Board 53: Program to Integrate Mobile, Hands-on Experiments into the ME, AE, and ECE Curriculum

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Abstract

This research effort builds off of earlier work that made extensive use of hands-on mobile experiments in the ECE Curriculum. Small, inexpensive platforms were developed which, when combined with student-owned data acquisition hardware and laptop computers, could be used to conduct experiments without the need for a dedicated laboratory classroom. Thus, the hands-on experiments could be conducted in traditional lecture classes, or even remotely in student dorms and apartments. The goal of this research effort was to extend the pedagogy of hands-on learning into the ME and AE curricula, tackling mechanical and thermal applications. This paper gives an overview on those activities as well as efforts to assess the effectiveness of the learning enhancements. Furthermore, because the hands-on experiments are often used in a collaborative way in student teams, the research has also studied the role of gender and ethnicity in the student teams, developing best practices for building effective teams formed from diverse students.

1. Introduction

Laboratory experiments form one of the foundational experiences for all engineering students. Well-designed laboratory experiences can make engineering concepts come to life, giving students a real-world confirmation of the theory and concepts from lecture classes. Conversely, the effectiveness of hands-on learning can be reduced if there are inadequate levels of student engagement and reflection [1] - [3]. Due to advances in portable data acquisition devices, laptop computers, and an array of affordable sensors, there is an unprecedented opportunity to bring hands-on experiments out of the centralized labs, and into lecture classrooms, and even student dorm rooms. While such mobile hands-on experiments have had substantial inroads in the fields of electrical and computer engineering (ECE) education, dissemination of these ideas to other fields has been slow to materialize. This research is focused on extending hands-on learning into the disciplines of mechanical engineering (ME) and aerospace engineering (AE).

Educational experiments in ME and AE labs are primarily conducted in centralized labs with student access limited to 3-hour time periods. Making experiments more portable and affordable allows them to be used in different settings such as classrooms and dormitories, but there are significant challenges. Many ME and AE experiments require moving parts, fluid flow under pressure, structures, and thermal effects all at a scale such that students can see, touch, or hear the physical phenomena being investigated. Hands-on learning in ECE, by its nature, involves much smaller platforms that are very easy to instrument and to obtain data. This research builds upon the authors' previous work in hands-on pedagogy in ECE courses and seeks to apply it to new platforms designed for ME and AE subjects.

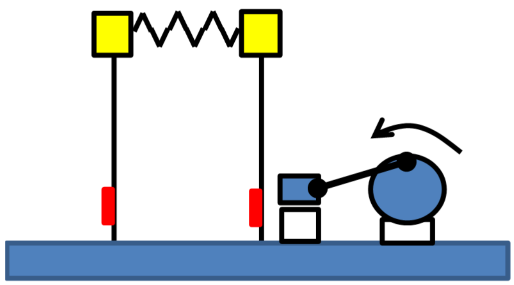
Among the research questions that are being addressed several stand out: Which topics have the greatest potential for enhancing educational outcomes through hands-on learning? What is the impact of the experiments on student performance, on student interest and confidence in the subject matter, and on long-term retention of the knowledge? Do these experiments have a positive impact on students from underrepresented groups in terms of performance, student interest, and retention? Since hands-on education is often associated with collaboration and group work, what are the best practices for impromptu team work, especially in the context of diversity and underrepresentation in these student groups?

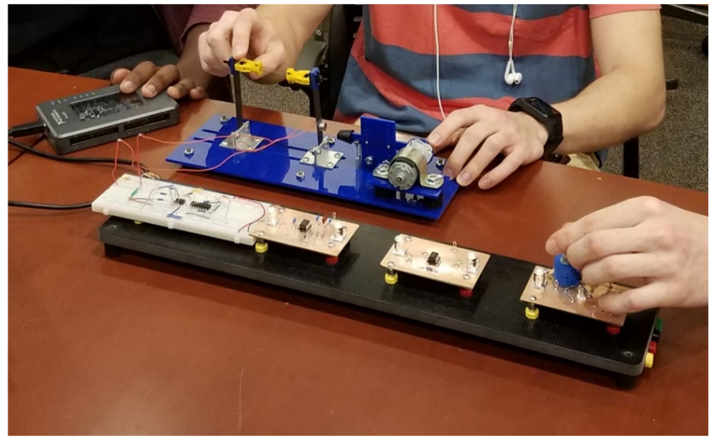
To address these research question, our work has several objectives. One goal is to develop experimental platforms and supplemental materials to support the learning of basic concepts and higher-level thinking processes in ME and AE courses. Part of this effort entails designing short learning experiences that are well thought out, and which involve adequate levels of engagement and reflection.

2. Development of New Platforms and Learning Experiences

The experimental platforms that have been developed under this research program have fallen into several categories. Several are designed to be used in traditional lecture classes to supplement lectures with hands-on learning incorporating physical hardware. Ideally, these platforms are small, low-powered, inexpensive, and highly portable so that students can work in groups of two or three and engage with the learning platform on a deep level. This is the model used in the ECE curriculum at the authors' institution, and which has been reported in several papers [4]-[8]. In other cases, the platforms are large enough and/or require significant instrumentation and power that they are better suited to demos conducted by an instructor at the front of a lecture class. While still portable from classroom to classroom, it may be impractical to make enough of them to distribute among the students. Although still effective, other researchers have found that the student experience and satisfaction are higher when the students can touch the experiments themselves and carry out the procedures themselves [9]. Another category of hands-on learning experiences developed under this program includes design experiences that can be used to give students a design-build-test experience. A very important aspect of the research has been that it has enlisted student teams as partners in education [10] and [11]

As an example of a small portable platform created for hands-on learning purposes, a two-degree-of-freedom mechanical vibration apparatus was developed. As shown in Figure 1, the device consists of two oscillators connected by a helical spring. The device is unique in that the excitation is supplied by non-contacting magnets, one of which can be oscillated harmonically by a DC-motor driven Scotch yoke mechanism. This means that the device can be used to study both free response and forced response, making it much more versatile. The device is also modular, so that it can be used to study either single-degree-of-freedom or two-degree-of-freedom systems. This device can be used in system dynamics courses and in vibrations courses in ME and AE. The force amplitude and frequency can also be adjusted to examine nonlinear vibrations to show advanced undergraduate or graduate-level concepts.



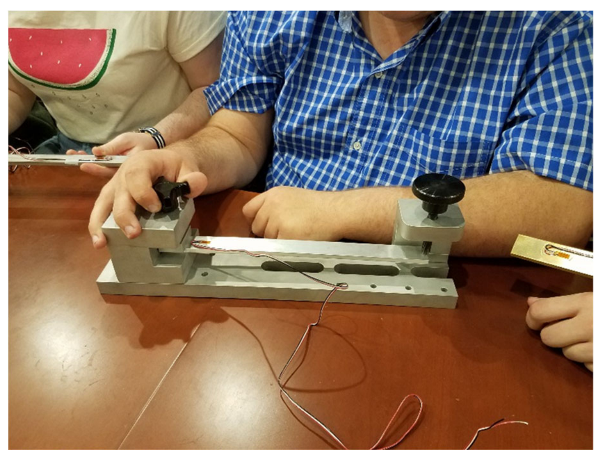


(a) (b)

Figure 1: Two-degree-of-freedom vibration platform. (a) Schematic showing key components, (b) photo showing platform with supporting electronics and data-acquisition device

Another example of a portable hands-on learning platform is the bending-beam apparatus shown in Figure 2. This device was designed and fabricated by a student team charged with the creation of a platform that could be used with many different beams of different dimensions and materials and could supply either prescribed displacements or prescribed loads. The device is equipped with strain gauges so that quantitative measurements can be gathered and displayed in real time in the classroom. These quantitative measurements can also serve as the basis of real-world data that students can analyze outside the classroom. The prototype shown in the figure is still fairly heavy and so it was used in a “demo mode” in an undergraduate Strength of Materials course that is required of AE, CE, and ME students. This device as well as some preliminary assessment results are presented in [12]. On-going work is focused on making the device lighter in weight and refining the procedures to produce enhanced comprehension from students.

(a)



(b)

Figure 2: Bending-beam apparatus. (a) schematic diagram, (b) photo showing device in prescribed-displacement mode.

A new design class in ECE served as the motivation for another hands-on learning experience. The ECE design course is meant as a pre-requisite to the capstone design class and covers both the design philosophy and a prototyping experience. As an example of a design experiment, the ECE students were asked to design a safe that could be opened using an electronic keypad, a wireless link, Bluetooth connection, or a combination of the above. Students, working in teams of four, designed their safe to meet certain specifications. They had to generate a working prototype, which required them to use tools in the makerspace. An example of a student-generated safe is shown in Figure 3. In this case, while the student teams in the design class created their physical device, the design assignment was carefully developed by a team of students who ensured that the device requirements were realistic and achievable in a 4-week period of time.

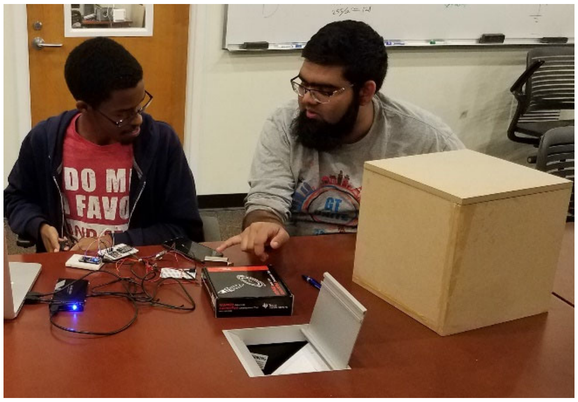


Figure 3: Student design team working on safe (wooden box on right)

3. Team Dynamics Research Study

Hands-on learning activities are very often carried out in small groups of students. These groups are often assembled in an impromptu fashion, without a lot of thought into group composition. Teamwork is found throughout the undergraduate curricula in virtually every engineering major, so although hands-on learning is a primary motivator for our work, the research effort could have far-reaching applications.

Teamwork is a vital skill for engineering students to develop while they are undergraduates since these skills are increasingly important in industry and graduate school. When teams work well together, they can be highly effective with all members contributing equally and with the team as a whole being more effective than the sum of its parts. However, when teams do not function well, they can be the source of considerable stress and feelings of exclusion. This is especially true in engineering for female students and students from underrepresented minorities (URMs) [13]. So, while teamwork and collaborative learning are almost universally viewed as positive aspects of the undergraduate engineering education, they can do a lot of damage if they are not managed properly.

Although a lot has been written about team building and team dynamics in education, relatively less has been written about the experience of URMs and females in team work – especially in groups that are temporary, informal, and/or impromptu in nature such as those often used in active learning, problem-based learning, and hands-on learning. Such groups are often formed without regard to student background, skills, or personalities; rather they are formed based on students who happen to be sitting nearby one another. Gender differences in small groups, for example, have been shown to diminish the effectiveness of teams and groups formed for active learning [13], [14]. For “male-typed” tasks, male students in mixed gender groups tend to dominate discussions. Unbalances in participation have been shown to greatly diminish the effectiveness of the learning environment [15]. Another observation repeated by several researchers is that the role and function of female team members in engineering teams often falls into gendered categories such as data recording or communication [16], [17]. For this reason, many researchers have recommended that URMs be divided among teams such that they are not isolated in groups [13], [17], [18]. However, such measures are not always sufficient, and are not always practical when the teams are not carefully established by the instructors, but are the result of proximity of desks in a classroom. Moreover, not all forms of underrepresentation are equally visible or known to instructors, such as LGBTQIA students [19].

Under this research program, we studied team dynamics in heterogeneous groups and formulated best practices that resulted in better outcomes. Some interventions are relatively minor; for example, many teams degenerate in their interpersonal relations through mistaken assumptions. Students that are struggling with the material are often misidentified as “social loafers” [20]. Another very important consideration by faculty is the nature of the task given to teams. Students must feel that the interaction between them and their groupmates is *productive for them and valued by the instructor* [19]. Forming “jigsaw” activities where students independently master different subtopics before interacting in their groups has also been shown to be much more effective than “single group” activities [15], also providing each student the opportunity to engage with other subtopic “specialists” in the other groups.

In the new junior design course, specific activities on teamwork training activities were conducted using the three major course projects. Students were assigned to teams for the first project based on balancing their skill sets across the teams. Prior to the first project, students did interactive activities in active listening and shared leadership, and wrote team contracts that discussed communication channels, tasks, meeting times, as well as group behaviors that each of them dislike (awareness of the undesirable behaviors is the first step in avoidance). After the project, each student did a reflection of the teaming and identified any dysfunctional behaviors. They had training on conflict resolutions and how to have “difficult conversations” using role-playing of interventions that were based on the dysfunctional behaviors that they identified. Students kept the same groups for the second project, but were asked to rewrite the team contract taking into account the dysfunctional behaviors that they had noticed on the first project and when enacting conflict resolution. The second project was followed by a survey of dysfunctional behavior and team reflection. Taking these two experiences with the same teams, the third project had teams that were completely new (no team had members who had been teammates in the first two projects). The goal was to see if the students could translate their new teaming skills to a new situation.

Inclusivity by all members was stressed during the active listening, brainstorming, and conflict resolution sessions. In brainstorming, everyone in the team is allowed uninterrupted time for briefly describing their ideas with the motivation being that every voice should be heard. For example, the three most common dysfunctional behaviors noted (though these were at a very low rate) were one or two people dominating the meetings; most of the work done by a few of the people; and some people not participating or showing up to meetings. The class discussed possible reasons that prompted these behaviors and drew some possible causality between the behaviors that drew attention to the importance of inclusivity. For example, if one person's dominance of the ideation session was perceived to be in excess of their expertise compared to others, then the teammates who felt excluded in the conversations might not be as motivated to work on those parts of projects. In the role-playing exercise, students were asked to pick roles and use one of the motivations that were identified by the students.

The initial plan was to find intervention methods that instructors could use when they notice that some students were being excluded. The students, though, felt that intervention methods targeted, at specific students would be counterproductive and requested that the inclusivity be part of the team expectations and training, rather than a targeted intervention.

In Fall 2018, the authors administered a pilot survey designed to validate the results of Zhu and Meuth's [21] survey of communication, teamwork, and motivation in inter-disciplinary engineering projects. In addition to some demographic questions and questions about students' motivation for studying engineering, the respondents were asked to rate their perception of their own skills and their opinions of the importance of skills including self-confidence, leadership, public speaking ability, as well as math, science, communication and business skills. Additionally, respondents were asked to rate their *degree of confidence, motivation, how successful they would be, and their degree of anxiety* about the following tasks:

- Conduct engineering design
- Identify a design need
- Research a design need
- Develop design solutions
- Select the best possible design
- Construct a prototype
- Evaluate and test a design
- Communicate a design
- Redesign
- Work as part of a team

Thirteen out of 33 students responded to the pilot survey, and responses showed a high degree of consistency. With this in mind, the survey was used at the conclusion of the Spring 2019 semester with two classes of approximately 66 students total. The authors also plan to administer focus groups with samples of those students in order to gauge their opinions on the value of the team building exercises and of the hand-on labs designed to teach design thinking.

4. Concluding Remarks

The research effort described above has several different aspects motivated by the desire to improve the learning experience for all undergraduates, while being inclusive towards students of different backgrounds, gender, and ethnicity. The authors feel that hands-on learning offers tremendous promise to make difficult concepts understandable to a wide range of students. Hence, a big part of the research effort is in development of portable, affordable, mobile experimental platforms suitable for ECE, AE, and ME students. But, like any form of active learning, the effectiveness of hands-on learning depends on execution as much as on hardware. Studies of team dynamics in small impromptu groups has been very important in determining root causes for poor dynamics. Efforts to improve and head-off team-based problems have led to the development of a set of best practices that will be tested in future work.

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