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Home-based Cantilever Beam Experiment for Civil Engineering Undergraduate Students

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Ms. Sotonye Ikiriko is currently a Doctoral student and Research Associate in the Department of Civil Engineering, Morgan State University (MSU) in Baltimore Maryland. Prior to joining the department in January of 2019, Ms. Sotonye Ikiriko was a Graduate Research Assistant (GRA) at Tennessee State University (TSU) in Tennessee State, where she obtained her master's degree in civil engineering. Ms. Sotonye Ikiriko obtained her Bachelor of Engineering (B.ENG) in civil engineering from the University of Port Harcourt (UNIPORT) in Port Harcourt Nigeria. Her passion for innovative and sustainable engineering research has led Ms. Sotonye Ikiriko to participate in several engineering research. In 2019 Ms. Sotonye Ikiriko was part of the Maryland Department of Transportation State Highway Administration (MDOT SHA) Project on Noise Abatement Decisions for the state of Maryland and co-authored the report 'HIGHWAY GEOMETRICS AND NOISE ABATEMENT DECISION'. In 2017 and 2018 Ms. Sotonye Ikiriko was part of a research sponsored by the Transportation Research Center for Livable Communities (TRCLC). And has authored, co-authored, and presented research papers published by the Transportation Research Board (TRB) and other engineering journals and conferences across the United States.

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Dr. Steve Efe is an Assistant Professor and the Assistant Director of the Center for Advanced Transportation and Infrastructure Engineering Research. He obtained his Doctor of Engineering in Civil Engineering with a major in Structural Engineering and minor in Construction from Morgan State University. He has more than 15 years of outstanding experience in practicing, teaching, and research in civil and transportation engineering. He is experienced in project management, inspection and construction supervision, adaptive materials and construction techniques, high performance material testing and simulations, material modeling and computational mechanics. His major areas of research interest are structural engineering, construction, sustainable infrastructure, new material development, physical and numerical modeling of structures, and engineering education.

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Dr. Shokouhian is an Assistant Professor at the Department of Civil Engineering, Morgan State University. His research focuses on performance-based design of structures made of high performance steel and concrete using theoretical, numerical and experimental methods. He has participated in many research projects and has published several peer-reviewed journal papers since 2004.

Dr. Oludare Adegbola Owolabi P.E., Morgan State University

Dr. Oludare Owolabi, a professional engineer in Maryland, joined the Morgan State University faculty in 2010. He is the director of the Center for Advanced Transportation and Infrastructure Engineering Research (CATIER) at Morgan State University and the director of the Civil Engineering Undergraduate Laboratory. He has over eighteen years of experience in practicing, teaching and research in civil engineering. His academic background and professional skills allows him to teach a range of courses across three different departments in the school of engineering. This is a rare and uncommon achievement. Within his short time at Morgan, he has made contributions in teaching both undergraduate and graduate

courses. He has been uniquely credited for his inspirational mentoring activities and educating underrepresented minority students. Through his teaching and mentoring at Morgan State University he plays a critical role in educating the next generation of underrepresented minority students, especially African-American civil engineering students. He is also considered to be a paradigm of a modern engineer. He combines practical experience with advanced numerical analysis tools and knowledge of material constitutive relations. This is essential to address the challenges of advanced geotechnical and transportation research and development. He is an expert in advanced modeling and computational mechanics. His major areas of research interest centers on pavement engineering, sustainable infrastructure development, soil mechanics, physical and numerical modeling of soil structures, computational geo-mechanics, constitutive modeling, pavement design, characterization and prediction of behavior of pavement materials, linear and non-linear finite element applications in geotechnical engineering, geo-structural systems analysis, structural mechanics, sustainable infrastructure development, and material model development. He had been actively involved in planning, designing, supervising, and constructing many civil engineering projects, such as roads, storm drain systems, a $70 million water supply scheme which is comprised of treatment works, hydraulic mains, access roads, and auxiliary civil works. He had developed and optimized many highway design schemes and models. For example, his portfolio includes a cost-effective pavement design procedure based on a mechanistic approach, in contrast to popular empirical procedures. In addition, he had been equally engaged in the study of capacity loss and maintenance implications of local and state roads (a World Bank-sponsored project). He was the project manager of the design team that carried out numerical analyses to assess the impact of the new shaft and tunnel stub construction on existing London Underground Limited (LUL) structures as per the proposed alternative 3 design of the Green park Station Step access (SFA) Project in U. K. He was also the project manager of Category III design check for the Tottenham Court Road Tunnel Underground Station upgrade Project in UK.

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Home-Based Cantilever Beam Experiment for Civil Engineering Undergraduate Students

Abstract

There is a growing concern in engineering fields during the ongoing pandemic regarding how students will be able to achieve one of the major learning outcomes: an ability to conduct appropriate experimentation (away from campus), analyze, interpret data, and use engineering/scientific judgement to draw conclusions. Experimental Centric Pedagogy (ECP) has been shown to promote motivation and achievement in electrical engineering among students. This paper developed a hands-on laboratory experiment for undergraduate students in the department of civil engineering, using portable electronic instruments, to improve experiential learning. The major goal of this paper is to design and conduct hands-on experiments remotely with students in civil engineering and to analyze the impact of this hands-on learning approach on students learning in civil engineering. The home-based experiment focuses on the measurement of strain resulting from displacement applied to the free end of an aluminum cantilever beam while being fixed at the other end. Data acquisition from strain gauges installed on the beams was made possible using a voltmeter which displays voltage readings upon beam displacement. The applied displacement was first converted to force and then to the maximum moment which was finally converted to bending stress and strain. Results from the descriptive and quantitative analysis conducted based on the quantitative data obtained from a pre-test and post-test survey administered to the students in the civil engineering department as well as students from other STEM discipline show that there are some improvements in students' motivation level due to hands-on learning implementation at the authors' institution.

1. Introduction

Hands-on experiential learning has increasingly gained attention over the years because it has been shown to be a more efficient learning style for students especially in the Science, Technology, Engineering and Mathematics (STEM) disciplines [1]. The hands-on experiential learning style has especially shown more effectiveness in the field of engineering as it increases students learning and engagement in the subject area. One approach to hands-on learning is Experiment Centric Pedagogy (ECP), originally the Mobile Studio project, which was developed by Rensselaer Polytechnic Institute to increase student's motivation and achievement in electrical engineering. With ECP, the experiment plays a central role in all learning and drives the learning process. The experiment is integrated with math and science principles, simulation, and system models, which are the core skills that engineers, and scientists develop. The objective of the ECP is for students to perform experiments together with their coursework with the sole aim of improving their motivation for the subject area [1].

ECP studies conducted in various STEM disciplines, have shown that when personal electronic devices are incorporated in experimental learning, student's engagement and motivation is increased. Many undergraduate students depend on technology to complete their daily course activities, incorporating personal electronic devices in experimental learning will be of great benefit to the students [2],[3],[4]. This study incorporated a device called the M1K device

(Analog Devices Active Learning Module - ADALM1000) in the cantilever beam experiment developed. Although studies have been published on different concepts of a cantilever beam experiment [5],[6], the authors are unaware of any that have incorporated the use of the M1K device in their cantilever beam experiment. Norman et al. [7] developed experiments on bending modal frequencies and mode shapes of cantilever beams that can only be implemented in a typical structures and material laboratory, not in a remote learning environment. Ferri et al. [2] developed a cantilever beam experiment similar to the one developed by Norman et al [7] to correct the misconceptions students may have in the area of structures and materials. Although Ferri et al. [2] provided a hands-on learning environment, the implementation and classroom evaluation showed little impact on resolving the misconceptions students had. The cantilever beam experiment designed in this study is applicable to both remote learning environment and in-person learning environment. The current study will determine the appropriateness for use outside of the classroom.

This paper presents the implementation of a hands-on experiment into structural engineering courses in the department of civil engineering at the authors' institution. As a result of the COVID-19 pandemic, colleges moved their classes online in response to public health guidelines. Several questions arose during this process: How can students perform their laboratory experiments while at home? How can students be effectively engaged during remote learning? How can the preconceptions and misunderstanding students have about structural analysis area be corrected? These questions have led to the development of a home-based hands-on experiment on bending strain in a cantilever beam. This paper focused on a home-based hands-on experiment because the skill and learning opportunity provided by the traditional on-campus laboratory experiment cannot be replaced by simulation alone. The COVID-19 pandemic has shown that there is an urgent need to develop more inexpensive home-based laboratory experiments.

Furthermore, this paper adopts the Classroom Observation Protocol for Undergraduate STEM (COPUS) to evaluate the performance of the students during the implementation of the experiment. COPUS is a protocol that enables STEM faculty to reliably characterize the activities of faculty and students in the classroom [8]. For this research COPUS was used only to characterize how the students were engaged during the experiment.

2. Experimental Concept and Theoretical Background

This experiment is designed with a half bridge type II strain gauge configuration which means that two 350 ohms strain gauges were installed on the beam while two resistors of the same resistance were connected to the bread board. The experiment in this paper evaluates the bending strain developed at exactly 0.6 inches away from the fixed support of a cantilever beam when a displacement is applied at its free end, hence the choice for type II strain gauge configuration. The displacement applied at the free end of the cantilever beam causes the beam to bend downwards making the top of the beam to stretch in tension and the bottom in compression (see Figure 1). With the top of the beam in tension and the bottom in compression because of the applied displacement, stresses and strain develop in the beam. This experiment installed two strain gauges at the top and bottom of the beam. See Figure 2 for the position of the strain gauge on the beam.

Displacement control method was used in this experiment instead of force control because displacement will be easier to measure using a ruler. The cost of purchasing very small weights to very large weights with small intervals to achieve the same displacement that could easily be displaced by hand while measuring with a rule was considered as well. The displacement applied at the free end of the cantilevered beam was converted to force (using Equation 1). The force was then converted to bending moment (using Equation 2) which was then converted to bending stress using the flexural stress formula in Equation 3. Using Hooke's law, the bending stress was converted to strain. (See equation 4). It is assumed that displacement applied is within the elastic range of the material.

$$F = \frac{3\delta EI}{L^3} \quad (1)$$

$$M = FL \quad (2)$$

$$\text{Bending Stress} = \frac{M_{max} \times C}{I} \quad (3)$$

$$\text{Strain} = \frac{\text{Stress}}{E} \quad (4)$$

Where 'δ' is the applied displacement, 'F' is the equivalent force caused by the applied displacement, 'E' is the young's modulus of the beam' material, 'I' is the moment of inertia, 'L' is the length of the beam, 'M' is the bending moment of the cantilever beam, 'C' is the vertical distance away from the neutral axis.

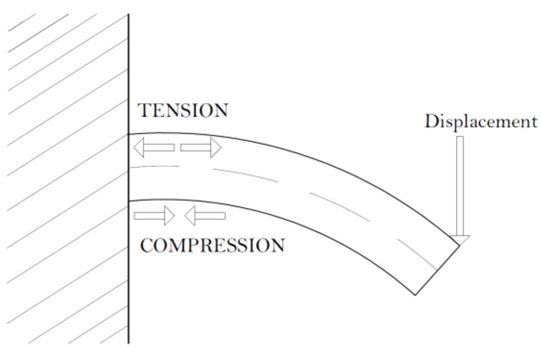


Figure 1: A cantilever beam with displacement applied at the free end.

The experimental objectives of this study are stated as follows:

- To measure deflections and strains in a cantilever aluminum beam.
- To compare the analytical and experimental values of strains in the beam.
- To be able to note the source of errors in a typical simply supported beam experiment.

The sensor used to measure strain in this experiment is the strain gauge. A strain gauge is a transducer whose internal resistance changes in proportion to the induced strain in the material to which it is bonded. Hence, it can be used to measure strain on different materials. A strain gauge is composed of thin fine metallic wires, where each strain-gauge is manufactured with its own Gauge Factor (GF). It is possible to estimate the theoretical strain using the equation below:

$$\mathrm{strain}(\varepsilon) = \frac{-2(V_t)}{GF} \times \left(1 + \frac{R_L}{R_G}\right) \qquad (5)$$

$$\text{where} \quad V_t = \left(\frac{V_{strained} - V_{unstrained}}{V_s}\right)$$

With, R_L = Lead resistance, R_G = nominal gauge resistance, and V_s = Source voltage

The strain gauge attached to the top of the beam measures tensile strain, while the strain gauge attached to the bottom of the beam, measures compressive strain. This sensitivity to strain is quantified in terms of the gauge factor which is the fractional change in electrical resistance per unit the fractional change in the length. This fractional change in length is referred to as the strain (see Equation 6).

$$\Delta L/_L \times GF = \Delta R/_R \qquad (6)$$

When a strain gauge is attached to a body that is deformed or strained, a voltage difference is developed across the Wheatstone bridge. With the aid of a Wheatstone bridge, there are different configurations and types for strain-gauges. The choice of which to use depends on the type of strain (bending or axial), and the level of accuracy required. This experiment utilized the half bridge type II configuration because it is sensitive to bending strain, while compensating for temperature over the quarter bridge configuration. The voltage difference resulting from the Wheatstone bridge is proportional to the strain and is of a relatively low magnitude. Hence the output of the Wheatstone bridge is connected to an amplifier to amplify the voltage.

In this cantilever beam experiment, the surface of the beam was first prepared for strain gauge installation. It is necessary to thoroughly clean the surface of the aluminum beam before installing the strain gauges. This ensures that the surface is free from dirt, grease, and any other contaminants. The second step was clamping the cantilevered beam to a fixed surface and then making a proper connection between the strain gauges, the circuit board, the M1K device and the computer system. The voltage readings were then collected relative to the displacement of the cantilever beam. Figure 2 shows the length of the beam and the area of the beam that was prepared for strain gauge installation. Figure 2 also show the area where the beam was clamped, and the 2 inches area labelled "sand this area" that was cleaned using 150 and 400 grit sandpaper, acetone, alcohol, water, and sterile gauze pads. The installation of strain gauge is done on both sides of the beam. Figure 3 shows a strain gauge that has been installed on one side of the beam. This study also developed an experimental manual with a step-by-step procedure to the experimental process. This experimental manual was provided to the students for easy implementation of the experiment.

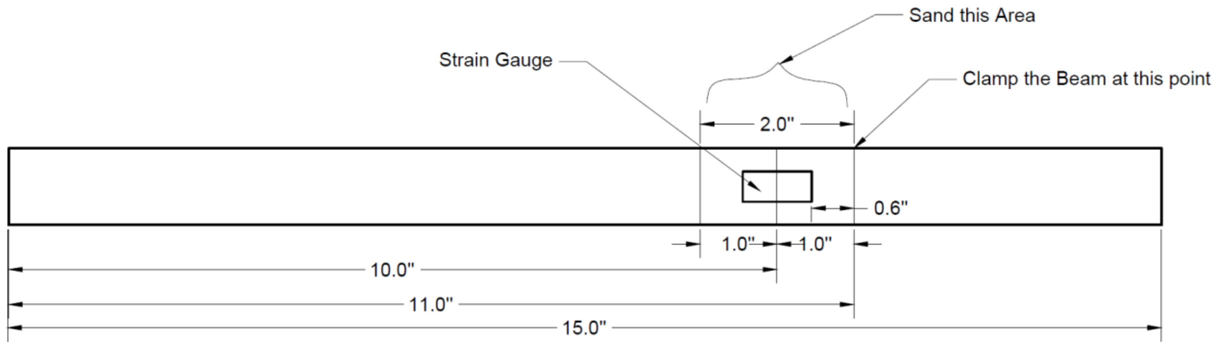


Figure 2: Beam markings and measurement

Figure 3: Strain gauge installed on one side of the beam

3. Experimental Setup

The circuit board is built with an amplifier that magnifies the difference between the positive and negative voltages generated from the strain gauge installed on the top of the beam and the one installed at the bottom, respectively. An amplifier was used in this case because the voltage change is very small. Figure 4 shows an illustration of the circuit on a breadboard. Figure 5 shows the experimental setup and the placement of the long rule to measure displacement. The circuit in the experimental setup generates a voltage signal that is proportional to the displacement of the beam via the strain gauge. The M1K device supplies 5 volts to the circuit when the device is connected to the computer system. The power supplied to the circuit board via the M1K device is what enables the strain gauge to generate results upon displacement of the beam.

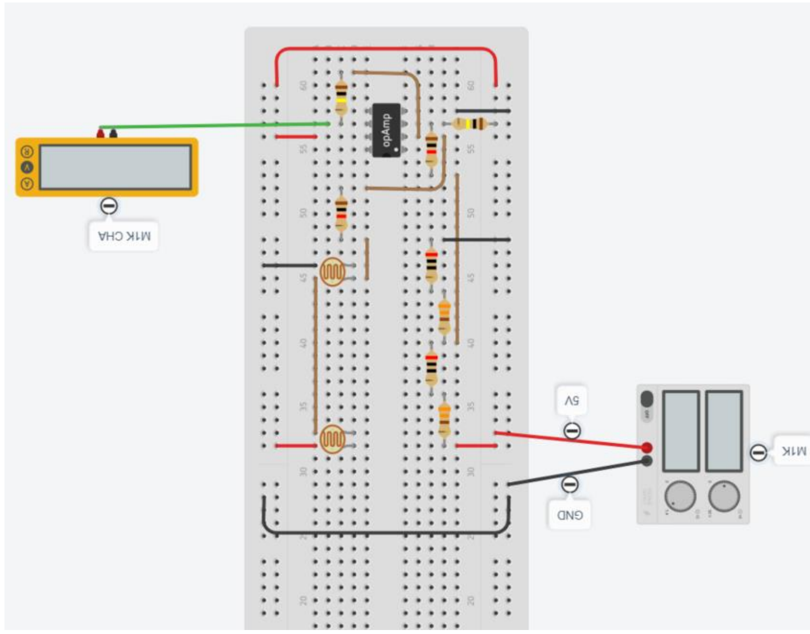


Figure 4: Electronic circuit on a prototyping board

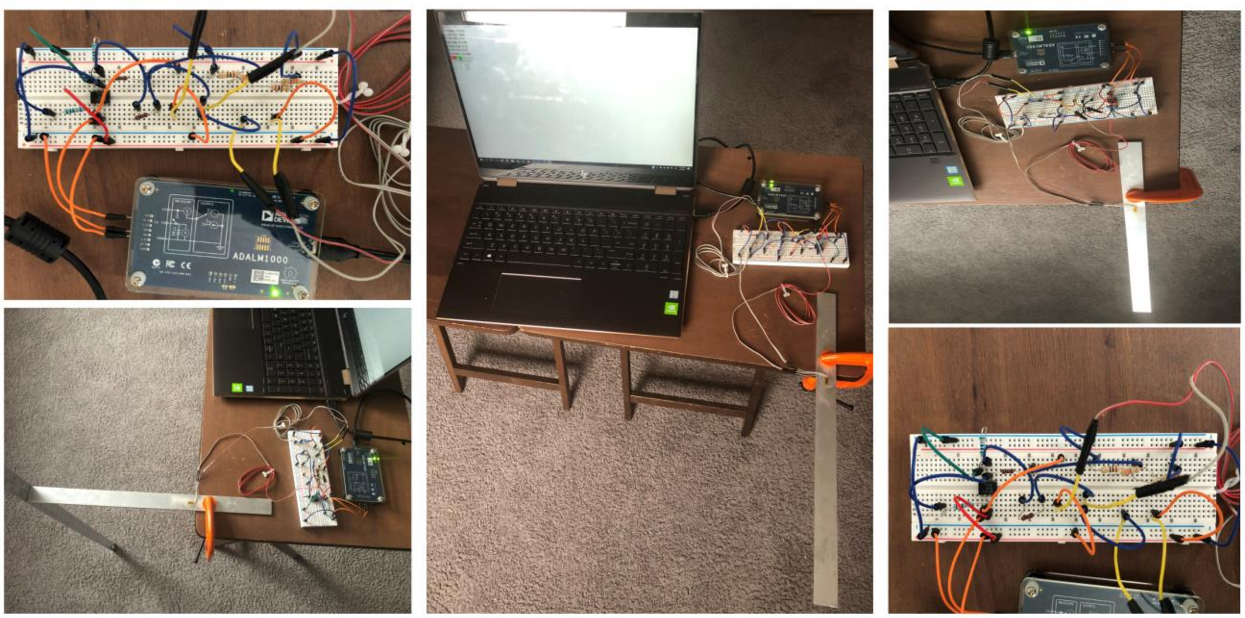


Figure 5: Experimental setup

4. Strain Gauge Calibration and Validation

Strain values for each displacement were plotted against the corresponding voltages for the respective displacement and the result is shown in Figure 6. The result shows a linear relationship between the strain and voltage. As the strain increases the voltage also increases. This means that an increase in the displacement at the free end of the cantilever beam results in an increase in voltage change. This also means that as displacement increases the strain also increases. Equation 7 is the strain gauge model developed in this paper. This model shows the relationship between voltage and strain and is only applicable to elastic range.

$$S = 0.0099V - 0.0023 \tag{7}$$

Where 'S' is strain and 'V' is voltage.

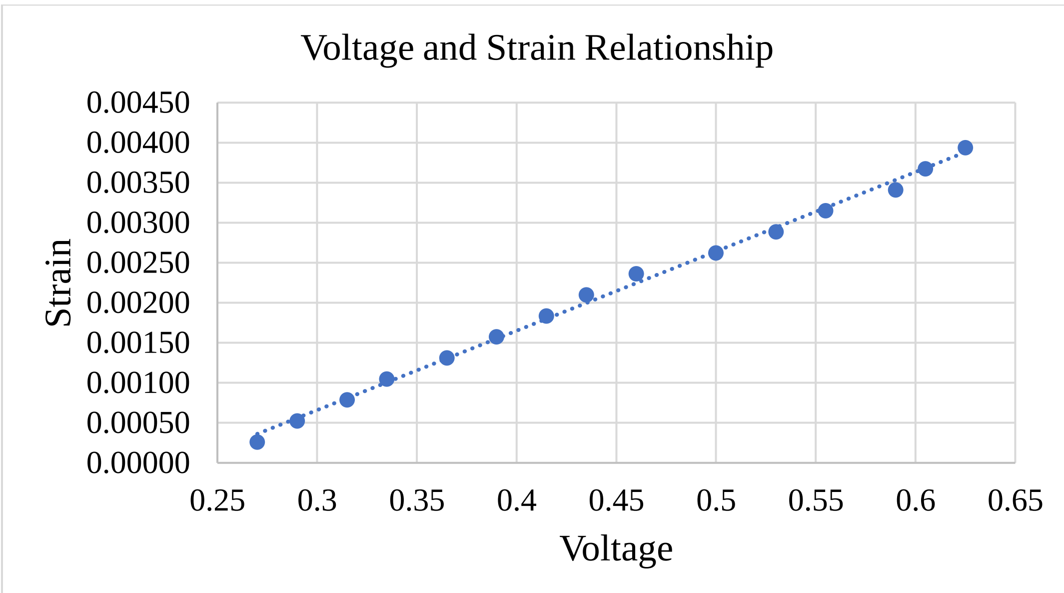


Figure 6: Relationship between the voltage and strain

A new set of data points was collected and used to validate the model. This means that the experiment was reconducted with new changes in displacement. The strain values were then estimated using equation 7 and then compared to the theoretical strain values calculated. Figure 7 shows that the theoretical strain and the experimental strain both have the same linear relationship with the displacement on the cantilever beam. A maximum and minimum percent error of 19.9% and -5.56% was observed, respectively. Possible sources of errors could be that the beam was not perfectly horizontal when clamped to the platform.

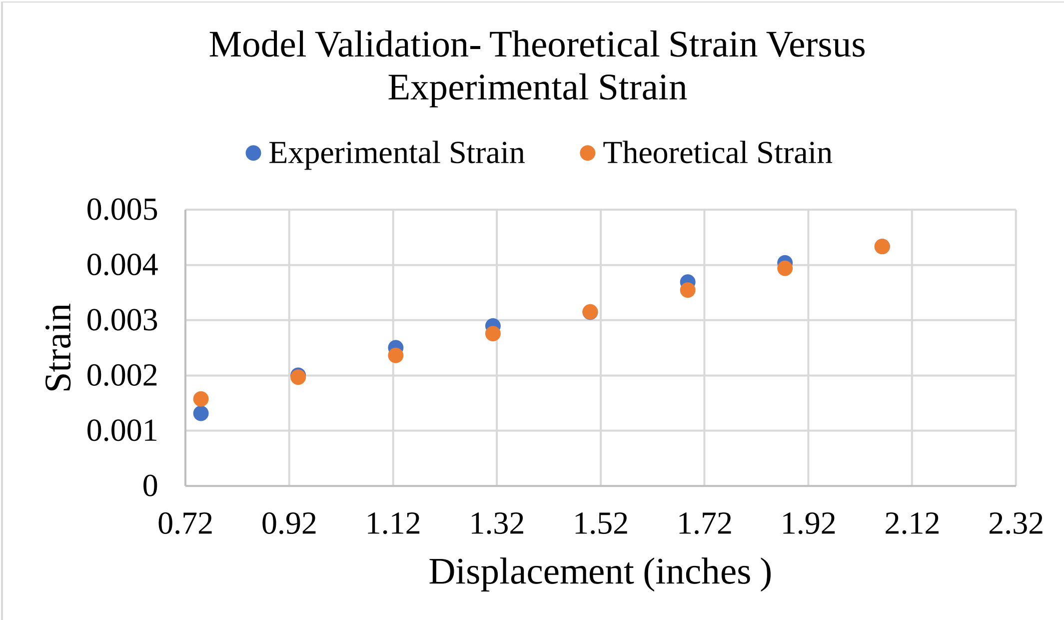


Figure 7: Model validation - theoretical strain versus experimental strain

5. Classroom Implementation and Students Activities

The students were first given a lecture about the strain in a cantilever beam, an overview of the experiment including materials used for the experiments and a detailed description of the experimental procedures to prepare them for conducting the experiment. Before conducting the experiment, the experimental apparatus was distributed to the students. Students who live within an hour of the university were encouraged to pick up the lab materials for the experiment at the authors' institution while students who lived further away or could not come to the university had the materials shipped to them. Before the implementation of the experiment all the students had a complete set of the materials needed for the experiment. See Appendices A and B for a list of the apparatus distributed to the students and those purchased by the students, respectively.

Students were also given access to a Google Drive folder that contained all instructions needed to complete the experiment. These electronic materials included laboratory manuals, pictures, videos, and other experimental guides. The experiment was conducted synchronously, via the Zoom virtual platform. Students had all their materials ready and were made to turn on their cameras while performing the experiment. Prior to the start of the experiment, students were given a pre-lab quiz to test their understanding in the subject area. The pre-lab quiz was graded and returned to the students. See Appendix C for pre-lab quiz questions.

Students were taught how to prepare the surface of the beam for strain gauge installation. The students used acetone, water, isopropyl alcohol, 150 and 400 grit sandpaper to clean the surface of the beam before installing the strain gauge on the beam. Each student installed the strain gauges on both sides of the beam. One strain gauge was installed during the synchronous class, under the supervision of the lab instructor, while the second strain gauge installation was given to the student as an assignment to be completed before the next class. See Appendix D, for a picture of a strain gauge installed by the students. During the experiment, the importance of properly cleaning the surface of the beam before installing strain gauges was emphasized to the students. Before the next class students were given feedback on their strain gauge installation. Some of the challenges they faced during this process was the ability to align the strain gauge properly with the beam. Some of the students had their strain gauges incorrectly slanted to one side (see Appendix D). Those who did not install their strain gauges correctly were given the opportunity to pick up a new set of strain gauges and redo the installation.

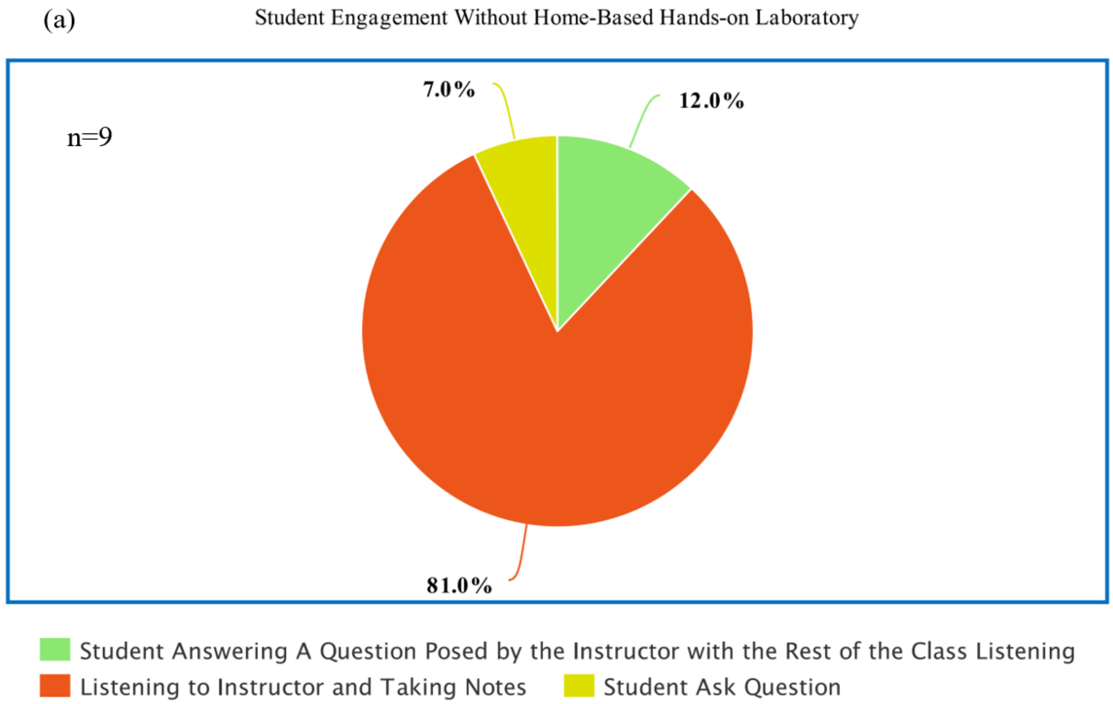
In the next class, students built their own circuit on a prototyping board. The students in this course have completed two prerequisite physics courses, including one on electricity, so they are familiar with building circuits. They were guided by the class instructor in building the circuit for this experiment. The students were able to build their own circuit before the end of the class. In addition, they were able to set up their experiment and collect data for analysis. See Appendix E for pictures of the experimental setup submitted by a student. Students worked as a team to collect data from the experiment. They were assigned into breakout rooms, in groups of two and three, to collect their data. Students worked as a team for data collection purposes; one student records the voltage readings displayed on the ALICE software while the second student deflects the beam and measure the deflection. Students measured the displacement by placing a long ruler perpendicular to the beam while they manually apply (with their hand) a downward deflection on the beam at its free end. The students change the displacement incrementally and recorded the corresponding voltage increase.

The process of building the circuit and collecting the data took about 90 minutes to complete. The students were taught how to establish a relationship between strain and voltage. With that knowledge they were able to develop a relationship between strain and voltage based on their data, compare theoretical strain with experimental strain, and estimate the percentage error between the experimental and theoretical strain. During the implementation, the students were engaged in the process and they enjoyed the implementation process. After the experiment, students were given a post-lab quiz (with the same questions as the pre-lab quiz) and an improved understanding was observed. Students were made to return the materials after the experimental activity was over. All materials for this experiment cost approximately $115 per student, for a lab kit.

6. Impact on Student Engagement

Students are often disengaged in the traditional learning approach because they are either listening or taking notes for most of the class period. One of the purposes of incorporating the home-based hands-on laboratory experiment in the class curriculum is to provide a means to reengage the students especially now that classes are online. The experiment was conducted in the Fall semester of 2020, with nine students enrolled in the class. COPUS was used to observe the implementation of the experiment as well as during the traditional learning approach. It was observed that students were effectively engaged (see Figure 8(b)) with hands-on learning when compared to the traditional learning approach (see Figure 8(a)). From Figure 8, students conducted the experiment for 53% of the class period while they only listened without engagement for 17% of the class time when compared to the traditional learning approach were, they listened without engagement for 81% of the time. It was also observed that the students were excited as they conducted the experiment. This is one of the benefits of effectively engaging the students especially in an online learning environment.

(a)



(b)

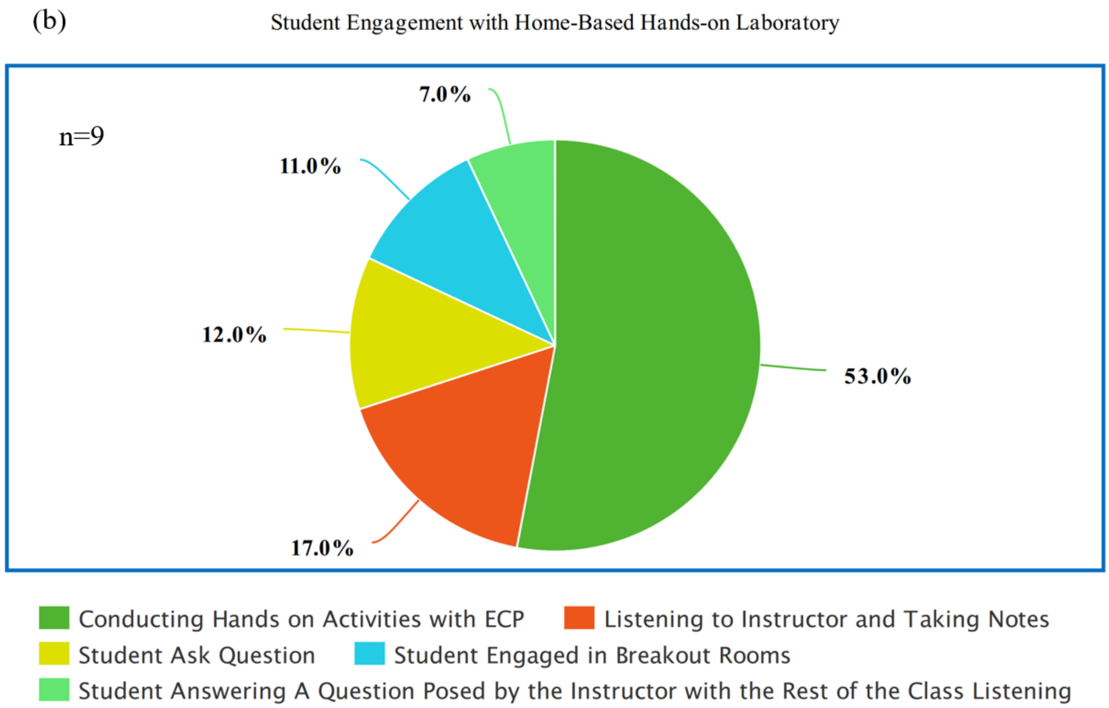


Figure 8: Student Engagement, (a) Student Engagement Without Home-Based Hands-on Laboratory, (b) Student Engagement with Home-Based Hands-on Laboratory

7. Impact on Student Motivation

The Motivated Strategies for Learning Questionnaire (MSLQ), created by Pintrich [9], was used to develop a pretest and a posttest survey which were administered to the students. Data extracted from the surveys were analyzed to quantify the impact of the home-based hand-on experiment on the students. This research analyzed data obtained for civil engineering students (who participated in the cantilever beam experiment) as well as students from other STEM discipline (students in Biology, Physics, Industrial Engineering and Transportation Systems who participated in other home-based hands-on experiment) with the objective of ascertaining whether the impact of a home-based hands-on experiment on the students would follow the same pattern. The pretest and posttest survey utilized seven main MSLQ constructs: Intrinsic Goal Orientation, Task Value, Expectancy Component, Test Anxiety, Critical Thinking, Metacognition, and Peer Learning/Collaboration, all of which were measured in this study. The survey administered to the students consisted of 50 statements and was administered to the students via an online link. The Statements in Table 1 and 2 uses a 7-point Likert scale (1-not at all true of me, 2, 3, 4, 5, 6, 7-true of me).

Table 1 shows results from the analysis that quantifies student's motivation in relation to the experiment. From the results in Table 1, there is an improvement in the motivation of the students after the implementation of the experiment. The negative sign in the percentage change for Test Anxiety construct shows that the test anxiety of students reduced after they took part in the experiment. Student became more interested in the subject area, as all the students (100%) agree that they are very interested in the subject area and they like the course content after participating in hands-on learning. Before participating in the experiment 89% of the student agree that they like the subject area and are interested in the subject area. Table 2 shows the changes in motivation of students because of implementing hands-on experiment for other STEM disciplines (Biology, Physics, Industrial Engineering and Transportation Systems). For other STEM disciplines, there was also a reduction in Test Anxiety due to implementation of hands-on experiment.

Epistemology items developed by Litman [10], were used to quantify student's perceived changes in epistemology. Table 3 shows that the interest and curiosity of the students in civil engineering improved after they participated in the experiment. Results in Table 3 also show a reduction in the frustration of the students after they took part in the experiment. Table 4 shows students' changes in epistemology in other STEM disciplines. Results for other STEM disciplines do not exactly follow the same pattern as those for civil engineering, this may be because of difference in individual students' motivation rate. Both Table 3 and 4 uses a 4-point Likert scale (1-Never, 2- sometimes, 3-often, 4-always).

Table 1: Changes in Students Motivation in Civil Engineering

		Pretest		Posttest		
MSLQ Item	**MSLQ Constructs**	**%Agree n=9**	**Mean**	**% Agree n=5**	**Mean**	**% Change**
In a class like this, I prefer course material that really challenges me so I can learn new things.	Intrinsic Goal Orientation	78	5.444	100	6.000	22
In a class like this, I prefer course material that arouses my curiosity, even if it is difficult to learn.	Intrinsic Goal Orientation	78	5.333	100	6.000	22
The most satisfying thing for me in this course is trying to understand the content as thoroughly as possible.	Intrinsic Goal Orientation	75	5.375	100	6.000	25
It is important for me to learn the course material in this class.	Task Value	78	5.444	100	6.250	22
I am very interested in the content area of this course.	Task Value	89	5.778	100	6.000	11
I like the subject matter of this course.	Task Value	89	5.889	100	6.000	11
I believe I will receive an excellent grade in this class.	Expectancy Component	89	5.889	75	5.750	-14
I am confident I can do an excellent job on the assignments and tests in this course.	Expectancy Component	89	5.778	75	5.750	-14
I expect to do well in this class.	Expectancy Component	89	5.778	75	5.750	-14
I have an uneasy, upset feeling when I take an exam.	Test Anxiety	67	4.667	50	5.000	-17
I feel my heart beating fast when I take an exam.	Test Anxiety	78	4.667	75	5.250	-3
I often find myself questioning things I hear or read in this course to decide if I find them convincing.	Critical Thinking	33	3.889	100	5.500	67
I try to play around with ideas of my own related to what I am learning in this course.	Critical Thinking	56	4.222	67	5.333	11
Whenever I read or hear an assertion or conclusion in this class, I think about possible alternatives.	Critical Thinking	56	4.333	67	5.333	11
When I become confused about something I am reading for this class; I go back and try to figure it out.	Metacognition	78	5.556	100	5.750	22
If course materials are difficult to understand, I change the way I read the material.	Metacognition	67	5.222	75	5.000	8
Before I study new course material thoroughly, I often skim it to see how it is organized.	Metacognition	78	5.444	75	5.500	-3
I try to think through a topic and decide what I am supposed to learn from it rather than just reading it over when studying.	Metacognition	78	4.889	100	5.750	22
When studying for this course, I often try to explain the material to a classmate or a friend.	Peer Learning / Collaboration	67	4.667	75	4.500	8
I try to work with other students from this class to complete the course assignments.	Peer Learning / Collaboration	56	4.333	75	4.750	19
When studying for this course, I often set aside time to discuss the course material with a group of students from the class.	Peer Learning / Collaboration	67	4.778	75	4.750	8

**MSLQ uses 7-point Likert Scale whereby 1=Not at all true of me to 7 true of me. % Agree = 5,6, &7 choices in scale collapsed*

Table 2: Changes in Students Motivation in Other STEM Disciplines

		Pretest		Posttest		
MSLQ Item	**MSLQ Constructs**	**% Agree n= 241**	**Mean**	**% Agree n=164**	**Mean**	**% Change**
In a class like this, I prefer course material that really challenges me so I can learn new things.	Intrinsic Goal Orientation	62	5.050	69	5.186	7
In a class like this, I prefer course material that arouses my curiosity, even if it is difficult to learn.	Intrinsic Goal Orientation	73	5.402	69	5.280	-4
The most satisfying thing for me in this course is trying to understand the content as thoroughly as possible.	Intrinsic Goal Orientation	81	5.707	71	5.329	-10
It is important for me to learn the course material in this class.	Task Value	90	6.208	81	5.696	-8
I am very interested in the content area of this course.	Task Value	79	5.601	71	5.317	-8
I like the subject matter of this course.	Task Value	76	5.508	74	5.317	-2
I believe I will receive an excellent grade in this class.	Expectancy Component	81	5.567	68	5.205	-13
I'm confident I can do an excellent job on the assignments and tests in this course.	Expectancy Component	79	5.574	70	5.292	-9
I expect to do well in this class.	Expectancy Component	84	5.870	73	5.416	-11
I have an uneasy, upset feeling when I take an exam.	Test Anxiety	79	5.709	71	5.410	-8
I feel my heart beating fast when I take an exam.	Test Anxiety	76	5.523	68	5.248	-8
I often find myself questioning things I hear or read in this course to decide if I find them convincing.	Critical Thinking	70	5.163	68	5.193	-3
I try to play around with ideas of my own related to what I am learning in this course.	Critical Thinking	67	5.071	65	5.112	-1
Whenever I read or hear an assertion or conclusion in this class, I think about possible alternatives.	Critical Thinking	65	5.058	66	5.155	0
When I become confused about something I'm reading for this class; I go back and try to figure it out.	Metacognition	81	5.675	76	5.484	-5
If course materials are difficult to understand, I change the way I read the material.	Metacognition	73	5.367	73	5.379	0
Before I study new course material thoroughly, I often skim it to see how it is organized.	Metacognition	69	5.254	73	5.317	4
I try to think through a topic and decide what I am supposed to learn from it rather than just reading it over when studying.	Metacognition	73	5.298	70	5.360	-4
When studying for this course, I often try to explain the material to a classmate or a friend.	Peer Learning / Collaboration	53	4.464	63	4.994	10
I try to work with other students from this class to complete the course assignments.	Peer Learning / Collaboration	57	4.774	68	5.174	11
When studying for this course, I often set aside time to discuss the course material with a group of students from the class.	Peer Learning / Collaboration	48	4.338	67	5.118	19

**MSLQ uses 7-point Likert Scale whereby 1=Not at all true of me to 7 true of me. % Agree = 5,6, &7 choices in scale collapsed*

Table 3: Students Perceived Changes in Epistemology in Civil Engineering

		Pretest		Post Test		
Statement	**I/D Scale Epistemology Items [10]**	**% Agree n=9**	**Mean**	**% Agree n=5**	**Mean**	**% Change**
I enjoy exploring new ideas.	Interest Epistemic Curiosity Scale	89	3.333	100	3.500	11
I enjoy learning about subjects that are unfamiliar to me.	Interest Epistemic Curiosity Scale	78	3.222	100	3.500	22
I find it fascinating to learn new information.	Interest Epistemic Curiosity Scale	100	3.556	100	3.500	0
When I learn something new, I would like to find out more about it.	Interest Epistemic Curiosity Scale	67	3.111	100	3.500	33
I enjoy discussing abstract concepts.	Interest Epistemic Curiosity Scale	56	2.778	75	3.250	19
Difficult conceptual problems can keep me awake all night thinking about solutions.	Deprivation Epistemic Curiosity scale	78	2.889	75	3.000	-3
I can spend hours on a single problem because I just can't rest without knowing the answer.	Deprivation Epistemic Curiosity scale	56	2.778	75	2.750	19
I feel frustrated if I can't figure out the solution to a problem, so I work even harder to solve it.	Deprivation Epistemic Curiosity scale	67	2.778	50	2.750	-17
I brood for a long time in an attempt to solve some fundamental problems.	Deprivation Epistemic Curiosity scale	67	2.667	50	2.500	-17
I work like a fiend at problems that I feel must be solved.	Deprivation Epistemic Curiosity scale	56	2.667	100	3.000	44

I/D Scale [10]**.** *A 4-point Likert Scale whereby 3 = Often and 4 = always. % Agree = 3 & 4 choices in the scale collapsed*

Table 4: Students Perceived Changes in Epistemology in Other STEM Disciplines

		Pretest		Post Test		
Statement	**I/D Scale Epistemology Items [10]**	**%agree n=241**	**Mean**	**% Agree n=164**	**Mean**	**% Change**
I enjoy exploring new ideas.	Interest Epistemic Curiosity Scale	86	3.328	85	3.238	-1
I enjoy learning about subjects that are unfamiliar to me.	Interest Epistemic Curiosity Scale	76	3.195	79	3.144	2
I find it fascinating to learn new information.	Interest Epistemic Curiosity Scale	86	3.385	80	3.231	-6
When I learn something new, I would like to find out more about it.	Interest Epistemic Curiosity Scale	80	3.236	77	3.113	-3
I enjoy discussing abstract concepts.	Interest Epistemic Curiosity Scale	78	3.152	72	3.056	-6
Difficult conceptual problems can keep me awake all night thinking about solutions.	Deprivation Epistemic Curiosity scale	57	2.721	63	2.770	7
I can spend hours on a single problem because I just cannot rest without knowing the answer.	Deprivation Epistemic Curiosity scale	58	2.721	62	2.736	4
I feel frustrated if I cannot figure out the solution to a problem, so I work even harder to solve it.	Deprivation Epistemic Curiosity scale	70	2.987	64	2.862	-7
I brood for a long time in an attempt to solve some fundamental problems.	Deprivation Epistemic Curiosity scale	61	2.815	63	2.825	2
I work like a fiend at problems that I feel must be solved.	Deprivation Epistemic Curiosity scale	64	2.857	61	2.818	-3

I/D Scale [10]**.** *A 4-point Likert Scale whereby 3 = Often and 4 = always. % Agree = 3 & 4 choices in the scale collapsed*

As part of the experiment a new device called the M1K was introduced to the students. Based on the results from the survey administered to the students, this study further analyzed the motivation of the students after using the device. Table 5 show that both students from civil engineering and other STEM discipline were motivated after using this device to conduct the experiment. All the students in civil engineering (100%) agree that the use of the device reflected their course content, reflected real practice, reflected their academic area, practice and course content, while slightly more than 50% of the students in other STEM disciplines agree the same. All the civil engineering students (100%) agree that using the device helped them develop interest in the subject area while 60% agree that they have become motivated to learn the course content because of using the device. Most of the civil engineering students (80%) agree that their knowledge in the subject area increases after they used the device, while 60% agree that using the device has increased their confidence in the subject area. The percentage change between civil engineering and other STEM disciplines, shows that students in civil engineering received more motivation when compared to students of other STEM disciplines. This may be because students have different motivation rate.

Table 5: Students Motivation Using the Device Used for the Experiment

	Civil Engineering			**Other STEM Disciplines**			
Statement	**Post % Agree n=5**	**Mean**	**STD**	**Post % Agree n=164**	**Mean**	**STD**	**% Difference**
The M1K or M2K provided opportunities to practice content	100	4.400	0.490	57	3.695	0.886	43
The use of the M1K or M2K reflected course content	100	4.200	0.400	55	3.638	0.864	45
Use of the device was relevant to my academic area	100	4.200	0.400	54	3.598	0.902	46
The use of the M1K or M2K reflected real practice	100	4.400	0.490	55	3.665	0.814	45
The time allotted for M1K or M2K use was adequate	80	3.800	0.400	49	3.506	0.884	31
The use of M1K or M2K suited my learning goals	80	4.000	0.632	48	3.546	0.881	32
My knowledge has increased as a result of use of the device	80	4.000	0.632	49	3.555	0.906	31
My confidence in the content area has increased because of use of the device	60	3.600	0.490	45	3.512	0.845	15
The hands-on M1K or M2K is important in my preparation for my future career	60	3.800	0.748	41	3.457	0.926	19
Using the Analog Device motivated me to learn the content	60	3.800	0.748	45	3.494	0.911	15
Using the device helped me to develop skills in problem solving in this subject area	80	4.000	0.632	53	3.604	0.874	27
Using the device helped me think about problems in graphical/pictorial or practical ways	80	4.000	0.632	54	3.616	0.822	26
The device helped me learn how electric circuits are used in practical applications	80	4.200	0.748	46	3.512	0.859	34
Using the device helped me recall course content	80	4.000	0.632	47	3.525	0.810	33
Using such devices help improve grades	40	3.600	0.800	42	3.391	0.900	-2
Using the device helped develop confidence in content area	40	3.600	0.800	48	3.500	0.830	-8
Using the device helped me become motivated to learn course content	60	3.800	0.748	48	3.503	0.889	12
Using the device helped me develop interest in the subject area	100	4.200	0.400	48	3.497	0.896	52
Using such devices help complete lab assignments	100	4.200	0.400	54	3.622	0.885	46

% Agree= Strongly agree and agree combined using a five-point Likert Scale

As part of the analysis, this paper evaluated the mean values, standard deviation, and p-values for each item and constructs, respectively. Sample size for the civil engineering department is small because of low enrolment due to the pandemic. The project is still ongoing; this means that qualitative as well as quantitative data will be improved by increasing the sample size.

Table 6 shows the overall descriptive statistical analysis and results from the paired sample t-test analysis on the MSLQ construct used in this study. It is seen that there is a difference in both the civil engineering department and other STEM discipline based on individual students' motivation rate. From the result, it is seen that students in the civil engineering department who participated in the home-based hands-on cantilever beam experiment experienced some improvement to their motivation level in all constructs listed in Table 6 (Intrinsic Goal Orientation (post-6.000>pre-5.384), Task Value(post-6.083>pre 5.704), Test Anxiety (post-5.125>pre-4.667), Critical Thinking (post-5.389>pre-4.148), Metacognition (post-5.500>pre-5.278), Peer Learning / Collaboration (post-4.667>pre-4.593)). The students in other STEM Disciplines also showed some improvement to their motivation in Critical Thinking (post-5.153>pre-5.097) and Peer Learning / Collaboration (post-5.095>pre-4.525)).

For the paired sample t-test conducted in this study, a p-value of 0.05 was considered significant. From Table 6, the civil engineering department obtained a p-value less than 0.05 for Intrinsic Goal Orientation (0.003) and Critical Thinking (0.005) indicating that there is a significant difference in students' motivational level based on these constructs. Task Value (0.086), Expectancy Component (0.222), Test Anxiety (0.170), Metacognition (0.372), and Peer Learning / Collaboration (0.372) however did not show any significant difference. Other STEM disciplines obtained a significant difference of 0.034 and 0.046 in Peer Learning / Collaboration and Expectancy Component respectively with no significant difference in Intrinsic Goal Orientation (0.591), Task Value (0.279), Test Anxiety (0.147), Critical Thinking (0.244), and Metacognition (0.901).

Table 6: Descriptive Statistics Values and P-Values for MSLQ Constructs

	Civil Engineering					**Other STEM Disciplines**				
	Pretest		**Posttest**		**TTest**	**Pretest**		**Posttest**		**TTest**
MSLQ Constructs	**Mean**	**STD**	**Mean**	**STD**	**P-value**	**Mean**	**STD**	**Mean**	**STD**	**P-value**
Intrinsic Goal Orientation	**5.384**	0.046	**6.000**	0.000	**0.003**	5.386	0.268	5.265	0.059	0.591
Task Value	**5.704**	0.189	**6.083**	0.118	0.086	5.773	0.310	5.443	0.179	0.279
Expectancy Component	5.815	0.052	5.750	0.000	0.222	5.670	0.141	5.304	0.087	**0.046**
Test Anxiety	**4.667**	0.000	**5.125**	0.125	0.170	5.616	0.093	5.329	0.081	0.147
Critical Thinking	**4.148**	0.189	**5.389**	0.079	**0.005**	**5.097**	0.046	**5.153**	0.033	0.244
Metacognition	**5.278**	0.255	**5.500**	0.306	0.372	5.399	0.165	5.385	0.062	0.901
Peer Learning / Collaboration	4.593	0.189	4.667	0.118	0.667	**4.525**	0.183	**5.095**	0.075	**0.034**

Descriptive analysis and paired sample t-test was also conducted on the epistemology items for both civil engineering department and other STEM disciplines. Although there is no significant difference in the epistemology items for both civil engineering department and other disciplines there is an improvement in the interest and curiosity of the students (Interest Epistemic Curiosity Scale (post-3.450>pre-3.200).

Table 7: Descriptive Statistics and P-Values for Epistemology Items

	Civil Engineering					Other STEM Discipline				
	Pretest		Posttest		TTest	Pretest		Posttest		TTest
I/D Scale Epistemology Items [10]	**Mean**	**STD**	**Mean**	**STD**	**P-value**	**Mean**	**STD**	**Mean**	**STD**	**P-value**
Interest Epistemic Curiosity Scale	**3.200**	0.257	**3.450**	0.100	0.128	3.259	0.086	3.156	0.070	0.101
Deprivation Epistemic Curiosity scale	**2.756**	0.0831	**2.800**	0.187	0.681	2.820	0.099	2.802	0.044	0.749

8. Conclusion

This study has designed and implemented a home-based hands-on laboratory experiment to bridge the gap in the learning difficulties that institutions may be facing because of the pandemic. Many institutions have moved their classes to online and remote learning. Therefore, it is important to replace the traditional online laboratory experiments with home- based hands-on laboratory experiment as students will be attending their class online while at home. The major goal was to design and conduct home based hands-on experiment and analyze the impact of the experiment on civil engineering students and also analyze the impact of hands-on learning on other STEM disciplines.

The experimental design goal was to simplify the concepts of bending strain in a cantilever beam experiment using hands-on learning, so that students can better understand the concept of the subject area. This study designed the experiment in a way to excite the students because an excited student is a motivated student. During the implementation of the experiment, students were effectively engaged as they performed the experiment themselves with guidance from the class instructor. Students also expressed their excitement and enthusiasm about the experiment after they took part in it. It was observed that students' excitement was because of how much they were engaged during the implementation of the experiment and they found the class to be fun. In response to the pretest survey one student stated: "I really enjoyed working with this device, this was a very cool experience. Technologies are something else, this was very intriguing". Students' performance in the pre-lab quiz on stresses and strain also showed an improvement in their understanding of stresses and strain. Many of the student did not know that strain is dimensionless but after the experiment they understood that strain is dimensionless based on their response to the post-lab quiz.

This study further conducted a descriptive analysis and a paired-sample t-test analysis based on quantitative data obtained from pre and posttest surveys administered to students of the civil engineering department as well as students from other disciplines. Results show that there is some improvement in students' motivation level due to the implementation of hand-on learning.

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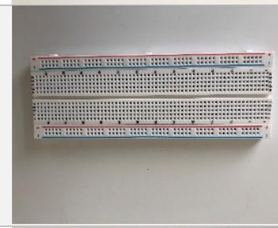
APPENDICES

Appendix A: List of materials distributed to the Students.

S/N	Name of Apparatus	Picture of Apparatus
1	A pack of two strain gages	
2.	Vernier Caliper	
3	M1k Device	
4	Long rule	
5	Transparent Tape	
6	150 Grit Sand Paper	

7	400 Grit Sandpaper		
8	C-Clamp		
9	Bread Board		
10	Sterile Gauze Pad		
11	Jumper Wires		
12	Tape Measure		
13	Pack of resistors and one Amplifier (Two 330-ohm Resistor Two 20-ohm Resistor Two 100K-ohm Resistor Two 1 kilo ohm resistor One Amplifier (7611 BCPA H9522))		

14	Super Glue		
15	Hand Gloves		

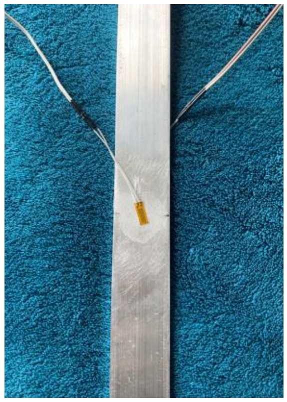
Appendix B: List of Apparatus purchased by students.

S/N	**Name of Apparatus**	**Picture of Apparatus**
1	Acetone (purchased by Students)	
2	Isopropyl Alcohol (purchased by Students)	

Appendix C: Pre and Post Lab Quiz

1. What is your understanding of Stress?
2. What is your understanding of Strain?
3. What is the unit of stress and strain?
4. What is a strain gauge?
5. What does a strain gauge measure?
6. Why is it important to measure Strain?

Appendix D: Sample of Strain gauges installed by the students



Appendix E: Sample Experimental Set up by Students