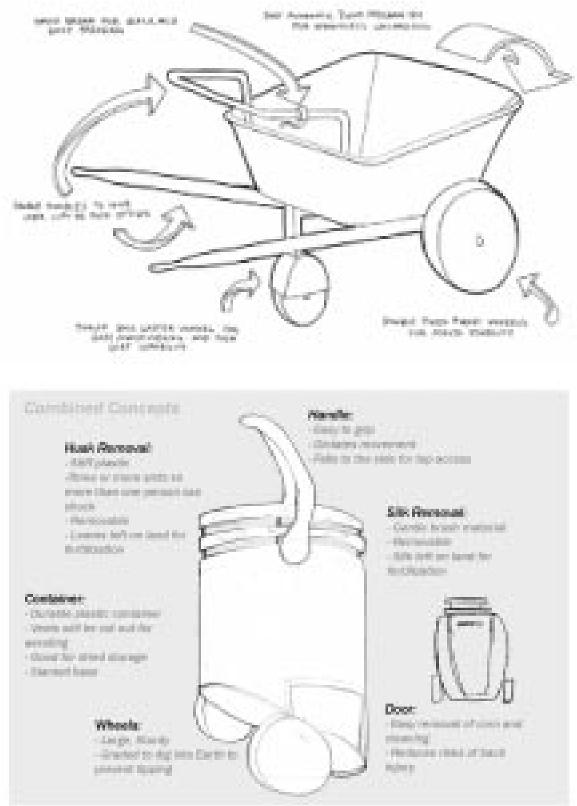

Fig. 1. (a) Garden cart that is suitable for use by people with back problems, weak joints, or low muscular capacity by Team Acme; (b) The easy Shuck corn husker to assist the harvest, husking, and carrying of loads of corn through fields by Team A-Maize-Ing.

back problems. Interestingly, students did a lot of research on life in third world countries and became sympathetic with the need to carry heavy loads over rough terrains for long distances. Figures 1(a, b) show early concepts for two of the projects.

EXPERIMENT AND ASSESSMENT PLAN

Four faculty members, two from industrial design and two from engineering, and the students enrolled in their respective courses participated in the experiment to determine if interdisciplinary teams were more beneficial than engineering only design teams. Two sections of the Exploration of Engineering Design course formed the experimental group of students, one section of 32 students from each of the two engineering faculty. These 64 engineering students were paired with 24 industrial design students to form 13 teams. One of the engineering faculty had a second section of the course, with 33 engineering students, that formed the control group, working in four engineering-only teams without collaboration with industrial design students. The experimental group, interdisciplinary teams, had nominally six engineers and two industrial design students per team and the control group, engineering-only teams, had nominally eight engineers working together per team. The primary objective of the experiment was to investigate the differences between the interdisciplinary teams and the engineering-only teams as well as secondarily observing any differences between the classes of the two engineering instructors.

Fig. 2. Student presentations forum.

All 121 students, experimental and control groups, were given the same information, resources, and presentations. The only difference in their treatment was in whether or not the teams were interdisciplinary. As shown in Fig. 2, all teams, experimental and control, presented their concepts and prototypes to all other teams in a large forum. In addition, all the teams had individual thirty minute faculty coaching sessions with the entire faculty team present, both of the engineering instructors and both of the industrial design instructors.

Assessment data is gathered from students on peer performance, from students on their own experiences and perceptions, and from faculty on students' performance. Assessment data is gathered at each of the project milestones and deliverables, including: concept presentations, faculty/team review meetings, rough prototypes, and final presentations that include final report, prototype, models, analyses, and design notebook.

PRELIMINARY RESULTS

As mentioned earlier, the experiment is currently underway to investigate student learning with interdisciplinary teams taking on assistive technology (AT) design projects. To date, students have identified their problems, developed and evaluated concepts, and have presented rough proof-of-concept physical models of product concepts. Final presentations, final reports, finished prototypes and design notebooks have yet to be completed and assessed. While results are preliminary at this point, early results are notable and, we believe, likely to predict the outcomes of the final project results and learning. Figure 3(a, b) shows two examples of rough proof-of-concept prototypes presented by the freshmen and sophomore interdisciplinary teams only four weeks after the project launch.

Fig. 3. (a) A system for transport and filtration to assist carrying the heavy weight as well as purify drinking water; by Team 2. (b) Broom and dustpan to minimize bending and holding requirements for users with back problems and limited hand–arm strength by Team Touche.

At the first forum for presentation of concepts, a survey was given to all the students in attendance. Students rated the presentations, from poor to excellent for each of the seventeen (17) teams (questions 1–17 on the survey) as well as answering twelve additional questions (questions 18–29 on the survey) pertaining to assistive technology projects, team dynamics and collaboration. Students were asked to:

1. Provide an overall evaluation (impression) for each team.
   a) Your impression should include the quality and organization of the slides, the delivery of the presentation, progress of the team, and creativeness of the concepts.
   b) Fill in your responses to 1–17 in the order that teams present.
   c) Score evaluations:
      1 = poor 2 = fair 3 = good
      4 = very good 5 = excellent

The average of student ratings for each of the 17 projects ranged from a low of 3.4 to a high of 4.3 with a mean of 3.71 for the engineers only teams (control group) and 3.84 for interdisciplinary teams (experimental group). On a similar evaluation form, the faculty evaluated student presentations of concepts with mean responses that were 2.97 for the engineer-only teams (control group) and 3.42 for the interdisciplinary teams (experimental group). The faculty, not surprisingly, were more critical/discerning of the presentations than the students. In both cases (student and faculty evaluation), however, the interdisciplinary teams (experimental group) were perceived to have better presentations and concepts than the engineer-only teams (control group).

Students were then asked:

2. For questions 18–29, answer the following questions related to your own impressions of the project and your team. (This is not a grade, but feedback on your experience.)
   Use the rating scale:
   1=disagree 2=somewhat disagree 3=neutral 4=somewhat agree 5=fully agree
   18) Human centered design projects are interesting.
   19) Open-ended projects are frustrating.
   20) Open-ended projects provide greater opportunities to learn and experiment.
   21) I prefer fully specified instructor provided problems over open-ended problems.
   22) Overall, my team works well together.
   23) Some members have not done their share.
   24) My team has a good leader/leaders.
   25) My team has met frequently enough to make needed progress.
   26) I am a reliable team member (show up to meetings and do my tasks).
   27) I am proud of the team progress to date.
   28) I am confident that the results of our project will be good.
   29) I enjoy collaborating with students outside of my major.

Figures 4–7 display the distributions of the answers to questions 18–21. These were the questions where the differences in responses between the experimental and control groups appear to be significant. Results shown in Figs 4–7 are shown for four categories of participants, including:

- EngE Only—the control group made up of teams with only engineering students, instructed by J. Terpenny,
- EngE JT—the experimental group made up of teams with engineering and industrial design students, instructed by J. Terpenny,
- EngE RG—the experimental group made up of teams with engineering and industrial design students, instructed by R. Goff,

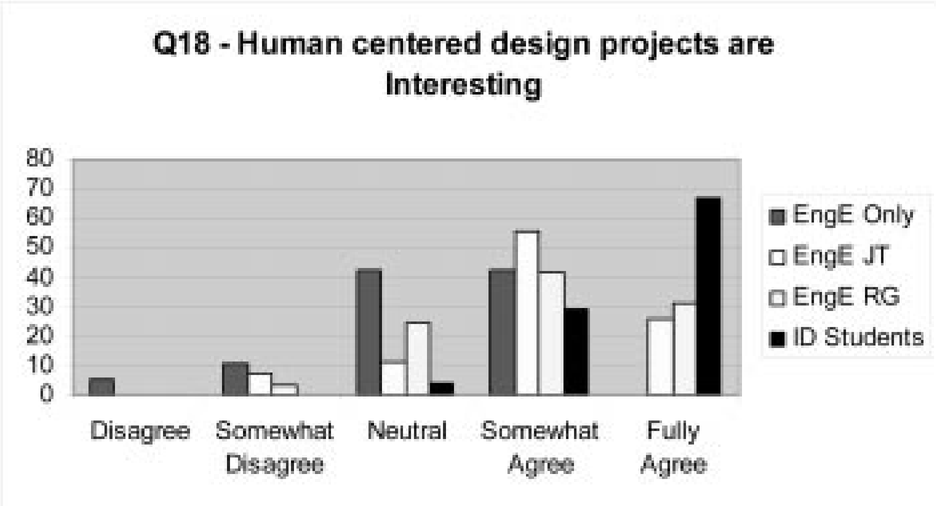

Fig. 4. Question 18—Human centered design projects are interesting.

- ID Students—industrial design students participating in one of the interdisciplinary teams from EngE JT or EngE RG experimental sections. These are reported separately so as to determine differences between engineering and industrial design students on individual perceptions.

In questions 22–29, all four categories of respondents had similar responses. For these questions the results are summarized.

In Fig. 4, it can be seen that most students are very positive about human centered projects such as the current assistive technology project, but the engineering students were not as positive as the industrial design students with the engineering only group being the least positive.

In Fig. 5 there appears to be a wide distribution of reactions to this question. Notice that the engineering-only group is less frustrated. Frustration may be due more to issues of interdisciplinary collaboration than the open-ended nature of the project.

In Fig. 6, the responses were generally positive to opportunities offered in open-ended projects. The engineering only group was not as positive as the interdisciplinary groups about these opportunities. The industrial design students were the most positive.

In Fig. 7, a wide distribution to this question can be seen with the engineering students' responses being spread across the spectrum leaning toward fully specified problems and industrial design students clearly preferring open ended problems.

As mentioned previously, in the responses to questions 22–29, all groups seemed to have similar responses. Results indicated the following:

Most teams seemed be working well together. Slight problems with engineering-only group.

Most feel that team members are pulling their weight.

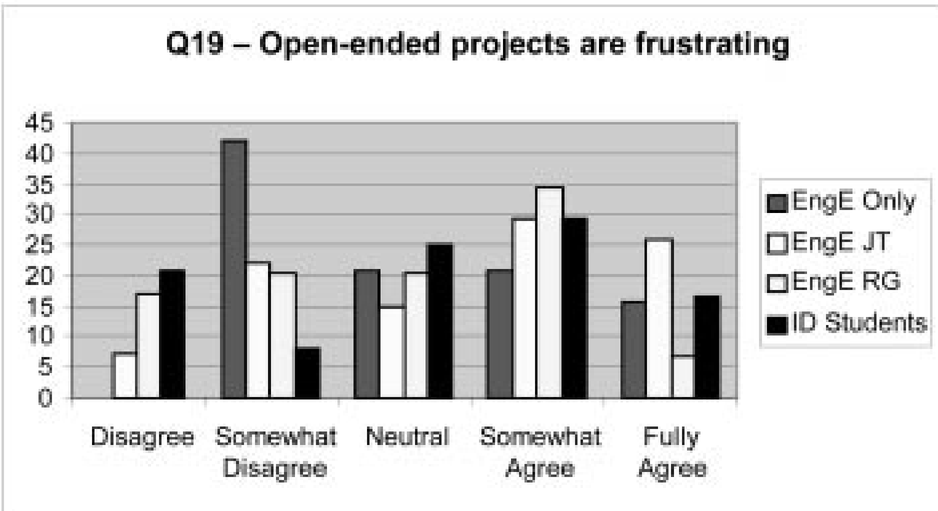

Fig. 5. Question 19—Open-ended projects are frustrating.

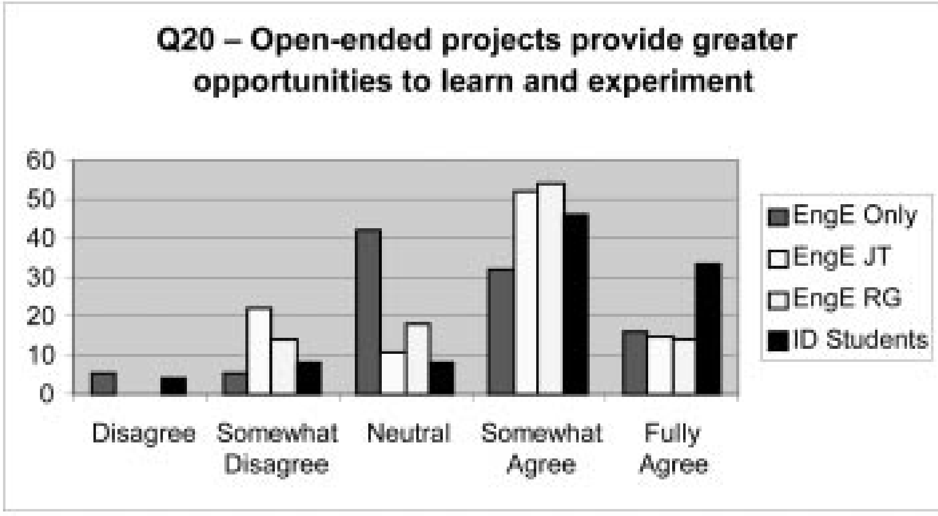

Fig. 6. Question 20—Open-ended projects provide greater opportunities to learn and experiment.

Leadership is good in almost all teams.
Most teams are meeting enough.
Self-assessment of reliability is positive.
Positive sense of progress.
High confidence in results at an early stage.
Strong support for collaboration among those collaborating.

CONCLUSIONS AND FUTURE PLANS

Open ended interdisciplinary team projects offer many learning opportunities in engineering design related to complex problem solving, teaming, conflict resolution, multi-criteria decision making, etc. that are often not available to students until their senior year capstone design experience. Introducing students to such experiences earlier can only increase these skills. From our observations and analysis of assessment data thus far, we can conclude that interdisciplinary assistive technology team projects are engaging and worthwhile for both faculty and students. The data indicate that there is a discernable difference between the projects of engineering-only teams (control group) and interdisciplinary teams of engineering and industrial design students (experimental group). On average, interdisciplinary teams produced higher quality results and value both the collaboration as well as the opportunities opened by working with people from another discipline. The project ideas generated by the interdisciplinary teams appear to have benefited from a wider vision of possibilities with multiple iterations based on diverse perspectives from the team. The dynamics, leadership, and progress of all teams regardless of composition functioned well. Clearly, we pursue and put energy into those activities that excite and engage us. This project is an example of such an activity.

Our immediate future plans include completing the experiment currently underway: refining and

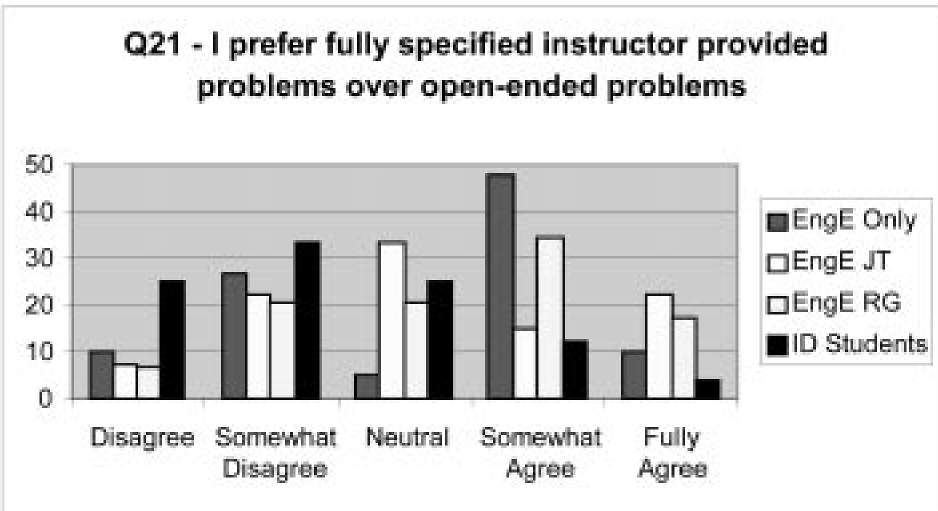

Fig. 7. Question 21—I prefer fully specified instructor provided problems over open-ended problems.

finalizing product prototypes, final design coaching sessions, demonstration and presentation of final products. Additional assessment instruments will be used, including surveys, peer evaluations and faculty evaluation of final products, presentations and reports. Just as preliminary results of the current experiment confirm our belief that interdisciplinary teams are beneficial to engineering design, we anticipate that the final analysis of remaining deliverables will also confirm this finding.

We plan to further address the validity of our assumptions that open-ended projects over other types of projects have significant benefits to learning for engineering design. Our plan for future experiments is to compare student teams with an open-ended assistive technology project with those who are assigned the more traditional and usual freshman or sophomore design project that is more fully specified such as a case problem requiring a mechanical device solution. For instance, while the three sections of engineering students this semester in our sections were focused on open ended assistive technology problems, the remaining 21 sections of freshmen enrolled in Exploration of Engineering Design focused on the glider launcher design competition offered by the American Association of Engineering Education (ASEE) for their term project [13]. It will be interesting to determine if there are significant differences in learning and skills of the two groups. We will also try to discern in a more formalized manner whether human-centric projects affect student motivation and learning and, if so, if this is true for certain student populations.

Other areas of future investigations will focus on studying strategies for teaching complex problem solving skills [14] and the interventions needed to facilitate behaviors that assist students' transition from naïve to expert designers. For instance, Crismond [15, 16], as a result of several years of studying designer behavior, has developed a Designer Strategy Table. In future work, we will investigate the development and evolution of student behaviors and project design teams. Of particular interest will be those beginner strategies noted by Crismond, including: sticking with the first design idea; proposing overly complex solutions; acting before talking or reflecting; doing problem solving first rather than problem finding; not reflecting on the mistakes of previous design iterations, and forever tweaking a design. Sources for these patterns of beginner designer behaviors include protocol analysis of naive, novice and expert designers doing investigate-and-redesign tasks, published cases of catastrophic failures of engineering firms, and observations made during interviews by engineering design professors, expert teachers and curriculum developers.

We anticipate valuable suggestions from the students currently involved in the interdisciplinary assistive technology project. Their feedback on the experience will have significant impact on the design of next year's project. We have already determined that the effort needs to start at the beginning of the semester with joint research being conducted by the teams. The full-blown design process might not begin until later in the semester, but we see the benefit of the teams having more time to become acquainted and to be involved in initial inquiry and discussion before launching into conceptualization and manufacture. Further, it is not a trivial pragmatic task to work with more than 120 students and 4 faculty from two different colleges and disciplines. The scheduling alone is a challenge, but we see possibilities for easing this challenge by modifying class schedules across all participating sections and courses a term in advance so as to align meeting times for group meetings. Finally, the lessons learned this year will certainly bring more focus, clarity and complexity to the assessment process and documentation in future experiments.

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