A New Approach to Teaching Statics Using a Makerspace

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***Abstract*—This Work In Progress (WIP), Research to Practice Category paper, addresses a new approach to teaching concepts within introductory statics for undergraduate engineering students using a low-resolution-preto/prototyping makerspace. As the benefits of physical modeling and communities of practice have been increasingly documented, makerspaces have sprung up across numerous college and university campuses. Although makerspaces vary between institutions, they generally have resources that provide users the opportunity to perform hands-on design and obtain build experience. These facilities also bring people of different disciplines together, encouraging the sharing of perspectives and fostering collaboration among users. Literature pertaining to makerspaces shows that enhanced learning occurs within students who utilize these spaces.**

The new approach was pilot tested in the fall 2018 semester. In this math and physics-intensive sophomore-level course, the instructional goals in utilizing the makerspace included an enhanced understanding of the physical significance and application of core course concepts. The main course concept demonstrated was planar truss design, as pursued through the physical construction and testing of balsa wood bridges. Students were asked to design, build, and test a bridge prototype in a hands-on fashion using the makerspace. A second section of the course taught by the same instructor did not utilize the makerspace to build and test a prototype; instead, the students designed and analyzed a bridge prototype using 3D modeling and finite element analysis software, enabling a comparison. An assessment plan was developed that included the gathering of both student-perspectives, as well as direct performance data, including students' performance on the bridge prototyping project. Via survey, students were asked, prior to and after completing the bridge project, their perspectives about the makerspace, and if the makerspace enhanced their understanding of statics as well as their creativity and other professional skills, respectively.

In this WIP paper, we will describe the bridge prototyping project and students' use of the makerspace from the instructional team's viewpoint. We will also present preliminary assessment data demonstrating student perspectives on the approach. Lessons learned will also be discussed, including the instructor's plans for continuing this approach in future semesters.

Keywords—makerspace, hands-on, engineering

I. Introduction

Society and technology are changing at an ever-faster pace. To overcome these new challenges, engineering graduates are expected to be highly educated and have a large range of skills. *The Engineer of 2020: Visions of Engineering in the New Century*, a report by The National Academy of Engineering released in 2004, attempted to get ahead of a changing world by envisioning attributes that would be vital to engineers, such as strong analytical and creative abilities, as well as soft skills like leadership and communication [1]. There has also been a growing movement across colleges and universities to promote innovation and entrepreneurship, with the U.S. government having recognized the increasing importance of cultivating these values in students [2]. The National Academy of Engineering, as well other organizations and researchers, have called for changes in engineering education to promote these skills with the goal of better preparing engineers for the future.

Makerspaces have been recognized as a possible method for promoting these skills, and have become increasingly common on colleges and universities over the past several years [3]. Makerspaces are facilities that supply users with various types of tools and materials, typically for use in prototyping and manufacturing. Users are free to design and build as they see fit, working on projects for class or themselves, and working individually or in groups. These spaces can vary considerably from one to the other in several areas. Some makerspaces, for example, include tooling designed for metal-working such as CNC mills and lathes. They may also differ in terms of organization. The makerspace at the University of Pittsburgh is led and run by student mentors; however, some may be led by faculty members or other staff. By having a place where students can work together and gain hands-on experience, these facilities bring together beneficial concepts of communities of practice and physical modeling [4].

Research has shown these facilities have a number of positive impacts on users. Retention rates increase when students are exposed early in their academic careers to team-oriented, hands-on design work [5]. Surveys have also indicated users feel these spaces had a beneficial effect on many traits critical to engineering, including design and problem-solving abilities, communication skills, management skills, and the ability to function as part of a team [4], [6]. While the literature on the effects of makerspaces has expanded significantly over

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the past decade, more research is still required to understand how makerspaces impact the students who use them, as well as how best to operate them.

Use of Makerspace for Teaching Statics

Students were tasked with designing, modeling, optimizing, constructing and testing a balsa-wood truss bridge in the makerspace. The bridge was to span 18 inches, be 5 inches wide, consist of two fixed-geometry main beams and consist of trusses, with fixed material geometry (i.e. cross-sectional area, not length). Bolts, washers and nuts were used to attach truss members to mimic pin joints used during the method of joints and/or method of sections analyses. A performance index (PI) in which the weight supported by the bridge, per the quantity of the weight of the bridges times cost of materials used, was introduced to provide a quantifiable metric of grading. The students were also tasked with writing a report, in which they provided justification of design considerations.

The students were first to design and optimize a truss structure to support a prescribed weight located at the center of the structure; optimization was focused on maximizing the PI by reducing the denominator. They had the ability to use computer-aided design tools, such as Matlab and Solidworks, to expedite the analysis portion. Once a design was decided upon, they constructed a prototype and tested the performance, until failure of the structure. A post-mortem analysis was performed, in which the students updated their designs. From there, they were able to repeat the prototype construction-testing-redesign cycle until they were satisfied. Once a final design was determined, they proceeded to final testing.

The other section of the course was given the same project description and deliverables, however, they were tasked with constructing a numeric model in Solidworks to validate and optimize their design in lieu of prototype construction and physical testing. The grading metrics (i.e., PI and report), were still included, with the latter being the basis of comparison between the two sections.

II. Methodology

Our preliminary study collected a mixture of both quantitative and qualitative assessments. At present, a portion of the data has been analyzed, specifically qualitative assessments. The qualitative data was acquired from three sources - a survey given mid-project, a survey given after completion of the project, and an open-ended reflection question given later in the semester. Both surveys were distributed electronically through Qualtrics, the university-approved platform. The mid-project survey was comprised of two open-ended questions asking students their thoughts about using the makerspace for the statics class and if there were any skills they hoped to learn or improve upon by using it. The post-project survey was comprised of three open-ended questions asking students if the space contributed to their understanding of statics and mechanics and whether any cultural or environmental aspects of the facility contributed to their creativity or other professional skills and abilities. Finally, the reflection question requiring a written answer was distributed in class near the end of the semester and was collected within the same class period.

For this WIP, a question from the mid-project survey was selected for analysis, which asked students, “What is your perspective on, or how do you feel about, using the makerspace for this course?” The results were analyzed using a coding scheme following a procedure recommended by Creswell [7]. The final themes presented in this paper emerged from the data itself, and were not determined a priori. To increase reliability, two researchers were involved in creating the coding scheme and content-analyzing student responses.

III. Results & Discussion

The coding scheme developed for analyzing the previous question is shown below in Table 1. This scheme was jointly developed by two analysts after they individually reviewed all student responses. It was found that student feelings towards use of the makerspace for the statics course could be broadly categorized as 1) beneficial, or 2) concerning or of limited value to students.

TABLE I. Coding Scheme

CATEGORY DESCRIPTION	CODE
Beneficial	
Opportunity for hands-on engineering; application, reinforcement and translation of concepts to real-life scenarios	HANDS-ON
Beneficial experience, adding value to learning	USEFUL
Enjoyed the experience of doing project at makerspace	FUN
Good alternative to traditional teaching methods	NONTRADITIONAL APPROACH
Concerning/Limited Value	
Overwhelmed with amount of work required in makerspace; time consuming; couldn’t coordinate with others	TIME CONSUMING
Learning theory is more rewarding than practical experience makerspace offers; prefer traditional teaching methods	CLASSICAL APPROACH
Makerspace offered limited mentors, hours of operation, tools, or training	SPACE

After development of the coding scheme, the student responses were independently coded by each analyst, and final codes were assigned after discussion and consensus by the analysts on each student response. The percentage of each code category found in the data was then calculated. There was a total of 47 responses to this question out of a class size of 60, yielding a strong response rate of 78%. These results are shown in Fig. 1.

It can be seen that more codes exhibited feelings of “beneficial results” towards using the makerspace for the statics and mechanics course, versus feelings of “concern or limited value,” with 75% (n = 52) of assigned codes aligning with benefits and 25% (n = 19) indicating concern or limited value. The two most prominent categories across all responses were "Hands-On" and "Fun", each appearing in 40% (n = 19) of all responses. Many students appreciated the experience of actually designing and building and being able to use what they learned in the classroom in a real-world application. Many students also found using the makerspace to be an overall enjoyable experience. Continuing with positive responses, the categories "Nontraditional" and "Useful" each appeared in approximately 15% (n = 7) of student responses.

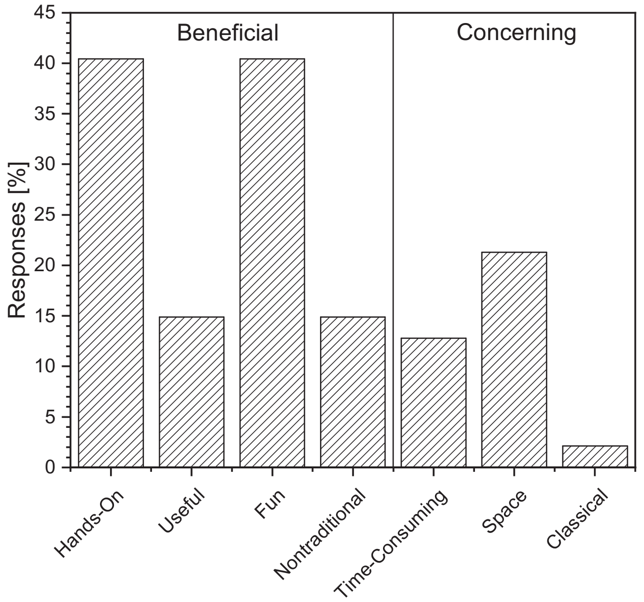

Fig. 1. Categories found in n = 47 student responses.

These students seemed to enjoy the change of pace and working outside the classroom. This student's response was interesting as it touched on the three main "beneficial" categories found in the data:

> "I really enjoyed using the makerspace for this course. I think the hands-on element really contributed to my understanding of what we learn in class. I also really liked that the bridge building assignment took the place of a homework assignment."

While fewer in number, student responses did indicate a level of dissatisfaction or concern with the use of the makerspace for the course. The largest category in this area was "Space", found in 21% of all responses. This was interesting because these feelings were directed towards the aspects of the makerspace as opposed to the bridge project itself. The two most noted aspects were the lack of access (i.e., the space is not open on the weekends), and the lack of usable tools (i.e., damaged or missing). Unexpectedly, the second most common category in this area was "Time-Consuming". Typically, the project(s) assigned for this course are theory-based and require no physical prototyping or construction. In comparison, the bridge project required a significantly larger time commitment. Finally, the "Classical" category was exemplified in the following response:

> "I felt like the time I spent building could have been spent learning the actual material."

It was not expected that every student would appreciate the hands-on aspect of the project, but it was surprising that students may have felt little to no gain from the experience, including decreased learning.

IV. Conclusions & Future Work

The use of a makerspace in the Statics class is providing us with an opportunity to understand and quantify the impact of the makerspace on the learning of statics by undergraduate engineering students. We are utilizing quantitative and qualitative surveys to determine the impact on student perspectives on their learning. In this paper, we focus on a question from the mid-project survey that assesses the perception of students who used the makerspace for the course. We had a strong response rate of 78% that supports the results we have for this paper. About 75% of the assigned codes indicated that the experience at the Makerspace was beneficial. They mostly reported the entire experience to be enjoyable and/or liked the hands-on nature of the project. Twenty-five percent (25%) of the assigned codes were associated with concerns, including the resources available in the space or the use of a new, non-traditional approach. Some students also found the project time consuming.

As part of our ongoing research, we plan to analyze the responses from another mid-project survey question as well as post-project survey questions. For example, the students' perspectives will be explored based on the skills they expected to gain from the makerspace. We also intend to examine whether the students felt the makerspace experience enhanced their understanding of statics using the post-project survey. This, combined with the quality of their design reports, will be used to make an overall assessment of the impact of the Makerspace on student learning and achievement.

In addition to this, we are interested in understanding the environmental and cultural aspects of the makerspace and its relationship to the professional learning process. This learning process includes professional development related to creativity, problem solving, and other professional skills. This analysis would be crucial in understanding more specific aspects of the learning that can be gained from makerspace use.

Finally, the instructor of the course plans to continue with using the makerspace for the course next fall, but with some changes in the structure of the project. Further, he will be using the results from this analysis to fine-tune the approach so that the students have a more enhanced learning experience from this project.

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