Paper ID #44784

Smartbeam: Teaching a Multidisciplinary First-Year Project for Exposure of Upper-Level Content with Active Learning

Dr. Stephanie L. Walkup PE, Villanova University

Stephanie Walkup is an Assistant Teaching Professor at Villanova University. She obtained both her BS and MS degrees from Lehigh University and her PhD from Villanova University. Her research interests include first-year engineering programs, repair and retrofit of structures, forensic engineering, and fiber reinforced polymer (FRP) reinforcement for concrete structures.

Dr. Shawn P. Gross, Villanova University

Dr. Shawn P. Gross is an associate professor in the Department of Civil and Environmental Engineering at Villanova University. He has as M.S.E. and Ph.D. degrees in Civil Engineering from the University of Texas at Austin, and a B.S.E. degree from Tulane

Jeffrey Joseph Cook, Villanova University

Smartbeam: Teaching a Multidisciplinary First-Year Project for Exposure of Upper-Level Content with Active Learning

Introduction

In 2005, the National Academy of Science recommended implementing first-year engineering courses to "introduce the 'essence' of engineering" early in the curriculum[1]. As a result, engineering colleges have developed various first-year engineering programming from a common first-year experience with multi-disciplinary projects[2,3] to more discipline specific courses for students with direct matriculation into a specific major[4]. These courses aim to provide an early introduction to the engineering discipline[5] thus positively impacting a student's engineering identity[6], which has been shown to increase student persistence within the engineering field[1].

This paper presents a successful multidisciplinary project, Smartbeam, that exposes first-year students to the world of smart infrastructure in the first semester of their first-year program. The goal of this mini project is for students to design and construct a structural flexural member (i.e., beam) instrumented with smart technology to span a given distance while meeting prescribed strain and deflection constraints.

The course is project-based with an introduction to civil, mechanical, electrical, and computer engineering topics and showcasing the interdisciplinary relationship of the engineering disciplines. This introduction allows students to develop domain identification – the extent to which students define themselves through a role or performance in activities related to the domain, such as engineering[7]. Domain identification has been linked to positive outcomes in classroom participation[8], higher achievement in grades and academic honors[9], and intention to pursue a career in engineering[10].

Major aspects of this mini project include an early focus on performing individually focused laboratory experiments to facilitate understanding of moment of inertia, stress-strain relationships, flexural behavior, electronic sensors, and coding. Teaching methodologies implemented in the course include inquiry-based learning, flipped classroom, hands-on activities, laboratory experiments, and brainstorming in group design sessions. The course supports the following seven ABET program Outcomes with italicized objectives assessed with an end of semester survey.

1. ***an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.***
2. ***an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare,*** as well as global, cultural, social, environmental, and ***economic factors.***
3. ***an ability to communicate effectively with a range of audiences.***
4. an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.

5. ***an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives.***
6. ***an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.***
7. ***an ability to acquire and apply new knowledge as needed, using appropriate learning strategies.***

Course and teacher survey data collected over the past six years is also used to highlight the success of the course.

Course Description

Smartbeam is a half-semester course scheduled over a total of sixteen class periods and is divided into five specific sections (Table 1). The class meets for one hour and fifteen minutes two times per week.

Table 1. Smartbeam class schedule: **class topic** with *associated assignments*.

Class Meeting	**In-class topic** *Assignment due*	Class Meeting	**In-class topic** *Assignment due*
1	**Mini Wood Beam Lab Part 1**	9	**Beam Build Period** *Real World Monitoring*
2	**Mini Wood Beam Lab Part 2** *Moment of Inertia Assignment*	10	**Arduino Tutorials** *Introduction to Circuitry*
3	**Axial Stress and Strain Fitness Band Lab** *Excel Moment of Inertia*	11	**Arduino Tutorials** *Group Coding Assignment 1*
4	**Flexure and Axial Strain Distribution Lab** *Fitness Band Stress-Strain Graph*	12	**Arduino Tutorials and Design** *Group Coding Assignment 1*
5	**Moment, Shear, and Composite Behavior Lab** *Strain Identification and Calculations*	13	**Arduino Design, Build**
6	**Introduction of Design Project and Initial Design Period** *Moment and Modulus of Elasticity Calculations*	14	**Arduino Design, Build / Troubleshooting**
7	**Second Design Period**	15	**Test Period** *Strain Monitoring Submission and Test Predictions Due*
8	**Third Design Period** *Group Beam Design*	16	**Final Project Presentations** *Presentation, Peer Evaluation*

Class Meetings 1 through 5: Introductory statics and mechanics concepts

Class Meeting 1 begins with students constructing mini basswood beams of various doubly symmetric cross-sectional shapes (Figure 1 and Table 2) using either glue, nails, or thumb tacks.

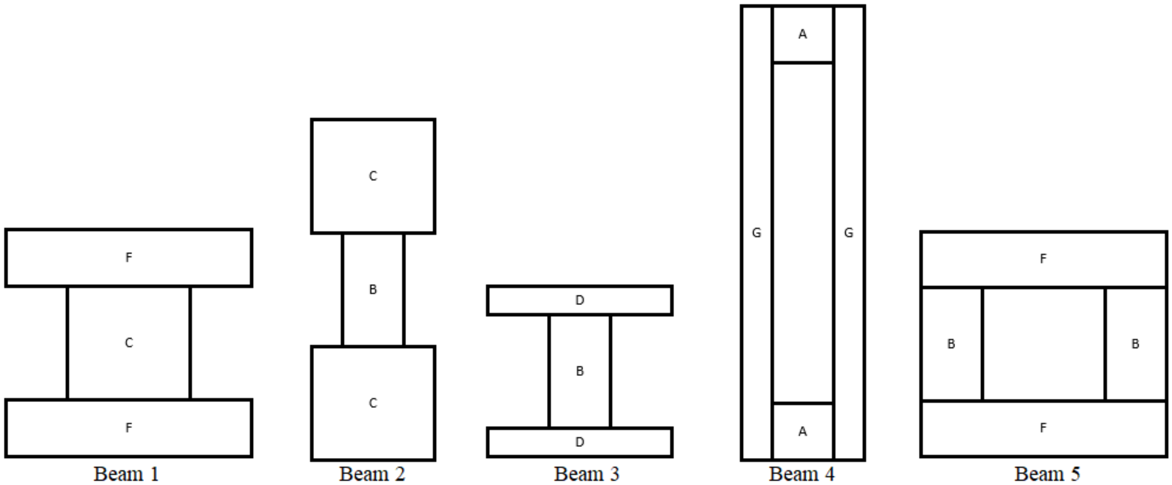


Figure 1. Mini basswood beams constructed during Class Meeting 1.

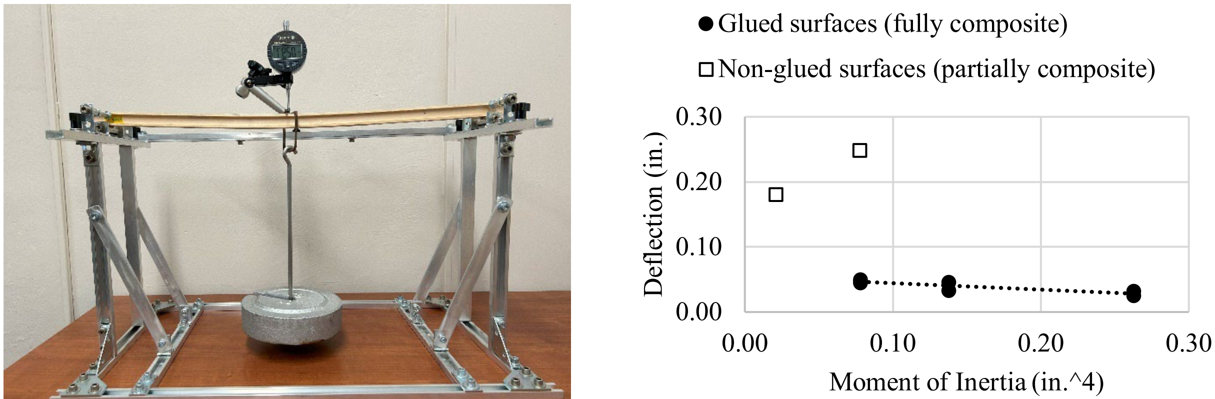
Table 2. Sub-shape sizes for mini basswood beams.

Shape	Thickness (in.)	Width (in.)
A	1/4	1/4
B	1/4	1/2
C	1/2	1/2
D	1/8	3/4
E	1/16	1
F	1/4	1
G	1/8	2

The students spend the rest of the class period in inquiry-based learning discussing the shapes and intuitively ranking the beams' expected deflections from lowest to highest when supported on a simple span and loaded identically. After class, the students watch a lecture on the concept of moment of inertia (I) and calculate the moment of inertia of their assigned beam cross section.

At the beginning of Class Meeting 2, the students re-rank the predicted beam deflections using their knowledge of moment of inertia. The students then develop an Excel spreadsheet to calculate moment of inertia of doubly symmetric beam cross-sections with guidance from the instructor and use the spreadsheet to calculate the moment of inertia of their assigned beam. The end of class is spent testing (Figure 2a) their constructed wood beams on a small test frame, and a moment of inertia vs. deflection graph (Figure 2b) is generated by the instructor in real time.

Lastly, students use inquiry-based learning, discussing the actual vs. predicted deflections as they relate to moment of inertia. Because one or two student groups will typically use only mechanical attachment (not glue), their beams will deflect more than others with similar cross-sectional shapes and this difference in data is used to introduce the concept of composite action.



(a) Test frame with load applied to beam

(b) Mini-beam test results

Figure 2. Mini basswood beam testing and results

Class Meeting 3 is inverted with students watching a pre-recorded video on stress and strain prior to the lab. During class, students test elastic fitness bands loading them and documenting the corresponding fitness band elongation. The students record the laboratory data, calculate stress, $\sigma = P/A$, where P = load and A = initial cross-sectional area, and strain, $\varepsilon = \Delta L/L_o$, where ΔL = change in length and L_o = initial length, for each load condition, and generate a stress-strain diagram in Excel for the six fitness bands (Figure 3). This lab allows students to visualize deformations and introduces Hooke's law, $\sigma = \varepsilon E$, where, E = Modulus of Elasticity.

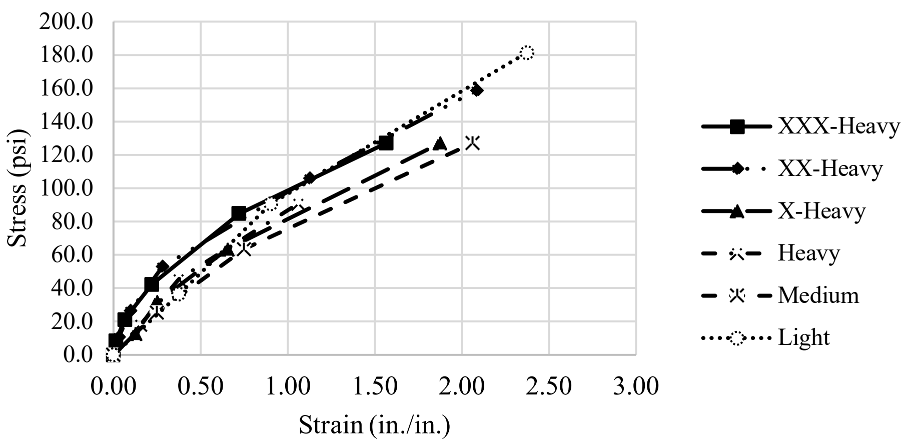
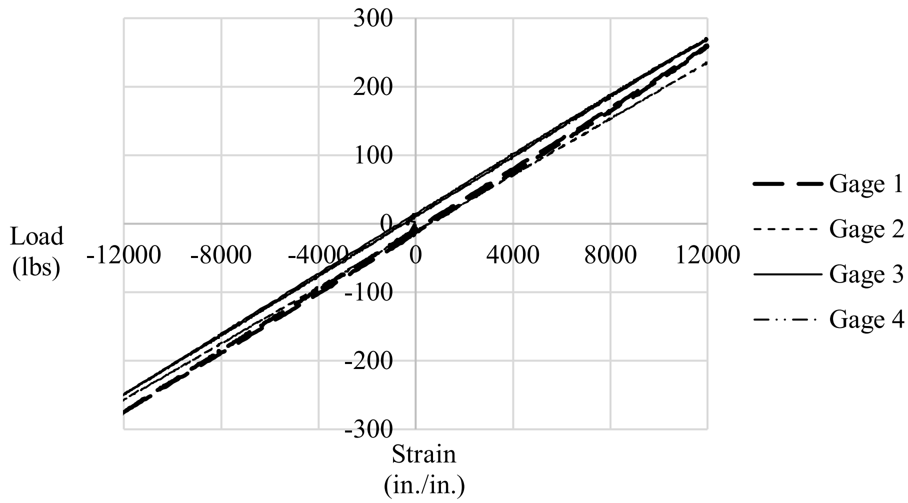


Figure 3. Fitness band axial load lab.

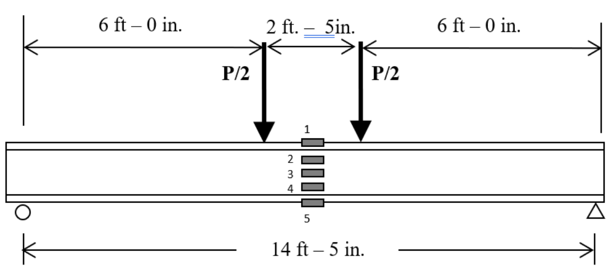
Students test a steel column and steel beam in Class Meeting 4, recording load and strain values and discussing the difference in behavior of axial vs. flexural specimens. A steel column is tested along the longitudinal axis in axial compression and tension with strain gages located at each face of the column. The students observe similar strains on each face of the column for each applied load (Figure 4). Construction tolerances and strain gage placement are discussed as they relate to the minor differences in gage readings. As the loads are being applied to the column, the instructor introduces the students to the concept of using strain gages to measure strains where deformations are small.

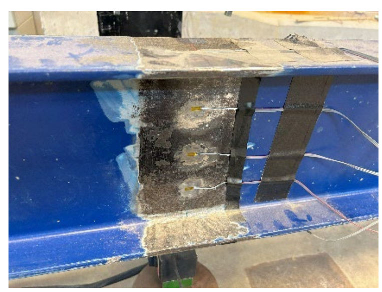


(a) Column (b) Column test results showing uniform strain for applied loads.

Figure 4. Axial load test with steel column.

For comparison, a steel wide-flange beam instrumented with Strain Gages 1 through 5 (Figure 5) is loaded in four-point bending on simple supports.





(a) Steel beam with loads and instrumentation (b) Strain gage placement

Figure 5. Steel beam flexural test setup.

Students observe that unlike the strains in the column lab the strains across the beam cross section vary through the depth of the cross section (Figure 6). The students observe from the real time load vs. strain graph that the strains are directly proportional to the applied load as well as to the distance of the gage from the neutral axis (Gage 3 placed at mid-height has a strain of zero).

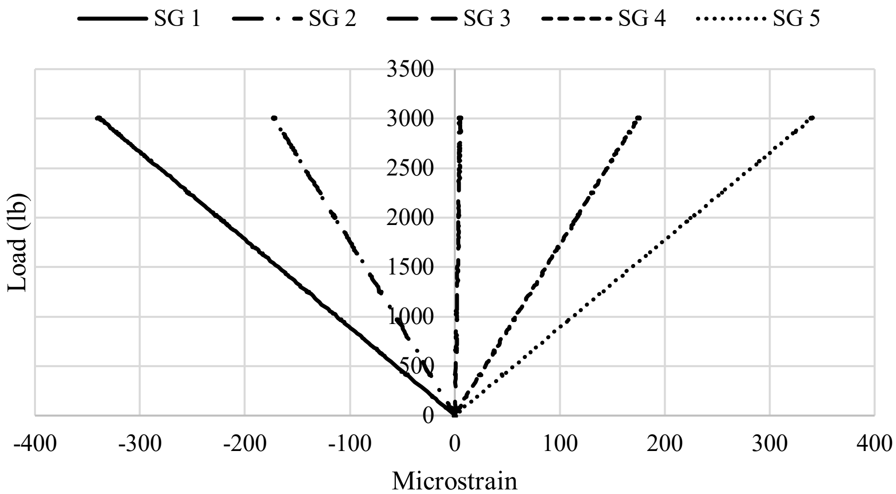


Figure 6. Steel beam lab results.

Following Class Meeting 4, students watch a video on flexure in beams with the derivation of the elastic flexural stress equation $\sigma = My/I$, where y = distance from neutral axis. The students apply this knowledge to calculate the stress and strain in an axially loaded solid aluminum cylindrical rod and the stress and strain in their Class Meeting 1 miniature basswood beams for a given bending moment, M.

In Class Meeting 5, students load non-composite and composite aluminum beams (Figure 7 and Table 2) and measure corresponding deflections. Students observe that the more fully connected beams (composite) deflect the least with the unconnected (non-composite) beams deflecting the most.

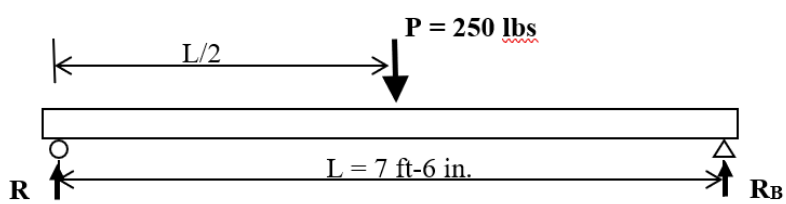
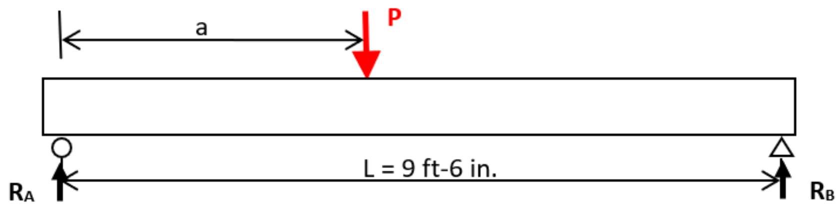


Figure 7. Load configuration for composite beam lab.

Table 3. Beam size, orientation, and connectivity for composite beam lab.

Tube orientation	Connectivity
Horizontally 	Double 1.5 x 3 x 1/8 – no connection
	Double 1.5 x 3 x 1/8 – center connection only
	Double 1.5 x 3 x 1/8 – ends only
	Double 1.5 x 3 x 1/8 – fully connected
Vertically 	Double 1.5 x 3 x 1/8 – center connection only
	Double 1.5 x 3 x 1/8 – ends only
	Double 1.5 x 3 x 1/8 – fully connected

A second laboratory station (Figure 8) is used to evaluate the effect of a traveling load. A student stands at 0 L, ¼ L, ½ L, ¾ L, and L, where L is the length of the beam, and the other members record corresponding mid-span deflections and support reactions.



Location, a (ft)	Reaction, R_A (lbs)	Reaction, R_B (lbs)	Midspan Deflection (in.)
0			
¼ L			
½ L			
¾ L			
L			

Figure 8. Lab station: effect of a traveling load on deflection and support reaction.

The students watch a final inverted lecture on load, P, shear, V, bending moments, M, and deflection, Δ, and calculate the modulus of elasticity, E, of the laboratory aluminum beam using their load and deflection data.

<u>Class Meetings 6 through 9: Design project: beam design and build</u>

Each student team is tasked with designing a built-up wood beam to span 7 ft.-6 in with a pair of concentrated loads spaced 1 ft.-6 in. apart and centered on the beam (Figure 9). Each team is assigned a unique value for total load, 2P, and a maximum strain limit (between 500 με to 800 με). All teams are also required to satisfy a maximum mid-span deflection limit of 0.25 in.=L/360, minimize cost, and use only available materials (Table 4).

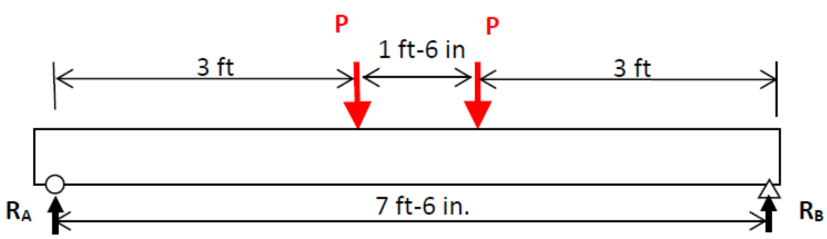


Figure 9. Load and support configuration for design project.

Table 4. Available materials for design project.

Component	Design Thickness (in.)	Design Width (in.)	Cost	
1x2 (8 ft. long, Pine)	¾	1 ½	$ 3.12	per board
1x3 (8 ft. long, Pine)	¾	2 ½	$ 4.80	per board
1x4 (8 ft. long, Pine)	¾	3 ½	$ 7.12	per board
1x5 (8 ft. long, Pine)	¾	4 ½	$ 12.48	per board
1x6 (8 ft. long, Pine)	¾	5 ½	$ 14.72	per board
Wood Glue (8 oz bottle)	N/A	N/A	$ 3.96	per bottle
Screws (#8; 1 5/8 in. long)	N/A	N/A	$ 0.07	per screw
Screws (#8; 2 in. long)	N/A	N/A	$ 0.09	per screw
Screws (#9, 2 1/2 in. long)	N/A	N/A	$ 0.11	per screw
Nails (4d; 1 1/2 in. long)	N/A	N/A	$ 0.02	per nail
Nails (6d; 2 in. long)	N/A	N/A	$ 0.04	per nail
Nails (8d; 2 1/2 in. long)	N/A	N/A	$ 0.06	per nail

Because the students are not expected to achieve mastery of concepts from Class Meetings 1 through 5, they are provided with an equation sheet and advised to use their moment of inertia Excel spreadsheet. A complete design report is required, including a bill of materials, sketches of their beam cross-section, and detailed calculations demonstrating that they met the design constraints. The students construct their beam in Class Meeting 9 (Figure 10).

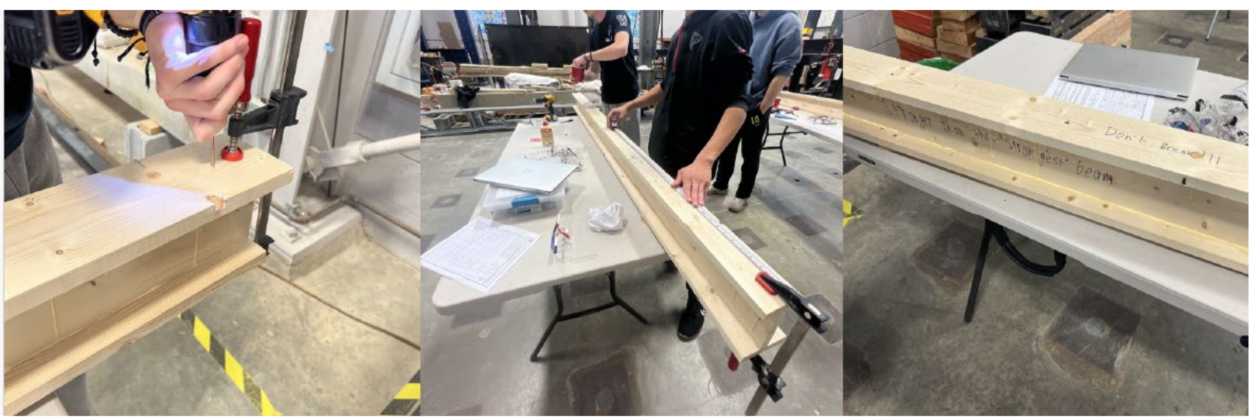


Figure 10. Beam assembly.

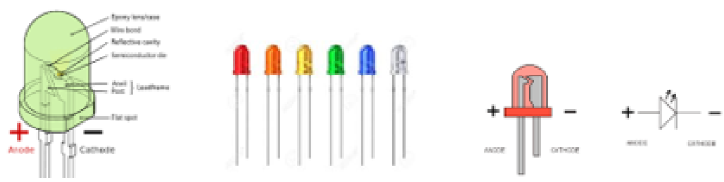
Outside of the design period classes, students watch two recorded videos and complete two related assignments in preparation for the instrumentation and monitoring portion of the course. The first video discusses applications of real-world monitoring. Students research two engineering monitoring techniques and report on these techniques in a written assignment.

The second video introduces the students to the Arduino board, Arduino programming language, breadboard wiring basics, and Ohm's law V = IR, where V = voltage, I = current, and R = resistance. Students evaluate a simple code for an LED three light traffic signal and calculate the resistor size required for the LED circuits provided a 5-volt input from the Arduino Uno board. Programming basics in the lecture video include variable declarations, digital output pins, setup functions, loop functions, and sub-routines.

Class Meetings 10 through 12: Arduino tutorials

Students are provided with a handbook of Arduino tutorials prepared by the instructor. Each tutorial includes background information, a sketch of the circuit, step-by-step instructions for constructing the circuit, and the required code for the Arduino Uno (Figure 11).

In this tutorial, you will make an LED light blink and learn how to use the Arduino IDE to create, verify, and upload code. An LED is a semiconductor device that emits light when an electric current is passed through it. Different semiconductor materials produce different colors of light. LEDs require very low current levels, so they are almost always used in combination with resistors. LEDs have an anode (+), which is generally the wire with the longer end for small LED bulbs, and a cathode (-), which is generally the shorter end.



Fritzing Sketch

```
/*
Blinking Light
TUTORIAL 1
EGR 1200
*/

int red = 13;                // digital pin for red light

void setup() {
  pinMode(red, OUTPUT);
}

void loop() {
  digitalWrite(red, HIGH);
  delay(1000);
  digitalWrite(red, LOW);
  delay(3000);
}
```

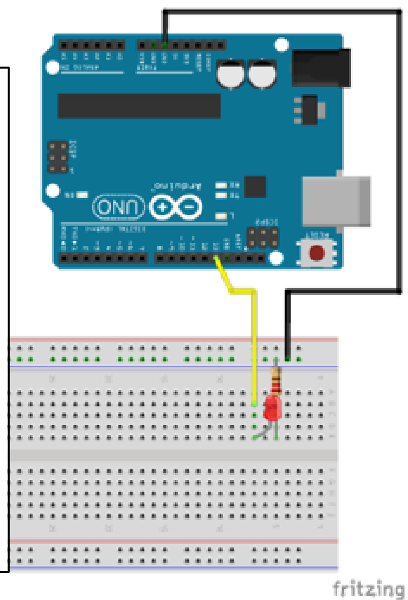


Figure 11. Tutorial 1 for blinking LED light (step-by-step instructions not shown)

In Class Meeting 10, students construct circuits related to traffic signaling to learn how to use digital output pins and wire and code LED lights. The tutorials include a blinking light, a traffic signal, an intersection, and an intersection with pedestrian crosswalk and push button (Figure 12). Tutorials are sequenced to build upon each other, and code to run the various circuits using an Arduino Uno is provided to the students.

Group assignments are used with the Arduino tutorials and include answering questions related to the various codes, modifying the codes to change light signaling, and creating circuity sketches using the software program Fritzing.

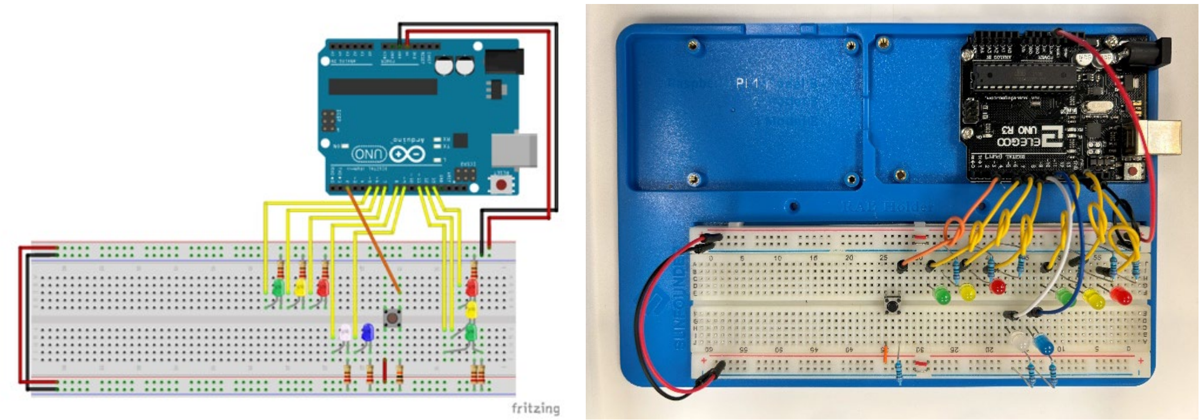
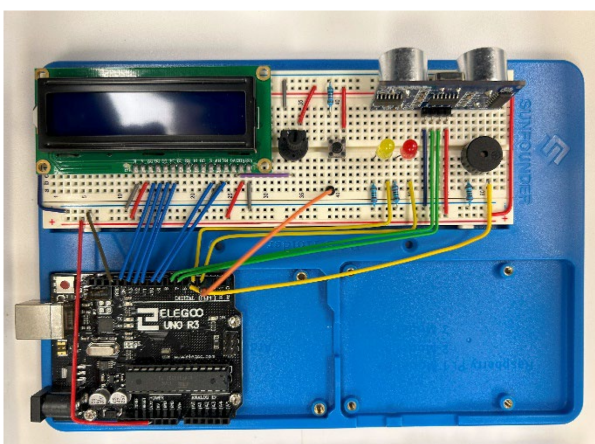


Figure 12. Fritzing circuity diagram (left) and actual construction (right).

In Class Meeting 11, students work with LCD screens, buzzer alarms, and a distance meter. Students begin by constructing a simple voltmeter with the voltage displayed on the LCD screen. Students learn concepts of analog-to-digital pins and resolution to understand how quantities such as load, deflection, voltage, etc. are measured using electronics.

The following two tutorials add the distance meter and a buzzer alarm and lights to the circuit. The buzzer alarm and lights are used to signify when the distance of an object from the distance meter is "CLOSE" and "FAR". The LCD screen is used in these tutorials to display CLOSE, FAR, or the value of distance from the distance meter to an object. The buzzer and lights are programmed to warn of the close (high tone and red LED light) and far (low tone and yellow light) limits. Figure 13 shows selected subroutines for the program as well as the circuitry.



```
void Readdistance() {
  delayMicroseconds(2);
  digitalWrite(trigPin, HIGH);
  delayMicroseconds(10);
  digitalWrite(trigPin, LOW);
  duration = pulseIn(echoPin, HIGH);
  distance = duration*0.340/2;
  digitalWrite(redPin, LOW);
  digitalWrite(yellowPin, LOW);
  lcd.setCursor(10,1);
  if(distance > farlimit) {
   lcd.print(" FAR  ");
   tone(buzzerPin, tonefar);
   digitalWrite(yellowPin, HIGH);
  }
  else if (distance < closelimit) {
   lcd.print("CLOSE ");
   tone(buzzerPin, toneclose);
   digitalWrite(redPin, HIGH);
  }
  else {
   lcd.print(distance);
   lcd.print(" mm ");
   noTone(buzzerPin);
  }
}
```

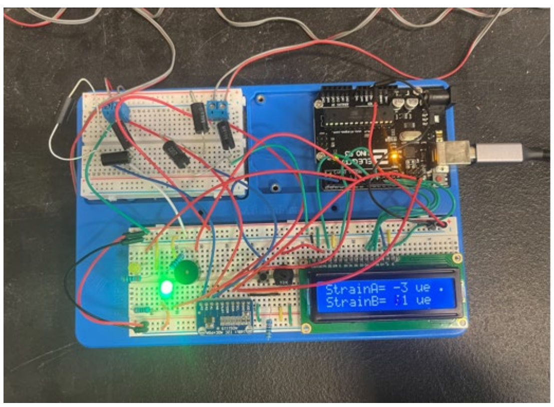
Figure 13. Completed circuitry for Class Meeting 11 (left) and selected subroutines (right).

Students are again provided with a group assignment which includes answering questions related to the tutorial codes such as resolution of a 10-bit vs. 12-bit analog-to-digital (A/D) converter, modifying the tutorial codes for different tones, limits, and delays, and drawing Fritzing sketches of the circuitry.

During Class Meeting 12, a thorough introduction to strain gages is provided in the tutorial including a description of the Wheatstone Quarter Bridge circuit that is used to translate the resistance in the strain gage to a change in voltage that can be read by a data acquisition system (Arduino). The students wire the circuit to read two strain gages and display the results on an LCD screen, which forms the base for their strain monitoring system. Students are provided with miniature beams instrumented with strain gages in their Arduino kit to test their circuits as they are constructed. A 16-bit resolution analog-to-digital (A/D) chip is added to the circuit and precision resistors are used to provide the required resolution for meaningful results.

<u>Class Meetings 13-14: Strain monitoring system design and build</u>

During Class Meetings 13 and 14, students design and build their strain monitoring system by adding components (lights, buzzers, etc..) to their strain gage circuitry (Figure 14) and programming the components to serve as an alert system for potential or actual overstrain conditions. Because mastery of concepts is not required, students are permitted to combine past circuitry and programming for their solution. Through inquiry-based learning and brainstorming, students realize that maximum, minimum, and/or statements, and absolute value functions are required in their code. An Arduino code book is provided for their use in developing these code lines. They install two strain gages on their wood beams selecting the location for the gages based on their mechanics knowledge developed in Class Meetings 1 through 5. A full design report including a sketch of their circuitry, their completed code, and a written explanation of the monitoring system is required.




```
void controlOutputs() {

  // Turn off both lights and buzzer initially
  digitalWrite(greenPin, LOW);
  digitalWrite(yellowPin, LOW);
  noTone(buzzerPin);

  if (abs(strainA) < 700 && abs(strainB) < 700)  {
    digitalWrite(greenPin, HIGH);  // Turn on the green light
  }
  else if (abs(strainA) >= 700 || abs(strainB) >= 700)  {
    digitalWrite(yellowPin, HIGH);  // Turn on the yellow light
  }

  if (abs(strainA) >= 800 || abs(strainB) >= 800) {
    tone(buzzerPin, 500);  // Turn on the buzzer
  }
}
```

Figure 14. Strain monitoring system with LED lights (left) and associated student developed sub-routine (right).

<u>Final testing and presentation of results</u>

Class Meeting 15 is spent testing their beams to their prescribed load. Students are evaluated on how well they met the strain and deflection design constraints and how well they can monitor their beams (Figure 15). Each team prepares a formal presentation of the design project and presents their work during Class Meeting 16.

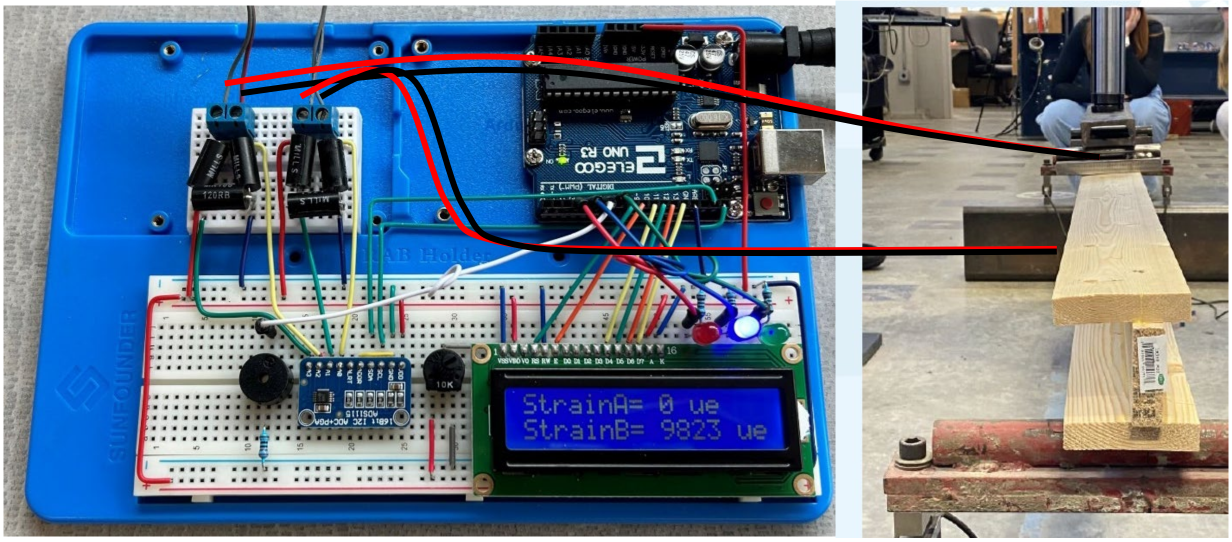


Figure 15. Final testing of built-up wood beam (right) with buzzer strain monitoring system (left). The strain gages are located under the spreader beam and at the bottom of the bottom flange (neither is visible in the photo).

Course Assessment

Two assessment methods were used to evaluate the effectiveness of the course and the student experience in the course.

Course and teacher survey (CATS) data over the past six years highlights the many aspects of the project that were successful. Students are asked to evaluate the CATS statements on a 1 through 5 scale with 5 being the highest rating. Compared with other mini project offerings in the same introductory first-year engineering course, Smartbeam has higher average scores in categories including hard work is required to get good grades, I found the course intellectually stimulating, I learned a great deal in the course, and overall value of course (Table 5 and Figure 14). One tailed t-test data indicates that the Smartbeam scores are statistically significant (p-values < 0.0001).

Table 5. Course and teacher survey data 2018 through 2023.

	Fall 2018		Fall 2019		Fall 2020		Fall 2021		Fall 2022		Fall 2023	
Section	All	***SB***	All	***SB***	All	***SB***	All	***SB***	All	***SB***	All	***SB***
Requires hard work	4.1	***4.7***	4.2	***4.7***	4.2	***4.5***	4.1	***4.9***	4.1	***4.6***	4.0	***4.6***
Intellectually stimulating class	4.2	***4.7***	4.2	***4.7***	4.2	***4.5***	4.2	***4.9***	4.1	***4.7***	4.1	***4.6***
Learned a great deal	4.1	***4.6***	4.3	***4.7***	4.2	***4.5***	4.1	***4.8***	4.2	***4.7***	4.0	***4.6***
Overall value	4.2	***4.6***	4.3	***4.6***	4.1	***4.4***	4.2	***4.7***	4.2	***4.5***	4.1	***4.7***

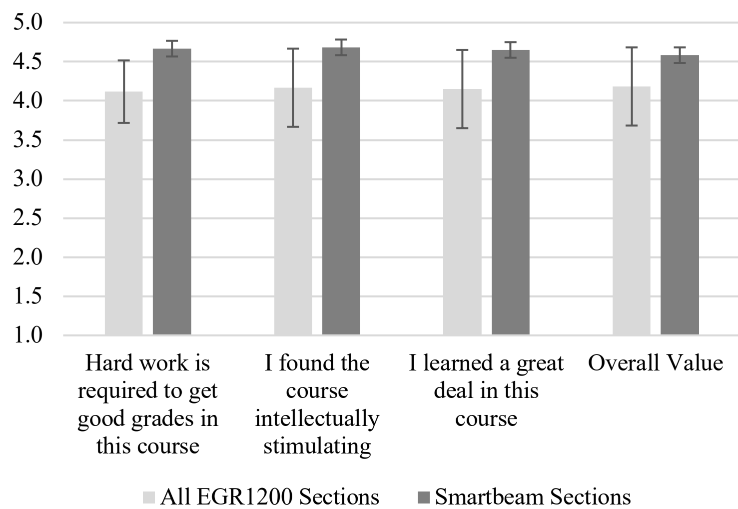


Figure 14. Combined results (mean ± standard deviation) of six years of CATS surveys evaluating effectiveness of Smart Beam mini-project vs. other mini-projects.

The results indicate that while the students find the course challenging, they enjoy the course material and find it intellectually stimulating. They learn a great deal and feel the course provides a high overall value to their engineering education.

To evaluate specific learning outcomes, the Fall 2023 Smartbeam section students were provided with a post-course optional and anonymous survey (48% response rate, n = 21). The data represents their perceived learning. Students evaluated how much they agreed with statements related to Teamwork, Communication, Data Collection and Analysis, Engineering Problem Solving Skills, and the Course Overall on a 1 through 5 scale with 1 = Strongly Disagree and 5 = Strongly Agree. Results of the survey are shown in Tables 6a through 6e.

Table 6a. Student survey of teamwork.

4.76 ± 0.54	• The Smartbeam mini-project course improved my ability to ***work as part of an engineering project team***.
4.67 ± 0.58	• Improved my ability to ***function collaboratively*** on a team. (ability to use a diverse set of skills and talent to work together toward a common goal)
4.76 ± 0.44	• Improved my ***understanding of awareness*** in team. (ability to create space so all teammates feel comfortable contributing unique skills and abilities)
4.71 ± 0.46	• Improved my ***communication skills*** as part of a team (ability to clearly and effectively communicate ideas to other team members)
4.76 ± 0.44	• Improved my ability to ***understand responsibility*** in a team setting (ability to complete accurate engineering calculations in a timely manner)
4.81 ± 0.40	• Improved my ability to ***actively listen*** in a team setting. (ability to make an effort to focus intently on one person as they share ideas, thoughts, or opinions)

Table 6b. Student survey of communication.

4.67 ± 0.58	• Smartbeam mini-project improved my ability to ***communicate engineering concepts***.
4.43 ± 0.75	• Improved my ability to ***write a technical engineering report***.
4.57 ± 0.60	• Improved my ability to ***convey engineering designs in graphical format*** (through drawings, tables, or figures).
4.62 ± 0.50	• Improved my ability to ***present engineering designs*** to an audience (verbal communication skills)

Table 6c. Student survey of data collection and analysis skills.

4.52 ± 0.60	• The Smartbeam mini-project course improved my ***data collection and analysis skills***.
4.43 ± 0.75	• Improved my ability to collect tabulated data
4.14 ± 0.85	• Improved my ***understanding of significant figures*** and ***importance of providing units*** with numerical values
4.10 ± 0.83	• Improved my ability to ***graphically present x-y data***
4.67 ± 0.58	• Improved my ability to ***think critically about data*** and ***use engineering judgement*** to determine if laboratory data appears correct

Table 6d. Student survey of engineering problem solving skills.

4.86 ± 0.36	• The Smartbeam mini-project course improved my ***engineering problem solving*** skills.
4.81 ± 0.68	• Improved my ability to ***ideate*** (brainstorm) solutions to engineering problems
4.67 ± 0.66	• Improved my understanding of ***design constraints***
4.71 ± 0.46	• Improved my ability to ***perform engineering calculations*** as part of an analysis / design

Table 6e. Student survey of engineering disciplines, identity, and confidence.

4.38 ± 0.80	• I understand the different ***engineering disciplines*** better having taken the Smartbeam mini-course
4.71 ± 0.46	• I am able to better ***identify as an engineer*** having taken the Smartbeam mini-project course
4.57 ± 0.68	• Completing the Smartbeam mini-project makes me feel more ***confident*** that I can be ***successful*** in my upper level engineering courses

Overall student rankings (shaded values) for the categories of teamwork and engineering problem solving skills exceeded 4.75 on a 1-5 scale with individual sub-categories all scoring above 4.50. In the categories of communication and data collection and analysis, student rankings were above 4.50 with all but two sub-categories scoring above 4.25. Students can better identify as an engineer (4.71) having taken the Smart beam mini project and feel more confident that they can be successful in upper-level engineering courses (4.57). Also, students better understand the engineering disciplines (4.38) which is important because students are directly matriculated into their major, so they have less flexibility to move between disciplines. The student evaluations quantitatively demonstrate the effectiveness of meeting ABET course outcomes.

Student comments (selected comments provided below) are consistent with the numeric evaluation.

- *"All the written coursework translated directly to the actual hands-on construction of the beam, allowing me to use what I had learned in the lecture in an actual example. Similarly, the process of designing the beam and strain monitoring system, constructing it, and testing its limits was particularly enjoyable and allowed me again to see the content discussed in class in a real-life example. The post-project presentation allowed me to reflect on both what went well and what didn't in the entire process. Overall, the course was very enjoyable for me."*

- *"The hands on projects that we did contributed most to my learning because we were able to learn how beams and strain gages worked. It kept us engaged and forced us to really think about what we wanted."*

- *"Watching the lectures prior to class and then seeing what we learned applied in a physical way was very effective and helped my learning experience."*

- *"The course was very interesting in that we actually got to build and create things with our own hands, something I think some other mini-projects missed out on. Because the class was so hands on, it was very effective at getting us to grasp concepts as well as obtain some experience for the future."*

- *"The project was broken into manageable pieces and while it was hard work, it was never overwhelming."*

- *"The mini project was a very good experience to get used to working in teams."*

- *"This course was very informative and will be helpful down the road."*

- *"I can confidently say that I learned more from this class than any other class this semester."*

Limitations and Future Implications

Limitations in student learning for the project relate to timeline for the project, physical resources and laboratory space. The course is only a half-semester long. To cover the entire project in that time most of the code for the Arduino tutorials is simply provided to the students. Students with prior programming skills tend to complete the group programming tasks limiting student knowledge gain by those less familiar with programming. In addition, one Arduino kit is provided per team limiting the hands-on experience in wiring the circuits. Students typically fall into roles (wiring, uploading code, creating Fritzing sketches, compiling electronic components for the circuit) when working on the Arduino tutorials. In the mechanics laboratory exercises, student experiences are varied with some students loading members, others recording data, and the remaining observing. Attempts are made to engage all students in the various laboratory exercises, but actual engagement remains variable.

The university's college of engineering is in the process of redesigning the fall first-year engineering course to extend the full semester. Evaluation of the strengths of this mini-project, as well as others, will be considered in the comprehensive redesign.

Conclusions

The Smart beam mini-project introduces students to the engineering disciplines in an engaging, cohesive, and rigorous half-semester project. Students learn to effectively work in teams, communicate engineering concepts, collect and analyze data, and apply engineering problem solving skills. While the students find the work challenging, they enjoy the course and are better able to role identify as an engineer and feel confident about pursuing an engineering degree with upper-level coursework. Students enjoy that the course is centered around project-based learning with active learning techniques. The course success results from various content delivery modalities including inquiry-based learning, flipped (inverted) classroom, laboratories, and collaborative teamwork all of which are based on active classroom learning.

1. National Academy of Engineering, *Educating the engineer of 2020: Adapting Engineering Education to the New Century*, 2005.
2. Malladi, "GIFTS: Showcasing Interconnectedness of Engineering Disciplines in an Introductory Engineering Class through a Climate Change Module," presented at the 2023 ASEE Annual Conference & Exposition, Knoxville, Tennessee, Jul. 2023. https://peer.asee.org/44841
3. Evans, M. J., & Esparragoza, I. E. (2019, July), *Inspiring and Engaging First-Year Engineering Students at a Small Campus Through International Team Design Projects* Paper presented at 2019 FYEE Conference, Penn State University, Pennsylvania. https://peer.asee.org/33714
4. Walkup, S. L., & Komlos, J., & Waters, K. A. (2021, July), Lessons Learned From Moving a Civil Engineering Fundamentals Course From Second-Year to the First Year Paper presented at 2021 ASEE Virtual Annual Conference Content Access, Virtual Conference. 10.18260/1-2—37441
5. K.P.Brannan and P.C. Wankat, Survey of first-year programs, *ASEE Annual Conference and Exposition, Conference Proceedings*, Portland Oregon, 2005.
6. Clark, A., Desing, R., Wallwey, S.A., Louis Kajfez, R., Mohammadi-Aragh, J., Sassi, S., Tracking first-year engineering students' identity metrics, International Journal of Engineering Education 36(5), 2020, pp. 1625-1639
7. Osborne, J.W. and Jones B.D., Identification with academics and motivation to achieve in school: How the structure of the self-influences academic outcomes, Educational Psychology Review, 23(1), 2011 pp.131-158.
8. Voelkl, K.E, Identification with school, American Journal of Education, 105, 1997, pp. 294-318.
9. Osborne, J.W., Identification with academics and academic success among community college students, Community College Review, 25, 1997 pp. 59-67
10. Jones, B.D., Parretti, M.C., Hein, S.F., and Knott, T.W., An analysis of motivation constructs with first-year engineering students: Relationships among expectancies, values, achievement, and career plans, Journal of Engineering Education, 99(4), 2010, pp. 319-336.