Board 261: Effectiveness of Vertically-Integrated Project Teams in Tackling an Engineering Grand Challenge

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Effectiveness of Vertically-Integrated Project Teams in Tackling an Engineering Grand Challenge

Abstract

This work details a multi-level and multi-disciplinary team approach to advance an *Engineering Grand Challenge* project and serves to evaluate its effectiveness and performance especially regarding the team makeup and experience.

The project administration, logistics, and activities were built on the AggiE-Challenge program platform, an initiative within the College of Engineering at Texas A&M University (TAMU). With the overarching goal to engage engineering undergraduates at various levels (freshmen to senior) in high-impact multi-disciplinary research challenges, vertically-integrated project (VIP) teams were constructed in lieu of the typical one-on-one mentoring of students for a more realistic, meaningful and effective engagement. VIPs unite undergraduate education and faculty research in a team-based context, whereby students earn academic credits and research experience, while furthering discovery. The *extended* team that was evaluated comprised of multiple faculty and graduate student mentors guiding a large multi-level undergraduate student team spanning multiple engineering departments. The prominent challenge was on enhancing virtual reality (VR) and involved the incorporation of haptic feedback and VR to detail the environment for minimally invasive surgery training. The team was successful in not only generating the knowledge and tools pertinent to advancing the problem but also in developing functional prototypes to address various aspects of the grand challenge.

The evaluation efforts involved assessing the effectiveness of VIP teams in providing enriching research experiences as well as measuring student inclination and/or intent to pursue advanced STEM study. In this capacity, research questions were asked to elucidate how the construction of the team affects its performance, how VIP affect learning experiences differently as compared to traditional one-on-one student mentoring as well as students' inclinations to pursue advanced STEM study and careers. On gathering information via surveys and interviews, conclusions were drawn that highlighted the benefits of constructing and deploying such teams in contrast to traditional one-on-one research mentoring of a student. In general, students showed significant growth under the categories of understanding engineering design, problem solving, and communication, besides positive impacts on their post-graduation plans.

Background

AggiE-Challenge is a unique program within the College of Engineering at Texas A&M University which is designed to actively engage engineering undergraduate students that have different technical backgrounds to form a multi-level and multi-disciplinary team to carry out a specific research project. There are typically 15-20 projects each year with each project spanning the academic year, *i.e.*, Fall and Spring semesters; these projects are selected from competitive proposals submitted by engineering faculty members. The projects are primarily catered to address the *14 Grand Challenges for Engineering* (articulated by the National Academy of Engineering), the *14 Grand Challenges for Global Health* (articulated by the Bill & Melinda Gates Foundation), and *Engineering World Health: Projects that Matter*. As a result, the selected projects span a wide variety of topics that have a multidisciplinary nature such as biological research, clean water, food, medical devices, robotics, energy, education, virtual reality, etc.

The AggiE-Challenge program allows students within a specific major to have a chance working with students from other engineering departments and sharing their knowledge/skills; at the same time, it also stimulates collaborative efforts between faculty with different research interests and backgrounds. The program allows for two project team sizes based on the problem scope defined by faculty applicants. A small team consists of 5-9 students and a large team has 10+ students. The college/program provides some financial support to the graduate student mentor as well as covers project expenses up to a certain limit. The graduate student mentor is required to work closely with both the faculty members as well as the undergraduate students on the project; he/she is also responsible for coordinating meetings and activities related to the project. Altogether, a vertically-integrated project structure is maintained that allows for faculty (groups) to effectively coordinate a large group of undergraduate students who are managed primarily by a cognizant graduate student (technically and administratively) to advance a project solution.

To recruit for the project, faculty reach out to relevant engineering departments to advertise to the potential students who may be interested and has experience related to the topic of interest. Undergraduate students can register for a particular project in the form of research credits, but id limited to a maximum of 3 credits per semester so that the effort is commensurate with the time and effort expended. Based on individual departmental regulations, these credits may be used as technical elective credits, capstone design credits, or research credits that count toward their degree plans. For high-performing honors students that are above a certain cutoff GPA, these credits are also eligible to be used as part of an honors section. Such flexibility allows for this AggiE-Challenge program to conveniently integrate with the curricula of the respective students. The deliverables required by the AggiE-Challenge program were individual video summaries and final project presentations including the dissemination of a poster at the college-wide Engineering Project Showcase event. Additionally, faculty could design the project content, grading rubrics, assignments, and other deliverables to achieve the student learning outcomes.

Project Details

Besides its growing use for entertainment, Virtual Reality (VR) is rapidly becoming a powerful tool for industrial and medical research, development, and daily use – consequently, the National Academy of Engineering (NAE) has designated “Enhance Virtual Reality” as one of the *14 NAE Grand Challenges for Engineering*. In order to tackle this grand challenge, especially in conjunction with the *Engineering World Health: Projects That Matter* challenge on enabling low-cost medical testing devices for the developing world, a multi-disciplinary and multi-level team approach that leverages the future generation of engineers is needed – this paper, in addition to detailing the project, investigates the effectiveness of such vertically-integrated teams in tackling essential aspects of this grand challenge.

This specific project utilizes a haptic device for VR-based surgical simulations in bone cutting operations such as drilling, sawing, and burring, as shown in Figure 1. Haptics refers to the feel of touch. Currently resident surgeons are trained on artificial models, cadavers, or real patients during minimally-invasive surgeries. Artificial models and cadavers are often unrealistic, while training in the operating room on a real patient exposes the patient to risk. Realistic VR simulators open a new paradigm in surgeon training for global health systems. However, current VR systems are unable to reproduce realistic haptic feedback due to the complex and highly dynamic reactions between surgical tool and bone (the workpiece) which includes multidirectional forces, vibrations and their changes during the operation. This multidisciplinary project, therefore, was proposed to understand the surgical haptics, reproduce it, and validate it.

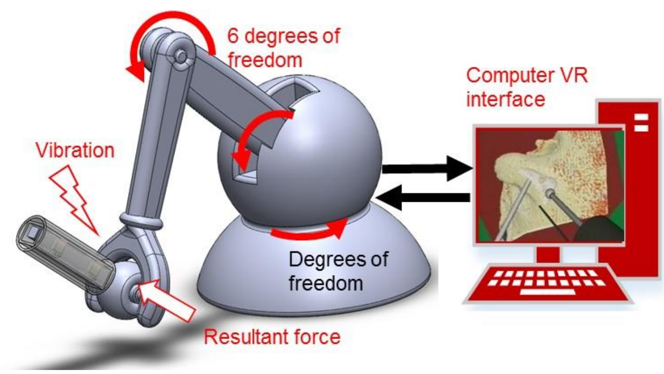

Figure 1. The concept of an enhanced haptic device for VR surgical training

Project tasks were planned to build on the knowledge gained from the preceding task, *viz.*, quantification of forces, vibrations and their changes during an operation; design and manufacture of haptic device components; control/feedback of the haptic device; and finally the integration with a VR environment. The multidisciplinary nature of the problem required students from mechanical engineering, manufacturing engineering, electrical engineering, and computer engineering, which ended up being the majority student composition of the assembled teams. In each semester, the 10-student group was split into three sub-groups, namely, a force/vibration characterization group, a hardware design group, and a psychophysical (*i.e.*, human perception) study group. Such sub-group settings limit a working group to 3-4 students, which is an ideal size for work assignments, scheduling, communication and collaboration in contrast to a full size team (10+ students). The students were assigned into subgroups based on their major, weekly class schedules and most importantly their inclination/experience towards a specific taskset. Such an arrangement also allowed students to interact with their team members who could be from other engineering disciplines. Moreover, students also participated in tasks undertaken by other sub-groups as appropriate. Sub-group meetings and full-team meetings were also set up throughout the entire semester. While the sub-group meetings dealt with individual tasksets, full-team meetings provided the big picture status of the project.

Over the course of this project, students were successful in characterizing the dynamic forces and vibrations experienced via a design of experiments (Figure 2(a)). These results along with the graduate mentor's numerical analysis have been documented as a peer-reviewed conference proceeding [1] and eventually as an archival journal publication [2]. Students also finalized the design of an actuator and manufactured a functional prototype (Figure 2 (b) and (c)) along with performing psychophysical tests to understand human perception to the vibration and its changes (Figure 2(d)). The human perception study provided useful information to determine the essential aspects of force and vibration that needed to be reproduced in the haptic device arrangement. The students from the subsequent project cycle were able to use this information to design the graphic rendering for the VR environment as well as for system integration.

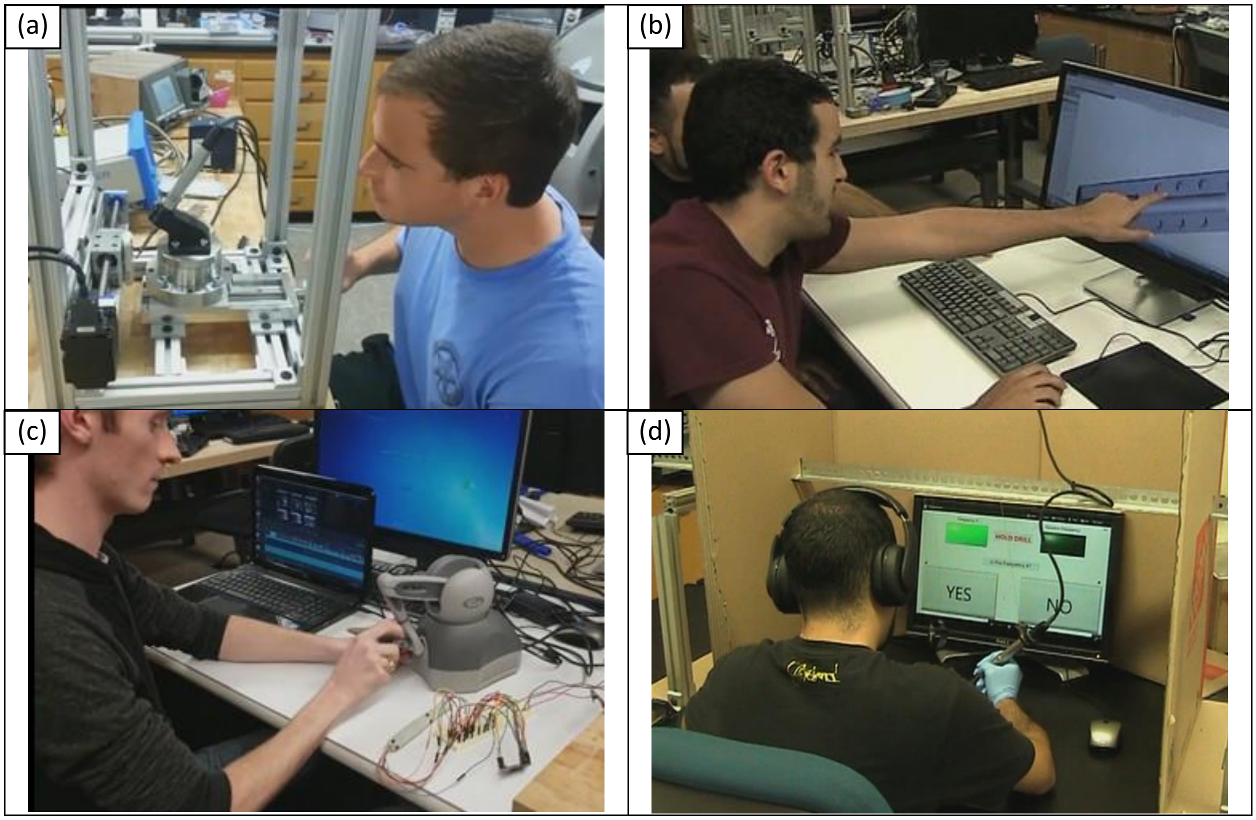

Figure 2. (a) Design of experiments for force characterization, (b) Haptic device housing design, (c) Integration of vibration actuator in the device, and (d) Psychophysical study to test the human perception to the force/vibration.

Vertically Integrated Projects (VIP)

In lieu of the typical exclusive one-on-one mentoring of undergraduate students in research, this project utilized an extend vertically integrated project team arrangement to provide for a more realistic, meaningful and effective engagement of undergraduates in a large research project. Initiated by Georgia Tech in 2009, Vertically Integrated Projects (VIP) unite undergraduate education and faculty research in a team-based context, where students earn academic credits and a research experience, while furthering discovery [3]. The effectiveness of such multidisciplinary [4] and mixing multi-level students [5] has been demonstrated [5-8] and adopted widely as a result [9-11]. The learning outcomes from a successfully carried out project using the VIP framework were expected to mirror some of the ABET outcomes from courses within engineering degree programs such as (i) an ability to apply mathematics, science, and engineering knowledge; (ii) an ability to pursue designs based on desired needs and within realistic constraints; (iii) an ability to function on multidisciplinary teams; (iv) an ability to communicate effectively; (v) ability to recognize the need and to engage in life-long learning.

Evaluation to Assess Effectiveness of VIP Teams

Project evaluation efforts involved deploying end-of-semester surveys much like that of a typical course assessment whereby student responses were anonymized, and only aggregate data was available to the faculty mentors. The questions asked were designed to primarily capture student perceptions related to four categories, *viz.*, (i) Understanding of Engineering and Design, (ii)

Problem Solving, (iii) Communication, and (iv) Teamwork – these contributed to an understanding of the effectiveness of VIP teams in providing enriching learning experiences. Additional questions were asked to elucidate how the construction of the team affected student perception and their inclinations to pursue advanced STEM study and careers.

The data below summaries the survey responses from AggiE Challenge student participants from across two academic years (4 regular semesters), and specifically from the course sections of the faculty mentors advancing this particular project on enhancing VR. The responses are based on a rating scale with a maximum score of 4, where "None" = 1, "Slight" = 2, "Moderate" =3, "A great deal" = 4. There were 8-10 undergraduate student in each of the semesters who came from four (4) different engineering departments within the college of engineering. In each of the four tables below, the numbers corresponding to each sub-question are the average scores calculated from the 8-10 respondents, and the last row in each of the tables indicate the average and standard deviation of the scores for each semester.

(i) Understanding of Engineering and Design: Under this category, because of their involvement in the AggiE-Challenge project, students rated their growth as:

Table 1: Average of responses to "Understanding of Engineering and Design"

#	Question	Year-1 Fall (average)	Year-1 Spring (average)	Year-2 Fall (average)	Year-2 Spring (average)
1	understanding of what engineering can contribute to society as	3.50	3.57	3.3	3.67
2	understanding of the language of design in engineering as	3.25	3.29	3.4	3.33
3	understanding of the process of design in engineering as	3.75	3.71	3.6	3.33
4	my ability to "do" design as	3.25	3.43	3.4	3.33
AVERAGE & STANDARD DEVIATION		**3.44±0.24**	**3.50±0.18**	**3.43±0.13**	**3.42±0.17**

(ii) Problem Solving: Under this category, because of their involvement in the AggiE-Challenge project, students rated their growth in their ability as:

Table 2: Average of responses to "Problem Solving"

#	Question	Year-1 Fall (average)	Year-1 Spring (average)	Year-2 Fall (average)	Year-2 Spring (average)
1	identify what information is needed to solve a problem as	3.50	3.29	3.4	3.67
2	apply an abstract concept or idea to a real problem or situation as	3.25	3.57	3.6	3.67

3	divide problems into manageable components as	3.75	3.71	3.4	3.67
4	develop several methods that might be used to solve a problem as	3.50	3.29	3.1	3.67
5	use established criteria to evaluate and prioritize solutions as	3.25	3.43	3.1	3.67
AVERAGE & STANDARD DEVIATION		**3.44±0.24**	**3.50±0.18**	**3.30±0.24**	**3.67±0.00**

(iii) Communication: Under this category, because of their involvement in the AggiE-Challenge project, students rated their growth in their ability as:

Table 3: Average of responses to "Communication"

#	Question	Year-1 Fall (average)	Year-1 Spring (average)	Year-2 Fall (average)	Year-2 Spring (average)
1	clearly describe a problem orally as	3.50	3.57	3.3	3.33
2	clearly describe a problem in writing as	3.00	3.14	3.1	3.33
3	explain my ability to others as	3.25	3.43	3.4	3.33
AVERAGE & STANDARD DEVIATION		**3.25±0.25**	**3.38±0.22**	**3.27±0.15**	**3.30±0.00**

(iv) Teamwork: Under this category, because of their involvement in the AggiE-Challenge project, students rated their growth in their ability as:

Table 4: Average of responses to "Teamwork"

#	Question	Year-1 Fall (average)	Year-1 Spring (average)	Year-2 Fall (average)	Year-2 Spring (average)
1	develop ways to resolve conflict and reach agreement in a group as	3.75	3.43	3.3	3.33
2	be aware of feelings of other members of the group as	3.75	3.71	3.5	3.33
3	listen to the ideas of others with an open mind as	3.75	3.57	3.4	3.67
4	work on collaborative projects as a team member as	3.25	3.71	3.4	3.67
5	ask probing questions that clarify facts, concepts, or relationships as	3.25	3.71	3.5	3.67
6	after evaluating the alternatives generated, develop a new alternative that combines the best qualities and avoids	3.00	3.57	3.4	3.67

	the disadvantages of the previous alternatives as				
7	evaluate arguments and evidence so that strengths and weaknesses of competing alternatives can be judged as	3.50	3.57	3.4	3.33
8	be patient and tolerate the ideas or solutions proposed by others as	3.00	3.57	3.5	3.33
9	understand that a problem may have multiple solutions as	3.75	3.71	3.5	3.67
10	use discussion strategies to analyze and solve a problem as	3.75	3.57	3.4	3.33
11	recognize contradictions or inconsistencies in ideas, data, images, etc. as	3.50	3.43	3.2	3.33
12	recognize flaws in my own thinking as	3.25	3.43	3.4	3.33
13	identify the constraints on the practical application of an idea as	3.25	3.71	3.2	3.33
AVERAGE & STANDARD DEVIATION		**3.44±0.29**	**3.59±0.11**	**3.39±0.10**	**3.46±0.18**

In general, students responded that their growth and ability under the four (4) queried categories were positively affected to "A great deal" as a result of their direct involvement in project via the AggiE-Challenge framework, as denoted by the average range of responses from 3.25 to 3.67; the standard deviations were fairly small denoting that there were no significant outliers. It is worth noting that there is a small but consistent increase in the scoring averages for the second semester of the academic year (Spring) denoting positive changes in student perceptions especially related to the value of the program and metacognition (the same set of students rated these experiences during a given academic year, *i.e.*, for Fall and then Spring).

When querying students on their post-graduation plans, a fairly even mix of interest in pursuing graduate school vs. pursuing an industry/government job was observed as indicated in the table below. For those who indicated interest in pursuing graduate school, 100% of them noted that their engagement with the AggiE Challenge program had a positive impact on their decision to continue education with graduate school. In this regard, it was heartening to receive a number of positive responses when they were queried on the most valuable aspects of their experience with the AggiE Challenge project for their professional career. A sampling of the responses is shown:

- *"Collaborating with others and learning by doing the design project with an actual real-life project."*
- *"Learned about real design challenges that they have to go through"*
- *"It helped me gain experience working on a team with others and going through the engineering design process."*
- *"The opportunity to work with people of different disciplines and skill sets."*
- *"Working with an engineering team on a relevant project with real-world effects"*
- *"Learned a great deal about how engineering theory can be implemented into product design."*

- *"Having the opportunity to work on a tangible product with a team of different types of engineers was the most valuable experience for my career."*
- *"I got insight into graduate programs and was able to have a mentor of sorts to help me to understand certain topics in a way that is easily communicable."*
- *"I learned how to better work with a team and how to problem solve and delegate tasks."*
- *"Gave me a greater appreciation for unseen hurdles"*
- *"Be able to work on a team and reach an ultimate conclusion on how to approach the issue. It helped me grow and understand how to work as a team."*

Table 5: Post-graduation plans of the students from the program

#	Post-Graduation Plans	Year-1 Fall (average)	Year-1 Spring (average)	Year-2 Fall (average)	Year-2 Spring (average)
1	Pursue graduate school	25%	50%	40%	67%
2	Join an industry or government for full-time	75%	50%	60%	33%

Finally, students were queried on their experience and reflections on working within a team to advance a grand challenge and how the construction of the team affected their experience on the project. Relevant responses along with percentages are summarized below:

1. *Do you think you learned/understood more about the project by working within such a team vs. working alone?*
   Yes, learned/understood more by working within a team (87.5%)
   No (0%)
   Maybe (12.5%)
2. *How did the multi-disciplinary (4 engineering department) construction of your team affect the research project performance?*
   Positively (87.5%)
   Negatively (0%)
   Neutral (12.5%)
3. *How did the multi-level (sophomore to senior) construction of your team affect the research project performance?*
   Positively (62.5%)
   Negatively (0%)
   Neutral (37.5%)

Conclusions

This paper detailed a multi-level multi-disciplinary team approach to advance an Engineering Grand Challenge project and served to evaluate its effectiveness and performance regarding the team makeup and experience. The project was built on the AggiE Challenge framework at Texas A&M University, where a team of undergraduates from different engineering departments and from different levels (freshman through senior) worked in concert with graduate students and faculty mentors to advance a large problem related to enhancing VR. Gathering student responses related to program performance and perception via surveys and interviews showed that constructing and deploying such multidisciplinary teams were beneficial, especially in contrast to traditional one-on-one research mentoring of a student. Students showed consistent growth under the categories of understanding engineering design, problem solving, communication, and teamwork with positive gains as they progressed through the program. Further, the experience was also shown to have had positive impacts on their post-graduation plans in terms of pursuing further study (graduate school) and/or pursuing an industry/government job in STEM.

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