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Work in Progress: Engaging First-year Engineering Students through Makerspace Project-based Pedagogy

Dr. Gisele Ragusa, University of Southern California

Dr. Gisele Ragusa is a Professor of Engineering Education at the University of Southern California. She conducts research on college transitions and retention of underrepresented engineering students, engineering ethics, PreK-12 STEM education, and also research about engineering global preparedness.

Dr. Erik A. Johnson, University of Southern California

Dr. Erik A. Johnson is a Professor of Civil & Environmental Engineering at the University of Southern California and has served since 2017 as the Vice Dean for Academic Programs in the USC Viterbi School of Engineering. Dr. Johnson earned B.S. (1988, with highest university honors), M.S. (1993) and Ph.D. (1997) Degrees in Aeronautical and Astronautical Engineering at the University of Illinois at Urbana-Champaign, and a Certificate in Biblical Studies (1991) from Trinity Evangelical Divinity School. Prior to joining USC, he was a visiting research assistant professor at the University of Notre Dame from 1997 to 1999. He served 2007-17 as the Associate Chair of the USC Sonny Astani Department of Civil and Environmental Engineering (and Interim Chair in 2011), as well as Interim Director of USC Viterbi's Information Technology Program for 2018-19 and 2022-23.

Dr. Johnson was the recipient of a 2001 U.S. National Science Foundation "Early Faculty Career Development (CAREER) Award," the Junior Research Prize and Medal from the International Association for Structural Safety and Reliability (2005), and an Outstanding Recent Alumnus Award (2003) and a Distinguished Alumni Award (2016) from the University of Illinois. He is a senior member of the American Institute of Aeronautics and Astronautics (AIAA), and a member of both the American Society of Civil Engineers (ASCE) and the American Society of Mechanical Engineers (ASME). Dr. Johnson has served as the Chair of the ASCE EMI Technical Committee on Structural Health Monitoring and Control, the Chair of the ASCE EMI Probabilistic Methods Committee, and as an Associate Editor of the ASCE Journal of Engineering Mechanics; he currently serves on the Board of Directors of the American Automatic Control Council and on the Advisory Board of the journal Structural Control and Health Monitoring.

Dr. Johnson's research interests include "smart" structures, control of structural vibration, controllable damping devices, monitoring structural health, random vibration, and computationally-efficient simulation algorithms for dynamical systems, as well as the future of engineering education.

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Abstract

This is a work in progress paper. As the United States continues to evolve from an industrial economy to a global economy, a significantly higher level of education for larger proportions of society has become a necessity for each individual and for the collective benefit of all. This trend has multiple direct implications for higher education and is particularly important for engineering workforce development. Demand for employment-relevant, technologically focused university programs is ever increasing, raising questions as to whether the U.S. postsecondary education system can continue to effectively respond.

Higher education researchers have noted increasing difficulties in students as they transition from K-12 experiences to colleges and universities, and especially for transitions taking place in research universities in engineering and in other technologically focused fields. This transitional phenomenon has become pronouncedly more challenging as a consequence of the COVID-19 pandemic, where the majority of high school students attended their last year or two of high school remotely or in hybrid form and then needed to transition to face-to-face experience as a first year college student.

The paper presents formative results of an innovative first year program for undergraduate students in which makerspace and human centered design projects served as a semester long team project that was intended to increase students' understanding of the role that engineers play in society nationally and globally.

Introduction and overview

This is a work in progress paper. Researchers who study college transitions posit that students often become lost when they are required to exhibit independence and navigate college during their first year without the watchful, anticipatory guidance of their parents and high school teachers. Their grades may plummet, which is particularly pronounced when students encounter the rigor of engineering curricular content. To address this dilemma, engineering schools across the country have developed first-year programs to support students in navigating through and succeeding in their first year in college.[1,2] Many of these programs contain remediation experiences, tutoring programs, and summer bridge skill oriented programs. These programs' successes have been quite variable and are typically modest when brought to scale.[3,4] Furthermore, there is sparse research that indicates such programs have significant longitudinal impact on students' career preparedness.[5] Our research attempts to address these described dilemmas.

Project-based learning in early engineering education

It is critically important that future engineers learn about engineering problem solving and engineering design, their similarities and differences, long before they enter the engineering workforce.[6] Project-based learning facilitates such pedagogical efforts that enable practices of engineering problem solving and or engineering design.

Engineering problem solving requires engineers to identify, recognize and understand the scope and the of nature of a problem, in other words, to create a problem statement. Furthermore, in engineering problem solving, engineers gather or collect data associated with a particular problem and verify its accuracy.[7,8] Through this process, practicing engineers often select and apply guiding theories and scientific principles associated with solving problems and then identify acceptable assumptions, knowns, specifications or givens related to the problems that they intend to address.[9] Moreover, practicing engineers must also identify constraints, restrictions, and associated limitations to the problems that they encounter. Once these processes are articulated, engineers must proceed to engaging in creating the potential solutions for of the problems that they encounter. Through this, engineers generate potential solutions to the problem, select an optimal solution, and design and engage in a step-by step-plan(s) and associated analysis using engineering disciplinary skills. They verify results, evaluate, and adjust the solutions they work on accordingly, until they reach an optimal solution for their identified problems.[10] This is an important process for practicing engineers, however, rarely are first year engineering students exposed to and able to practice this process. Our program addresses this important practice during the first semester that students enter the academic landscape.

Different but intricately related to engineering problem solving, engineering design is intended to design a solution for an engineering problem or challenge. This process is often iterative beginning with prototyping and proceeding to designing and testing a solution. Engineering design is goal oriented and often human centered or citizen centric.[11] It is especially a decision-making process in which mathematics, sciences, and engineering skills and knowledge are applied to meet an objective. This process most often involves creativity and innovation with many ideas and brainstorming provided on its front end. Engineering design involves research, modeling and prototyping followed by analyses and evaluation and often involves business planning which may result in bringing a product to customers and to market.[12,13] Similarly to engineering problem solving, the design process is typically not taught to first year college students. In our program, both exposure and practice of the design process is very much a part of the first year.

Providing students with guided practices in these critical engineering processes in which practicing engineers engage is best accomplished when it is initiated early in undergraduate engineering students' academic experiences. The benefits include an early understanding of the role that engineers play in society as problem solvers and innovators. Furthermore, students can connect the content they have in early science and mathematics courses to that which is tangible and relatable through the iterative practices that they go through in trying to design a solution to a problem under the anticipatory guidance of professors with their peers.[14] They also receive first-hand team experiences in this process and begin to understand the value of multiple perspectives in solving engineering problems. They can connect their future work to the business world as well. It keeps them motivated during the early period of their undergraduate programs because they see immediate relevance to that which they are working on. Adding a makerspace component to this process further reinforces the "hand-on" nature of engineering problem solving and iterative design processes.[15,16]

Impacts of human centered design on formation of practicing engineers

Human centered design is a particular type of engineering design that is especially important for novice engineers.[17] It has been found to increase students' motivation to persist in and graduate from engineering programs nationally and is of particularly importance for those who have been traditionally underrepresented in engineering, as it engages them in experiences that often have personal or community focused relevance to them.[18]

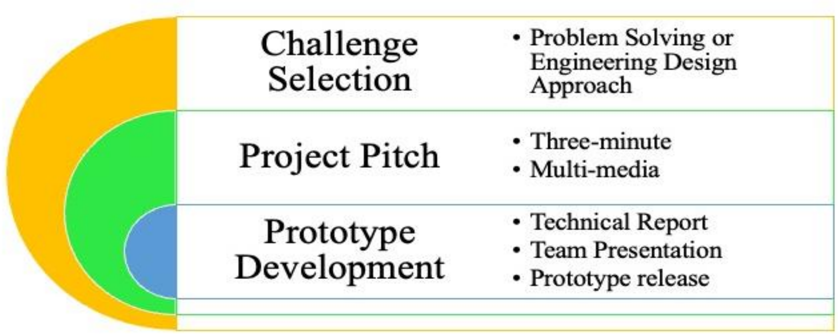
Research context

In contrast to the remedial or discrete skill bolstering first year engineering program efforts prescribed by many colleges and universities, our research reports on a comprehensive first year engineering program in which students enroll in a first year academy in which they engage in project-based pedagogy utilizing a makerspace experience. The goal of the program is to provide the students with a hands-on engineering experience from the first week that they enroll in college with an intent to provide the students with "real life" engineering experiences that align with their other technical courses so they can be fully engaged in working with peers and connect course content across their first year with that which will occur once they enter the engineering professions.[19]

Research approach

The students in the described first year academy program are grouped across the engineering disciplines and work in cross-disciplinary teams on a semester-long team project that addresses a student selected National Academy of Engineering Grand Challenge (NAE) or United Nations (UN) Sustainable Communities Goal. Through this process, the student teams develop a prototype to address a problem associated with an NAE or UN global challenge.[20, 21] The teams engage in societally relevant engineering design and problem solving processes in a makerspace environment and complete a four component team project consisting of: (1) a multimedia project pitch, (2) a scientific project report, (3) a team presentation, and (4) a physical prototype to address their selected challenge using design and problem solving principles and frameworks through their work within the makerspace. Figure 1 illustrates the process and its components.

Figure 1: Project Based Learning with Makerspace Pedagogy



Student sample

The students included in this engineering education research are first year students at a large private urban research university. There is nearly a 50-50 split in terms of students' gender and the student sampling mirrors that of the college population at large public and private research universities nationally in terms other diversity characteristics. Sixty-six first year students participated in this formative research.

Research questions, data collection and assessment tools

For this research, we address the following questions: (1) What is the relationship between the students' previous design and technical experiences to their success in makerspace project-based learning? (2) What role do team dynamics play in the success of their team projects? and (3) In what ways do students' team dynamics change as they near completion of their team projects. To measure the impact of the first year academy team experience in the makerspace, we utilize a set of multidimensional rubrics to assess the four team project components. We also collect students' background and experiential information during the semester. Furthermore, we collect information about the students' descriptions and report of their team dynamics, strengths and challenges.

The students receive specifications documents so that there are no "surprises" with regard to what was expected of them for completing the four components of the projects. Given that each of the four project components built upon the former components, each assessment product provided formative feedback to the students for the remaining components of the team project.[22] So, for example, for the project pitch, the student teams created a group multi-media, three minute project pitch that they shared with their classroom peers. These pitches received formative feedback from peers, some graduate business students, and the first year faculty provided narrative feedback in addition to a score on their pitch. The faculty feedback was intended to inform the teams' scientific project report, its final prototype, and its presentation, thereby informing the teams on how they could prepare to design and create their project prototype, report on it in the form of a scientific report, and create and present a final presentation of their prototype. The students' final report was designed to mirror that which they would write if they were engineers in industry. This facilitated guided practice for the teams in technical report writing and guided them in their final presentations.

Data analyses

We analyzed the quantitative components collected for this research for the team project using descriptive statistics. For the qualitative data obtained from the questionnaires and comments within our scoring rubrics, we engaged in thematic analyses and categorized and coded the data based on problem solving, design principles and team interaction. Given that this is exploratory, "work in progress" research, across time we intend to compare results across course sections and years in future research.

Formative results

Formative results of the research indicate the following. The participating students had a variety of precursing experiences as they entered their undergraduate engineering programs. These ranged from no precursing experience in engineering design to participating on robotics teams, taking engineering courses in high school, and to engaging in outside experiences in pre-engineering and computing.

In terms of the team projects, all of the participating students were able to successfully navigate the team experience and complete a pitch, report, presentation, and prototype to address a contemporary global engineering problem. Their project scores ranged from 80% to 99.25% The team projects demonstrated design thinking and iteration, societally relevant innovations, consideration and articulation of engineering ethics, and a shared understanding of the value of teamwork and collaboration.[23] The participating student teams created various prototypes including a solar powered windshield, self-cleaning bottles, apps for students with special needs, alcohol detection breathalyzer tooth covers, and wind energy kites among others. The students were creative and innovative in their work and presented their projects professionally. There were twenty-one projects in total across the participating sixty-seven students.

The strengths of the teams assisted the participating students in successful project completion, which was indicated by their report of team synergies and associated project scores. We saw qualitative improvement of this between the early assessment of team dynamics to the mid and end of semester assessment of the teams' interaction and dynamics. Resulting from the team orientation of the project, the participating teams reported working well together, having shared "detail orientation," having the ability to "divide and concur" tasks to complete the projects, and being able to "proactively create" their proposed engineering solution. The challenges that the teams faced at the beginning of the project primarily were related to finding time to work together. The teams reported that occasionally the work became "uneven" in terms of responsibility and that the teams noticed that if a teammate didn't "show up" at a particular class, they would not fully understand their project tasks when teams met outside of class to engage in their work on the projects. We noted that the teams were able to work through their team interaction difficulties and work distribution with very little intervention on the part of the faculty, however we were available to assist and had a total of team dynamic related team meetings with teams that asked for such assistance. The teams described the team process as "fun," a "hard working" process, and "an opportunity that's the best it can be." Accordingly, the formative results of this process indicated that the projects and experiences were successful empirically and in terms of qualitative feedback from the students.[24]

Discussion and future work

This "work in progress" first year experience engineering education research enabled the participating students to experience teamwork, prototype development, human centered design research, and reporting and presenting just as a practicing engineer would, early on in their undergraduate experiences. Working in the makerspace enabled the participating students to "tinker" with workbench tools and design elements, and to practice three dimensional prototype printing with the use of computer aided design that included measurement and associated software. In future years, as the project progresses, we intend to expand the research to multiple sections of the course and to compare the results of the project both across years of the first year academy and from freshman to senior year via a senior capstone experience.

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