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Development of Team-Based Hands-On Learning Experiences

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Development of Team-Based Hands-On Learning Experiences

1. Introduction

Student learning is known to be enhanced when students are able to engage with new material on many different levels. Active learning and other evidence-based learning strategies promote a deeper understanding of complex material because students are forced to think about the material and apply fresh concepts to new situations [1]-[4]. Hands-on learning is a particular form of active learning where students engage in a topic in several different ways including sight, sound, and tactile sensory input [5]-[8]. While engaging multiple senses, students can interact with other students and reflect on how their understanding of some topic can be used to explain a particular phenomenon. When the hands-on experiences are well-designed, students can go beyond the lecture material and observe how theory is manifested in the real world. Unfortunately, many engineering experiments are costly and complicated, restricting their use to instructional laboratories. Another common occurrence is that engineering lab classes often encompass a wide variety of learning objectives [9]. For the purposes of ABET evaluation and assessment, it is not uncommon for lab classes to be used to assess student outcomes beyond experimentation, and including student outcomes having to do with communication, teamwork, ethics and professionalism, and life-long learning. Communication, in particular, is a component in lab classes that often results in the majority of time being spent on the preparation of written reports rather than on actually doing the experiment or in reflecting on the results [10]. As a result, students in dedicated lab classes often experience dissatisfaction not because they dislike hands-on learning, but because they are overwhelmed by other components and deliverables of the lab class.

At the other end of the spectrum, some hands-on learning has focused on very simple manipulators that are designed to provide a qualitative reinforcement of concepts. One of the goals of this NSF IUSE project is to create simple hands-on experiments that can be highly portable for use in lecture rooms, laboratories, or even dorm rooms but can still go beyond qualitative demos and yield quantitative confirmation of engineering models. Due to advances in portable data acquisition devices, laptop computers, and affordable sensors, there is an unprecedented opportunity to make hands-on engineering experiments a reality. Because these hands-on experiences can be interjected into standard lecture classes, they can be much more focused on one or two concepts and can forgo other objectives of laboratory courses.

The use of analog circuits constructed from breadboards and electrical components (resistors, capacitors, inductors, op-amps, etc.) has already made considerable inroads in electrical engineering education [5], [11]-[13]. One goal of this project is to bring equally effective and affordable solutions to the fields of mechanical engineering (ME) and aerospace engineering (AE). However, ME and AE experiments can be more difficult to develop because they may require moving parts, fluid flow under pressure, structures, or thermal effects, all at a scale that students can see, touch, or hear the physical phenomena being investigated.

Among the research questions that are being addressed several stand out:

1. Which topics have the greatest potential for enhancing educational outcomes through hands-on learning?
2. 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?
3. Do these experiments have a positive impact on students from underrepresented groups in terms of performance, student interest, and retention?
4. 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, the research 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 involve adequate levels of engagement and reflection. We also seek to develop appropriate assessment techniques to measure the effect of the hands-on experiments. Finally, we are developing strategies for managing impromptu team-work between small numbers of students so that all team members are equally engaged and included in the learning process. This is particularly important for female and underrepresented groups within STEM fields.

2. Development of New Platforms and Learning Experiences

Many universities and programs have developed hands-on learning experiences that have been very effective for their students. From the perspective of "hardware," one could argue that there is a lot of duplication and similarity in experiments from school to school. In a way, the situation mirrors the situation of multiple textbooks covering virtually the same subject material and differing mainly in style or in the choice and number of examples and homework problems. But given the similarity in the textbooks, there has always been a rich and dynamic space of innovation by individual instructors in how they use their textbooks within their courses. And, of course, new textbooks are published each year, with supposed improvements in presentation, or in online functionality, or in supporting materials, etc.

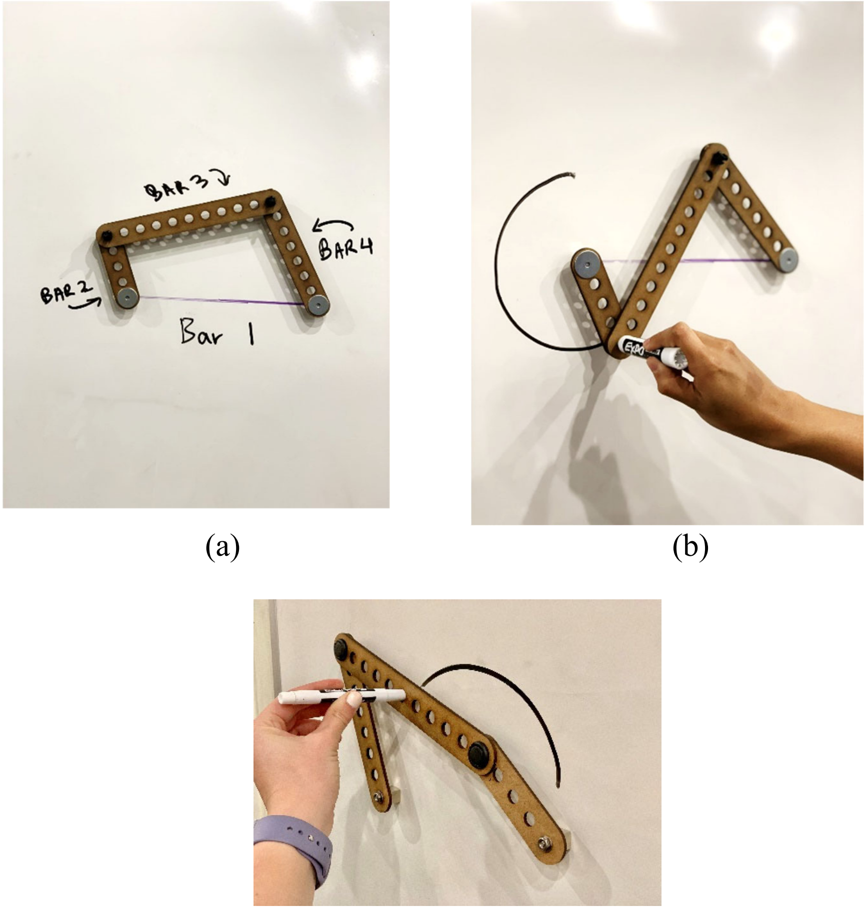
One way to appreciate the broad range of hands-on learning experiences is to review the YouTube channel "Mobile Hands on Learning STEM" [14] that archives many descriptive videos from a variety of engineering fields. It can be seen that there are many different hardware platforms that have been developed. But, equally important is to see how the hands-on learning experiences are integrated into various courses and curricula. It is also seen that, in some cases, students must first expend effort in the design and construction of the hands-on learning platform. In other cases, the experiment is more of a turn-key apparatus which serves to produce realistic signals and measurements that can be compared with theory.

Several types of experimental platforms have been developed over the course of this research program; see, for example, [6]-[8]. Hands-On Learning experiments for circuits and electronics have reached a mature state of development. Such experiments are compact, affordable, and measurement systems are very accurate and capable of supporting careful comparisons between theory and experiments. Because of the mature state of development, these experiments are an excellent starting point to focus on the pedagogy and the learning environment surrounding hands-on learning. In section 2.7, we will describe efforts used in studying the team dynamics for these learning experiences.

2.1 Four-bar mechanism

In previous work, we have discussed the role of student teams to develop hands-on learning material [7]. Students are excellent partners in this process because they are very familiar with the impediments to learning certain topics and are creative in suggesting solutions. One topic that many students struggle with is the kinematics of linkage mechanisms. In particular, they have difficulty in picturing how the mechanisms move, and how it is possible for some links to have 360-degrees of rotation, while other components rotate or rock back and forth. There are many ways to address this difficulty, including videos and through the introduction of real-world mechanisms that students can touch and feel. But such mechanisms miss out on an opportunity for students to study the design and synthesis of mechanisms to accomplish different types of motion. At the authors' university, the ME curriculum previously required a course on the analysis and design of mechanisms, but that course was removed from the required curriculum two decades ago. Hence, a student design team was tasked with developing a mechanism that would support both visualization and design. The design of the mechanism had to be very affordable and small enough that it could comfortably fit on a desktop or table where it could be shared by two or three students. And, to support the design aspect of the assignment, it had to be easily assembled and disassembled and had to allow variable link lengths. The students first considered a slider-crank mechanism, but then settled on a 4-bar mechanism because of the much larger design space.

Figure 1 shows the final design of the four-bar mechanism. The device consists of two stationary pins and 3 movable links. The fourth "link" in the 4-bar mechanism is supplied by the stationary frame. The moving links are made from wood that was cut using a laser cutter. It is seen that each moving link has a series of holes equally spaced along the length; various link lengths are achieved simply by pinning the links together using different holes. Spacers are strategically used at the pin locations to facilitate the movement of links in front of or behind one another. A unique feature of the design is the use of strong permanent magnets to secure the two stationary pin joints. This allows students to adjust the pivot points in order to explore how their location influences the type and range of motion. Furthermore, the students discovered that the magnets made it possible for the 4-bar mechanism to be affixed to the white boards on the walls of standard classrooms on campus. (According to a survey conducted by the students, approximately 90% of the whiteboards on the authors' campus are backed by a ferro-magnetic material.)



(a) (b)

(c)

Figure 1. Final design of the four-bar mechanism.

The 4-bar mechanisms can be used by an instructor in front of a classroom, or can be used by small groups of students each using a portion of the whiteboards in front and/or along the sides of the classrooms. In order for the mechanisms to be used at desk stations, the students also envisioned that the mechanism could be affixed to small, portable marker boards, which worked very well.

In order to increase interest in the hands-on activity, the 4-bar mechanism easily lends itself to a design activity. Figure 2 shows a three-position synthesis exercise that can easily be incorporated into a 50-minute class. Students are given a large sheet of paper that has the follower link (bar 3 in Figure 1(a)) in three positions (Link 3 is shown as a triangle in Figure 2). Students need to find the locations of fixed points **O2** and **O4**, and the link lengths L2 and L4 that allows the given motion. The technique is based on the observation that the 4-bar mechanism causes points **A** and **B** to move along circular paths. The three positions of point **A** uniquely identify the circle on which pin **A** travels; in particular, it determines the location of the center **O2** and the radius, L2. Likewise, the three positions of point **B** uniquely determine a circle with center at **O4** and radius L4. By placing the pins **A** and **B** through various holes in links 2 and 4, and by moving the magnetic rotation points to the locations **O2** and **O4**, the students can check that their mechanism indeed moves through the three desired positions. Furthermore, by placing a dry-erase marker through the various holes in link 3, the students can trace out the “coupler curves” that a 4-bar mechanism can generate.

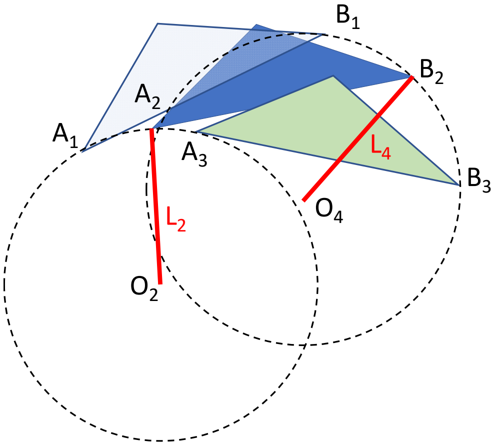
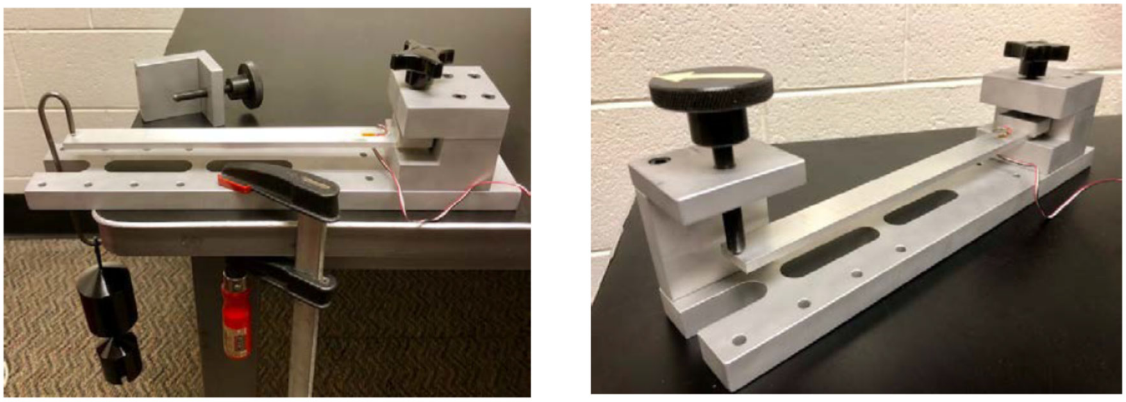


Figure 2. Three positions of a triangular follower link. Pin **A** moves through locations A_1, A_2, A_3, while pin **B** moves through locations B_1, B_2, B_3, respectively.

When the 4-bar hands-on activity is conducted within a dynamics class, the linkage designed using the three-position synthesis technique can be the starting point to a more elaborate set of assignments. Students can analyze the full range of positions using MATLAB [15] or using a CAD program such as SOLIDWORKS [16]. The mechanism can also form the basis for velocity and acceleration analyses if the students are given input parameters of crank (link2) rotation rate and crank angular acceleration.

2.2 Bending-torsion beam experiment

In previous work, the authors presented a portable bending beam experiment that was very effective in clearing up student’s confusion about stress and strain [8]. The device was designed to explore the role of material properties in the deflection of cantilever beams of equal cross-section and length. The apparatus is shown in Figure 3. When configured as in Figure 3(a), the beam can be loaded by different weights hanging from the tip. Through use of strain gauges at the beam’s base, the students can observe that stresses on identical beams depend only on the applied load, while the strains depend on the material. When configured as in Figure 3(b), the beam can be given prescribed tip displacements. In this case, students observe that the strains at the beam root do not depend on the material, but the stresses increase with increasing elastic modulus. Through use of pre-test and post-test concept inventory quizzes, the effectiveness of the hands-on learning demonstration was measured.



(a) Applying tip loading using weights (b) Applying tip displacement

Figure 3. Desktop beam bending apparatus.

While the platform worked fairly well, there were some shortcomings that limited the ease of use. First, the measurement of tip displacements had to be estimated by counting the number of turns in the screw at the tip of the beam (see Figure 3(b)). Second, when the beam has an open cross-section, transverse loads will lead to both bending and torsion. Hence, an accurate way of measuring the beam deflection and twist was needed.

At the authors' institution, AE, ME, and CE students take the same, general strength of materials course. For this introductory course, symmetric cross sections are adequate to describe and reinforce foundational material in beam bending. However, AE students (and advanced ME and CE students) have a greater need to study beams with a variety of cross-sections that are more prevalent in lightweight folded-sheet and aircraft structures. Beams with unsymmetrical, thin-walled sections behave quite differently than beams with simpler solid, symmetrical cross sections and can develop significant shear stresses in addition to the more familiar axial stress, both of which are induced by the variation in bending loads along the beam. In thin-walled sections, the shear stress is described by its resultant called the shear flow (with continuity properties analogous to the flow of an incompressible fluid within channels defined by the edges of the thin walls). This shear flow in open thin-wall open sections leads to extremely low torsional stiffnesses which in turn can lead to unexpectedly large twisting if the beam loads are not applied so that they act through what is called the "shear center" of the section. In addition, if the load axes do not coincide with axes of symmetry for the section, very significant cross-axis deflection can result, especially in cases where the bending stiffnesses about the orthogonal axes are quite different. In many situations, these factors can lead to behaviors that are highly nonintuitive and contrary to what might otherwise be expected. In such cases, confirmation of theoretical results by simple experiments can be of great importance in the classroom.

2.3 Shear center

The shear center of a cross section is the point on the section where the transverse loads must be applied to be statically equivalent to the shear flow that they induce in the section. Thus, if the loads are not applied through the shear center, they will induce a twisting moment in addition to the more obvious bending moment. Open thin-walled sections are sections in which the walls do not fully enclose an area (called a cell), and these sections have dramatically lower torsional stiffnesses than sections with one or more closed cells. Common thin-wall open-section shapes include L-shape (angle section), C-shape (channel section), T-shape and Z-shape sections. The C-section is unusual because the shear center lies to the left and often well outside the section itself (when imagined as the letter C). This can lead to unusual requirements of special loading fixtures to ensure that the beam loads are applied at an offset to the section centroid that typically defines its axis.

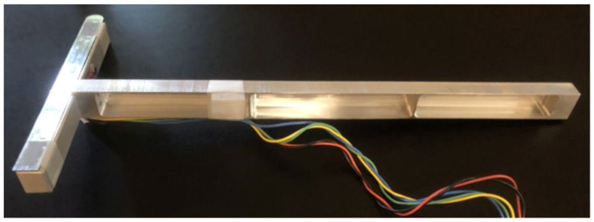


Figure 4. CNC machined C-section beam and tilt sensor fitted on cross-bar

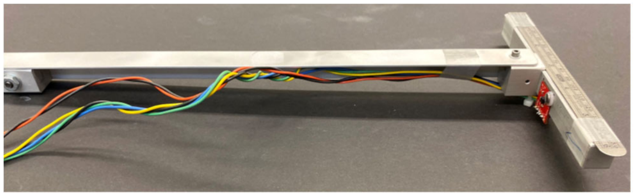


Figure 5. Extruded angle section and tilt sensor (red) fitted on cross-bar

In our earlier experiments, we employed CNC machining to fabricate desktop-scale thin-wall beams with C-sections as shown in Figure 4, and we also used extruded angle sections shown in Figure 5. These beams are clamped into the platform shown in Figure 3, and a tip load can be applied at different points across a small cross-bar fitted to the tip as shown in Figure 6. This allows a fixed tip load to be applied at different degrees of eccentricity about the beam axis so that a twisting moment is created along with the usual bending moment. In response, the beam develops not only a vertical deflection at the tip, but it also twists quite noticeably.

Using an inexpensive Micro-Electro-Mechanical System or MEMS 3-axis inertial accelerometer (Analog Devices ADXL337 visible as red object in Figure 5) similar to those widely used in cell phones and smart watches, it is possible to create a sensitive tilt sensor by measuring the horizontal axis acceleration. In tests, the students place a small fixed weight at successive positions along the cross-bar and record the tilt sensor output using a National Instruments myDAQ [17] data acquisition device connected via USB to a laptop running a straightforward MATLAB program using the Data Acquisition toolbox. From these measurements a plot of the tilt sensor output versus the load position (Figure 7) immediately reveals the horizontal location of the shear center as the zero-crossing which defines the point where the vertical load can be applied without creating any twisting. Interestingly, the shear center location can be “felt” if one presses down lightly with a fingertip at successive positions across the cross-bar. This induces much less deflection when pressing at the shear center and this feels like the beam is much stiffer at this point! Having students “feel” the phenomena of a shear center helps them to understand it and also to appreciate its significance for structural engineering.

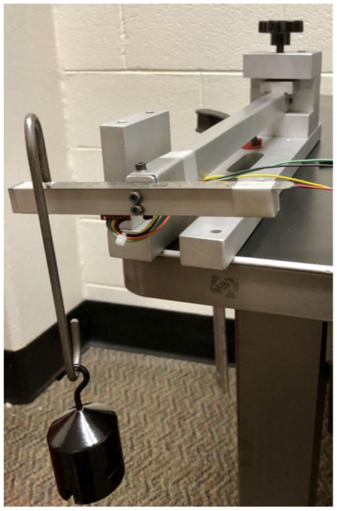


Figure 6. Shear center test setup.

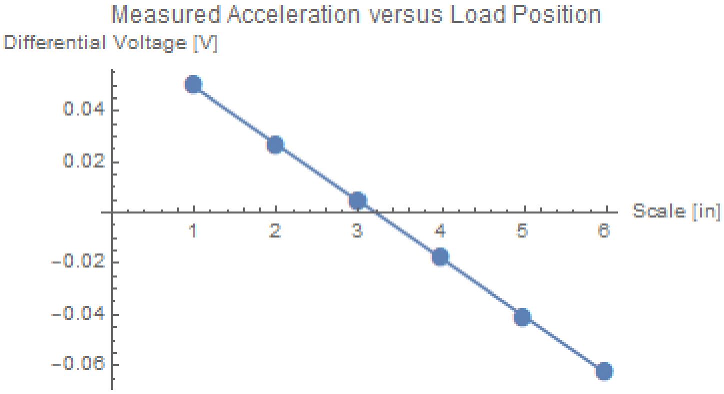


Figure 7. Twist versus tip load position on cross-bar; zero-crossing defines location of the shear center.

The CNC-machined C-sections are costly to make and require machining skills well beyond most undergraduate engineering students, so they leave the students a little less engaged in the process, even though they are surprised to find that the shear center lies outside the cross section of the C-section. In a significant development, we have been able to use high-precision 3D printing using ABS and nylon plastic materials to create a range of both open and closed thin-wall section beams with cross section heights and widths of up to 25x50 mm and wall thicknesses as small as 0.7 mm and length of up to 300 mm as shown in Figure 8. These are made directly from SOLIDWORKS [16] models created by students.

We have carried out shear center measurement experiments in the classroom with extruded aluminum thin-wall angle and CNC machined C-sections as well as 3D printed Z-sections. Even using these relatively small-scale models with simple, low-cost measurement systems, we have achieved errors of less than 5% between the measured and calculated shear centers.

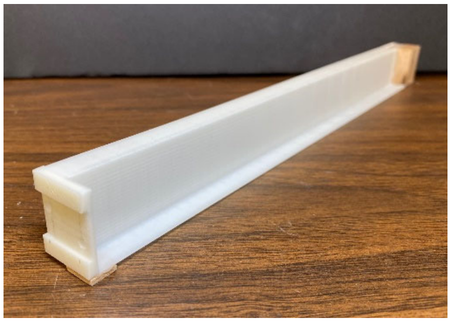


Figure 8. A 3D printed ABS plastic Z-section thin-wall beams showing integral tip plate for attaching cross-bar or optical target.

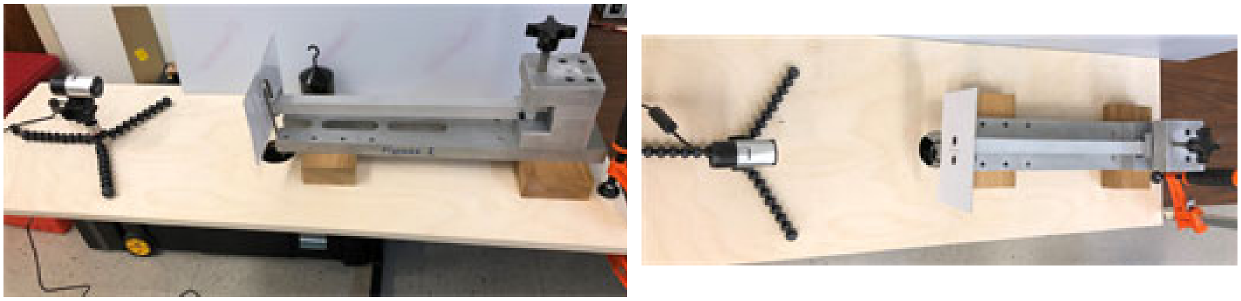
2.4 Unsymmetrical section beams

When the loading axis system for a beam is not aligned with an axis of symmetry of the cross section or if the section has no symmetry axis, the bending behavior becomes more complex due to the appearance of a non-zero sectional cross-bending stiffness in the governing differential equations as well as in the equation for the bending stress developed in response to the applied bending moments. Such situations are generally referred to as “bending of beams with unsymmetric sections” and these configurations are avoided whenever possible. However, they are difficult to avoid when designing thin-wall section beams for aircraft structures. They can also arise in industrial applications when designing low-cost, lightweight, thin-wall sections fabricated by folding narrow thin metal sheets to form beams.

The governing equations for the 2D lateral deflection of a beam with an unsymmetrical section consist of two coupled second or fourth order ordinary differential equations that are driven by bending moments applied about the two cross section axes (typically vertical and horizontal). When the beam loads are applied along only one of these axes (typically the vertical axis), the result will be not only a proportional deflection in the loading direction, but it will also be accompanied by a deflection in the lateral direction. Moreover, for certain types of cross sections, this lateral deflection may be significantly greater than the deflection in the loading direction. This can be counter-intuitive because if either of the loading axes is an axis of symmetry, there will be no lateral deflection at all, and this is, by design, the most common situation. This absence of a strong intuitive understanding can be a barrier to student learning, but it presents a good opportunity to introduce suitable desktop experiments to demonstrate and quantify this behavior.

One of the key objectives of our desktop experiments is to keep the costs and complexity as low as possible in order to allow wider deployment of the experiments and to reduce the learning curve required to understand the experiment. Moreover, the data acquisition and data processing should be implemented in a basic laptop computer using software with which the students are already familiar. There are a number of ways to measure deflections in two dimensions using both contacting and non-contacting methods, but we have found these to be far too expensive for the desktop experiments Instead we have developed a relatively straightforward method for measuring the 2D displacement of the tip of a cantilever beam using a low-cost USB webcam and readily available image acquisition and analysis software. For this purpose, we have focused on using MATLAB programming with the MALAB Image Acquisition and Image Processing toolboxes which are part of the general software available to our students [15-19].

Figure 9 shows a typical configuration for a desktop experiment with a cantilever beam mounted in a simple test fixture. An optical target is affixed to the tip of the cantilever, and a webcam is placed coaxially with the beam axis and pointed at the target so that the vertical and lateral tip deflections result in 2D movement of the target in the plane of the target. Unfortunately, this also requires that the apparatus be placed on a flat base that leaves the beam tip over the edge of the table (to allow the loading weights to hang below the tip) while cantilevering the webcam out further in front as shown in Figure 9(a). An alternate configuration could raise the beam testing apparatus and webcam high enough above the table top so that the loading weights can be suspended beneath.



(a) Setup on wooden platform cantilevered over table edge and ready to test using kg weight attached to tip behind the target

(b) View of test setup from overhead showing webcam aimed at tip target

Figure 9. Desktop setup for measuring 2D tip deflection using a USB webcam.

The optical target shown in Figure 10 consists of two small (12.5 mm diameter) disks spaced 25 mm apart with thin horizontal and vertical axes added to allow accurate positioning of the target. The targets are designed using basic graphics software (e.g., Inkscape [18]) and printed at 100% scale on a B/W laser printer. In calibration testing, these target dimensions were found to work well at focal lengths of about 250 mm, and targets with either a horizontal or diagonal axis alignment were found to perform equally for horizontal and vertical deflections with a resolution of 0.05 to 0.10 mm and an accuracy of 1-2%.

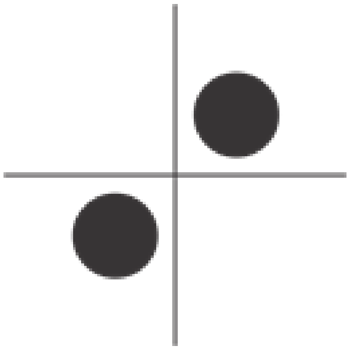


Figure 10. Optical targets with two 12.5 mm diameter disks separated by 25 mm.

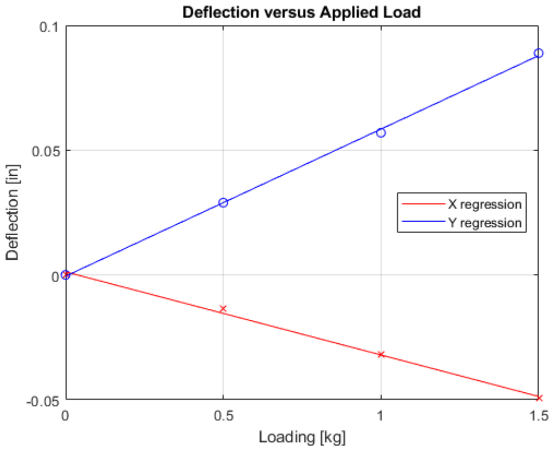


Figure 11. Plot of 2D tip deflection from tests of a 3D printed Z-section.

The image acquisition program allows the user to capture a wide view to set exposure and then define a region of interest (ROI) that includes only the target. The initial version of the software is used to acquire a reference photo images of the target along with a series of images and loading data during the test, and this is saved to a file. A separate image detection and tracking program is then used to read the images from the data file and track the target movement. This is done by first converting each true color image to a B/W image to provide consistent edge definition. The reference image is used to interactively measure the diameter of a disk in order to provide a suitable initial guess for the detection algorithm. The program then processes each of the images and accompanying loading data and produces a plain text (.CSV) output file of the target vertical and horizontal displacements and rotation along with a combined plot of the vertical and horizontal target displacement versus load, an example of which is provided in Figure 11. An option allows linear regression calculations as well.

The program uses the known disk diameter and separation between the disks and the measured pixel dimensions from the entire test to establish the calibration for each test. This has proven so reliable that the current version of the software combines these programs into a single image acquisition and processing program. Interestingly, the ability to measure tip twist angle could be used to replace use of the tilt accelerometer when measuring the shear center, but the complexity of mounting the optical target to allow tip loads to be placed at successive locations along the cross-bar has prevented this so far.

2.5 Design, Build, Test projects

The 3D printing of thin-wall beams has been so successful that it has led to a new series of desktop design, build and test (DBT) projects that we are currently evaluating. Since the high-precision 3D printing facilities are part of maker spaces accessible to ME and AE students that also includes general 3D printers, laser cutters, a water-jet cutter, and a range of woodworking tools, we are developing as part of the junior/senior level aerospace structural analysis course a project in which teams of students will design, build and test their creations of airfoil-like thin-wall beams with combinations of open and closed cells. The designs will be developed in SOLIDWORKS and the supporting analysis will be carried out in MATLAB and/or Mathematica [19]. Figure 12 shows one of the relatively simple 2-cell designs developed to test the process for measuring the shear center location and the ratio of vertical to lateral tip deflection (both independent of the material properties). Members of the grant team will then try to assess the impact of these DBT projects on student learning and course outcomes, independent of the instructor and team that designed the DBT project.

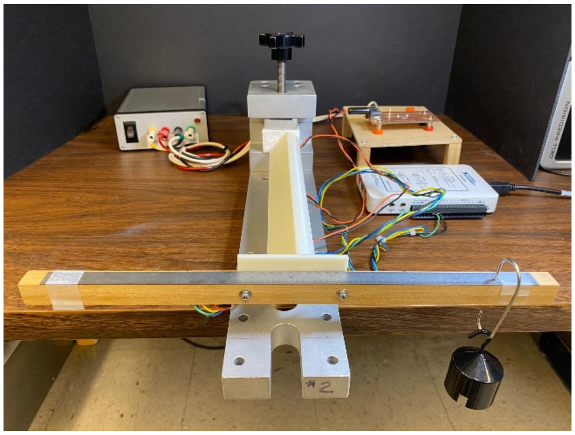


Figure 12. Shear center testing of a 3D printed 2-cell airfoil model.

2.6 Electric Circuits and Electronics

Hands on learning platforms for circuits and electronics are fairly well developed and have been used for several years at the authors' institution [5], [11] – [13]. The hands-on learning activities are designed to be completed within the time constraints of a 50-minute lecture period. One course that uses these hands-on experiments is a class offered by the School of Electrical and Computer Engineering for students in the other majors such as aerospace engineering, biomedical engineering, and mechanical engineering. Students purchase inexpensive lab kits that include breadboards, resistors, capacitors, inductors, and op-amps. Signals are measured through use of student-owned myDAQ devices and laptop computers. Students work in small groups of two or three students and these "teams" are formed informally, usually based on who is sitting nearby.

The hands-on experiments in circuits and electronics have demonstrated that they have the ability to increase student understanding of the theoretical concepts in the class. However, the experience of underrepresented groups (females and minorities) has not been thoroughly investigated. Prior work on the team-based projects in STEM fields have shown that URMs can sometimes feel uncomfortable depending on the makeup of the teams [20] – [25]. In many respects, the circuits and electronics class offers an ideal testbed for studies of how URMs feel when working together on experiments. The class enrolls approximately 500 students each fall and spring; approximately 25% of the students are female, approximately 8% are Hispanic, and approximately 5% are African-American. Up until now, students have not been given any special instructions on how the teams should deal with diversity and how to promote a comfortable, inclusive environment. Recent observations of team dynamics in this class have shown that female students are sometimes excluded from participation. It was also observed that two-person groups where both members were of the same apparent gender seemed to have less trouble working in close proximity to one another. This allows them to both engage more completely with the experiment, both in the construction of the circuit and in the measurement and analysis of the circuits. Conversely, two-person groups that were mixed in gender seemed to be more reluctant to work in close proximity to one another. Given the importance of learning the material and in learning how to work closely in diverse groups, the authors feel strongly that methods should be explored that can alleviate any sort of awkwardness that may be present in these impromptu groups.

In order to improve the experience of female students during the labs, the following intervention strategies are undergoing the IRB approval process, to be used individually or in tandem with each other:

- Announcing at the beginning of class that each student is expected to build a portion of the circuit and participate in reading and analyzing the data.
- Asking students to sign a mutual agreement at the beginning of class specifying that each member of the team will actively contribute to circuit assembly and analysis.
- Reminding the students during the lab period that all members of the team are expected to contribute.

Providing specific suggestions to teams in which the participation is observed to be uneven. Preliminary class observations using some of these interventions showed definite improvements in the level of engagement among female students. More extensive observations of team dynamics will be made both before and after implementing the interventions, in order to determine their efficacy. Results that were intended to be collected in the Spring 2020 semester have been delayed to Fall 2020 and Spring 2021 due to the cancellation of in-person instruction in the second half of Spring 2020 as a result of the Covid-19 health crisis.

2.7 ECE Design Class

A junior-level design course for electrical and computer engineering was developed that required three team-based hands-on learning experiences, where students used either portable experiments or built portable projects in a makerspace. Inclusivity was an important goal in the team dynamics. During student interviews and focus groups conducted prior to designing the course, it was determined that underrepresented students often feel isolated and left out in team-based work, but they do not want interventions that single them out. Instead, inclusivity was approached from the perspective of "every voice is important" scaffolded with training and awareness exercises. Interventions were developed in this class using training activities: pretraining using an activity around active listening [26], exploration of dysfunctional team behavior and possible root causes, and role-playing scenarios to gain practice resolving conflicts that result from those root causes. The training activities were coupled with a mutual expectations team agreement, peer feedback on the projects, and reflection in order to improve team dynamics on the second project. Based on the survey data, the training activities instilled an understanding and empathy in the students. The motto "every voice is important" was well accepted and repeated by the students often, for example, in reflections, mutual expectation agreements, and design reviews. Due to the Covid-19 health crisis, specific performance data and student surveys results that were intended to be collected in the Spring 2020 semester have been delayed to Fall 2020 and Spring 2021 due to the cancellation of in-person instruction in the second half of Spring 2020.

3. Conclusions

Hands-on learning continues to be a research topic that has great potential to improve engineering education. Although many experimental platforms have been developed to date, there are many other subjects that can benefit from a hands-on learning experience. Additionally, hands-on learning concepts that have been developed are in need of being improved so that they are less expensive, more accurate, more capable, or more portable. This paper presents progress made in the are of developing new hands-on learning devices, and in refining existing devices to extend their use to more-advanced classes.

The paper also discusses the use of an existing set of hands-on experiments to address diversity and inclusion aspects of teamwork in experimental studies. Using circuits and electronics experiments and the junior design class, the authors have studied different intervention strategies that can be easily used by instructors to promote greater engagement by URMs in engineering teams.

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