Initial impact of an experiment-centric teaching approach in several STEM disciplines

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Dr. Oludare Owolabi, a professional engineer in Maryland, joined the Morgan State University faculty in 2010. He is the director of the Center for Sustainable Transportation Infrastructure Development, Smart Innovations and Resilient Engineering Research at Morgan State University and the Interim Associate Chair in the Department of Civil Engineering as well as the director of the Civil Engineering Undergraduate Laboratory. He is the accreditation coordinator and the Chair of the curriculum for the CE department. He has over 25 years of outstanding experience in practicing, teaching and research in Civil Engineering. He is also an expert in, geotechnical engineering, field experiential education, sustainable infrastructure development and management, advanced modeling and possesses the required expertise to address the challenges of advanced material research and development. His academic background and professional skills allow him to teach a range of courses across three different departments in the school of engineering. This is a rare and uncommon achievement. He is a great proponent of experiential learning pedagogy.

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Dr. Akinyele Oni, Morgan State University

Dr. Akinyele Oni is a faculty in the department of Biology at Morgan State University, Baltimore, Maryland. He earned academic degrees in the Biological Sciences, Chemical Sciences, Criminal Justice (Forensics), and Bio-Environmental Sciences at B.S., M.S., and Ph.D. levels respectively. Having worked in the

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Dr. Adedayo Ariyibi, Morgan State University

Dr. Adedayo Ariyibi is a faculty in the Department of Biology, Morgan State University in Baltimore Maryland. Prior to joining the department in 2010, the Department of Veterinary Biochemistry, Physiology and Pharmacology of the Veterinary School, University of Ibadan, Nigeria appointed Ariyibi as Lecturer 11 and later Lecturer 1 to pioneer the teaching and research in Veterinary Biochemistry from 1992 to 2000. Dr. Ariyibi relocated to the United States for Post-doctoral appointment at Carver Research Center and concurrently served as an Adjunct Assistant Professor in the Department of Biology at Tuskegee University from 2001 until 2010. Dr. Adedayo Ariyibi, a Veterinarian by profession, trained at the University of Ibadan, Nigeria where she earned a Doctor of Veterinary Medicine degree and an MSc in Biochemistry. Ariyibi's research area of interests are Using Innovative Technology and Techniques to Enhance and Enrich the Learning Experience of Science in and outside the confinement of a classroom and laboratory.

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Ms. Caroline Ndirangu has earned a Bachelors degree in Science from The University of Nairobi, Kenya and is currently pursuing a Master's degree in Science (Biology) at Morgan State University, Baltimore, Maryland. She is currently working in a molecular microbiology lab for her thesis and as a research assistant for the Experiment Centric Pedagogy (ECP) project that aims to promote students' academic achievement in STEM.

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Dr. Mehdi Shokouhian, Morgan State University

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.

Ms. Sotonye Ikiriko, Morgan State University

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 conferences across the United States.

Dr. Antony Kinyua, Morgan State University

Dr Kinyua is an Associate Professor of Nuclear Science and currently affiliated to the Physics Department at Morgan State University (MSU) as an adjunct faculty member, teaching Engineering Physics and Earth Sciences. He has more than 30 years' experience in quality control of material products by use of Nuclear and Related Analytical Techniques (NRATs) and the teaching of engineering principles of momentum and the changing mass of a rocket. As part of his course in 2014 he participated in the installation and launching of the MSU Weather Station that received campus wide publication (https://news.morgan.edu/morgan-launches-new-campus-weather-station/). Through the MSU-NASA GESTAR program, he has also participated in the training of MSU students in Satellite data analysis and recommended some to NASA scientists as student interns. Since 2016, Dr. Kinyua has participated in some training projects with All Nations University (ANU) in Ghana, West Africa that have led to the development and signing of Memorandum of Understanding (MOU) with Morgan State University and NASA that culminated in the launch of Ghana's first historic satellite GhanaSat-1 in July 2017.

Initial impact of an experiment-centric teaching approach in several STEM disciplines

Abstract

According to National Science Foundation data, the percentage of college-aged Blacks in the United States population is five to seven times the African American B.S. degree recipients in the geosciences, physics and engineering disciplines. Since Historical Black Colleges and Universities produce a disproportionate number of African American STEM graduates, there is an urgent need for them to increase their focus on broadening STEM participation among these students. There are untapped opportunities to develop intervention strategies and programs to increase recruitment, retention, and success of minorities in STEM and the workforce. Experiment-Centric Pedagogy (ECP) has been successful in promoting motivation and enhancing the academic achievement of African American electrical engineering students. ECP uses a portable electronic instrumentation system, paired with appropriate software and sensors, to measure a wide range of properties, such as vibration and oxygen levels.

This work in progress describes the initial adaptation of an evidence-based, experiment-focused teaching approach in biology, civil engineering, industrial engineering, and physics. Instructors use ECP for in-class demonstrations, for cooperative group experiments, and for homework assignments. The paper will highlight the criteria used for selection of initial experiments to adapt, the modifications made, and resulting changes in the course delivery. Preliminary results using measures of key constructs associated with student success, such as motivation, engineering identity, and self-efficacy are provided. This project is conducted at a historically black college/university and most participants are from groups historically underrepresented in STEM.

Introduction

According to National Science Foundation data, African American students comprise 2% of the B.S. degree recipients in the geosciences, 2.6% in physics and 3.9% in engineering, while Blacks comprise 14.9% of the college-aged population [1]. Thus, there are opportunities to increase the representation of African American students in these and other STEM fields. Experiential learning has been shown to increase student learning and engagement in engineering courses. One such intervention strategies is a high impact, evidenced based experiential pedagogy called experiment-centric pedagogy that has been successful in promoting motivation and enhancing achievement among African Americans especially in electrical engineering. The term ECP originates from 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 Mobile Studio I/O Board, a personal electronic instrument, was used as the technology to support the ECP. It is a portable, inexpensive, but highly useful hardware platform, which recreated a classroom or laboratory environment e.g. at home. When coupled with the Mobile Studio Desktop software, the system duplicated a large amount of the hardware often used to teach electrical engineering, computer engineering, physics and K-12 technology-oriented courses.

There was a lot of refinement of the project through pilot studies and subsequent results showed that the use of personal electronic instruments increases the level of student engagement and motivation [2], [3]. Prior studies addressed the barriers and the benefits of the Mobile Studio I/O Board both at institutional and instructional levels [3]. Apart from facilitating the development of engineers with a system view of engineering design, the tool can be utilized to teach experimental concepts such as simulation, measurement, debugging techniques, and the impact of real-world variables. Similar tools are now available through National Instruments, Analog Devices, and other companies. When this pedagogy is applied to teaching and learning activities the students easily utilize the hardware on a wide variety of hands-on experiments [4]. Several institutions have utilized mobile hands on STEM pedagogy in Electrical and Computer Engineering (ECE). Currently, there are 13 HBCUs with ECE programs and some engineering programs in Puerto Rico that are also utilizing the pedagogy. ECE courses have been redesigned in order to allow students to design and conduct experiments outside the laboratories. The Board also facilitated the conversion of face-to-face laboratory experiments into online experiments. Faculty (95%) stated that students were more motivated and had higher engagement with course content. The results from the 13 HBCUs implementing the experimental-centric pedagogy showed that: (i) faculty and students benefited from the use of these devices, (ii) students and faculty reported higher level of interest and motivation, (iii) greater participation in hands-on, experiential learning resulted in a higher score in knowledge gains, interest in the degree program, and ability to function as a professional engineer. The mobile boards have also been utilized in other disciplines such as mechanical engineering using two experiments developed and tested in a class. [5-12].

Connor et. al. observed that to successfully adopt and incorporate innovative educational devices into curricula within and across multiple institutions, understanding the potential advantages is essential, but understanding the barriers that can occur is just as important to ensure the effectiveness of implementation. For the Mobile Studio project, they identified barriers as: (i) reflected experience of both students and instructor, (ii) the use and the development of supporting resources to the device and, (iii) availability and accessibility of the device [3]. They suggested that the barrier of instructor experience can be alleviated by an increase in instructor awareness of the importance and usability of the Mobile Studio I/O boards for student learning conveyed through training and collaboration with institutions already utilizing the pedagogy. According to their findings whether the students, teaching assistants or instructors are experienced or not, student perceptions of Mobile Studio effectiveness consistently exceed 50%, even in courses where they originally come to class without any interest in the subject (e.g., mechanical engineering students in ‘Electronic Instrumentation’), especially when they are given the time and resources to work in such a new subject at their own pace.

As the adoption of mobile hands-on learning using Mobile Studio, and similar platforms, spreads to more campuses and additional supporting materials are made available, the remarkable results obtained will continue to improve. Mobile, hands-on STEM has been implemented and studied in multiple NSF funded projects. In all cases, hands-on learning has been successfully implemented at low cost, with more engaged students and instructors, and hands-on learning implemented in courses that were traditionally only theory based. Although the development and spread of this exciting new approach to STEM education argues for broad application, the documented case for its adoption is not yet at the stage where all STEM educators can fully appreciate its merit [12-18].

This study seeks to extend the implementation and assessment across other STEM fields at Morgan State University, one of the HBCUs involved in the initial adoption. As noted by Connor et al, the hands-on pedagogical approach need not be limited to courses in electrical engineering as engineers and scientists in a rapidly growing number of disciplines rely on electronic instrumentations in their daily work [19]. Therefore, the development, documentation, and dissemination of mobile hands-on pedagogy beyond the field of electrical engineering could enhance student learning and interest in all STEM disciplines.

Research Approach

This work in progress describes the initial adaptation of an evidence-based, experiment-focused teaching approach in biology, civil engineering, industrial engineering, and physics. Instructors use ECP for in-class demonstrations, for cooperative group experiments, and for homework assignments. It has been noted that experiential learning connects contents to real-world applications and such learning experiences have been instrumental in improving student performance and achievement especially among minority students in both face-to-face and online settings [12-23]. The paper will highlight the criteria used for selection of initial experiments to adapt, the modifications made, and resulting changes in the course delivery. Preliminary results will be provided using measures of key constructs associated with student success, such as motivation, engineering identity, and self-efficacy. This study builds upon accomplishments in enhancing students' engagement in electrical engineering and extends the ECP to seven other STEM disciplines, although this paper will focus on four of these disciplines. In this paper, we seek to address the following subset of the project high-level **research questions**:

1. Does Experiment-Centric Pedagogy enhance student learning, motivation and curiosity beyond the field of electrical engineering?
2. How does the implementation of ECP impact students' learning in the various STEM fields?

The following **hypotheses** will be used to test the above research questions.

1. ECP will enhance student learning, motivation and curiosity beyond the field of electrical engineering as engineers and scientists in a rapidly growing number of disciplines increasingly rely on electronic instrumentation in their daily work.
2. Participants (both students and faculty) will experience higher general satisfaction with and positive perceptions of the hands-on experiences that were used to support learning.
3. Use of experimental centric pedagogy supported through a mobile multi-function instrument will contribute to increase in proven prerequisites to learning such as their self-efficacy and ability to learn.

A modified (non-random) Solomon Four experimental design is used with a set of students in a section of a course, with more than one section, using the ECP approach and the other section not receiving the pedagogy. Formative and summative assessment results of the impacted classes (two+ in each discipline) should demonstrate the "enhanced student learning and motivation" with course grades compared to control group or previous course administrations. Additionally, course evaluations, and measurements of cognition, engagement, and motivation will be determined using the Motivated Strategies for Learning Questionnaires (MSLQ) [24] amended with specifically designed additional items or measures to capture the project's intervention.

During the planning phase for the project, the following criteria were developed for selecting courses in each discipline for the pilot test implementation of ECP in Spring 2020: 1) Courses where electronic instrumentation is used to acquire experimentation data; 2) Adequately developed course structure with modules where ECP can be seamlessly implemented; 3) Adequate knowledge of the existing probes/sensors/interface that is currently been utilized in experimental data acquisition; 4) Feasibility of conversion of the probes/sensors/interface to electrical signals that can be connected to the personal electronic instrument; and 5) Ability to design course module that is aligned with the ECP template.

Curriculum Development

In order to improve learning outcomes in each discipline, learning objectives are structured to progressively move up the scale of Bloom's taxonomy. Assessment is also varied, following Bloom's hierarchy of cognitive skills, as the adopted hands-on pedagogy facilitates the utilization of skills and abilities. The resulting changes in the course delivery is captured using the ECP module instructional design form which captures the purpose of the module, instructional process to be adopted, formative/summative assessment, differentiated instruction and instructor reflection. Table 1 illustrates the process that was used during the curriculum development process to ensure the electrical engineering team developing the circuit to support the experiment understood the interaction with the content expert (user) and the assessment team. The module(s) developed for each course is outlined below.

Biology: The module developed for the Biology 101 course in the pilot phase was designed to illustrate the scientific method. The existing experiment involved measuring the pulse rate using a commercially available device before and after exercise for hypothesis testing. The redesigned experiment involved using a photoplethysmograph sensor connected to a personal electronic instrument (ADALM2000) with the software displaying the pulse and pulsatile blood flow. The experimental procedure remains the same. Based on user feedback the sensor is enclosed in a 3D printed housing to increase accuracy of measurement and increase user acceptance. Figure 1 and Figure 2 below show the final experimental setup and results.

Civil Engineering: In the civil engineering curriculum, two new modules were designed to enhance student understanding by utilizing ECP to introduce deflection and vibration concepts by acquiring experimental data using strain gauges and accelerometers. Two instructional modules deflection of beam and vibrations of cantilever were designed. The beam deflection module is placed within the Mechanics of Materials and laboratory course of the Civil Engineering curriculum, a lower level course. In the past students found it difficult to grasp the underlying guiding principles of beam deflection. This module was developed to visualize the relationship between deflection, load, modulus of elasticity and second moment of area. In order to improve students learning outcome, the module objectives have been structured to move progressively upward Bloom's taxonomy as stated in the attributes that students will be able to accomplish at the end of the module. During the module students are introduced to the personal electronic instrument (ADALM1000 or M1K) and exposed to the concept of beam deflection. Students are divided into groups, and each group is assigned both in-class and out of class group activities. Figure 3 below shows the deflection experiment setup during user testing phase.

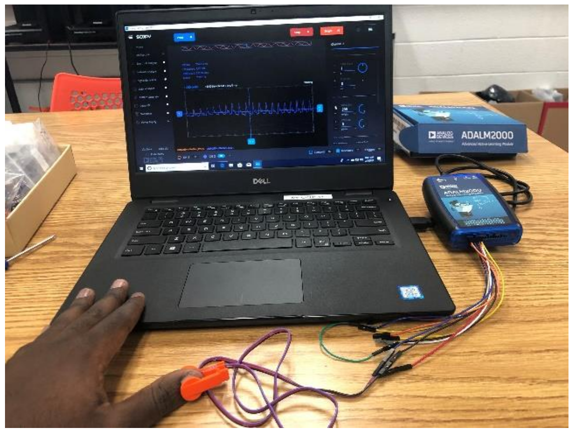


Figure 1: Final setup for photoplethysmography

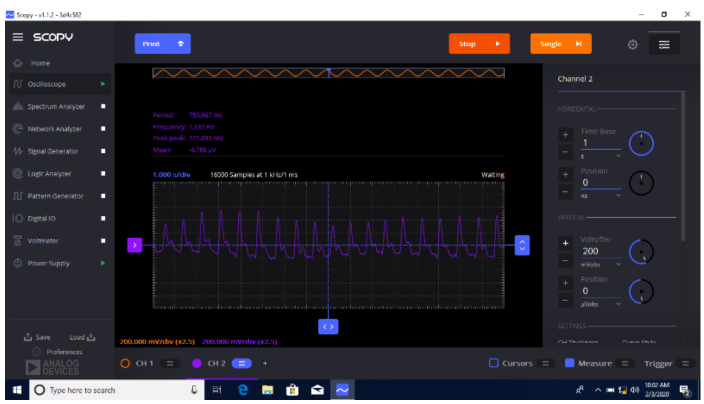


Figure 2: Screenshot for Scopy software interface displaying pulses in real time using an oscilloscope

The vibration in a cantilever beam module is introduced in the upper level Dynamics course. Prior to taking this module, students are expected to be able to apply Newton's laws of force equilibrium to determine axial forces, shear forces, and bending moments in a statically determinate beams as well as calculate and use simple deflection table to determine the defection in a statically determinate beam. In this module the strain and acceleration parameters of a vibrating beam will be determined through the strain gauge and the accelerometer that are connected to the M1K board. Upon the completing of the module students will be able to determine the frequency of vibration of a cantilever beam, describe the deflection curve and vibration of a horizontal cantilever beam under a vertical load, determine the frequency of vibration and inertia effect on a vibrating beam, determine the deflection and acceleration in a vibrating cantilever beam and compare results to theoretical calculation, and conduct an experiment to take linear measurements and evaluate beam properties.

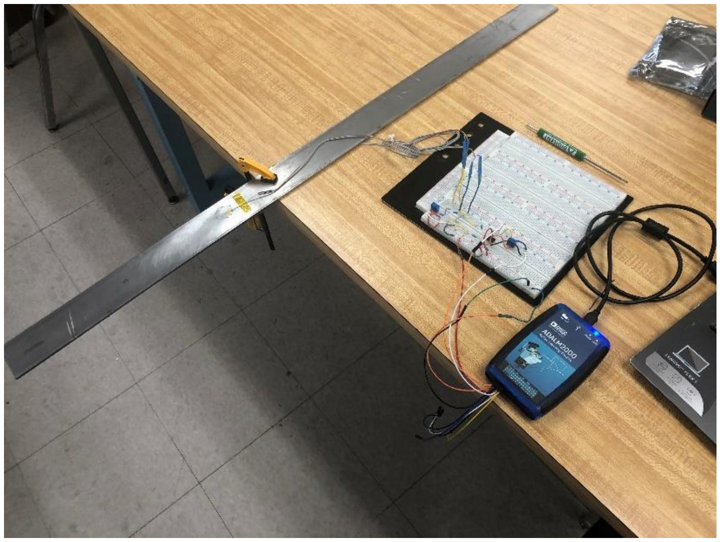
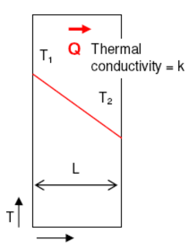


Figure 3: Experimental setup for deflection experiment - ruler instrumented with strain gauge and bridge circuit

Industrial Engineering: The first pilot module for industrial engineering is an existing laboratory exercise that introduces students to calorimetry by designing an apparatus to measure heat loss from a system. Students are introduced to basic concepts of different modes of heat transfer, heat properties of different materials and Fourier's law of conduction with the governing equation by first performing a hand-on experience on heat transfer. This module is placed in the middle level thermodynamics course of the industrial engineering curriculum. After the completion of this module, students should be able to (i) use Fourier's Law of heat conduction to determine rate of heat flow (Q/t) and heat rate constant (K) when given other parameters such as dimensions of the materials and temperature at both ends of materials, (ii) determine the thermal conductivity of different materials (such as steel, brass, copper and aluminum) and (iii) determine which material is suitable to be selected for other applications considering the thermal conductivity of the materials. Following are the questions that have been developed to demonstrate students' mastery of the concepts that ECP will be used improve students learning outcomes in this module:

Problem 1: Determine the rate of heat transfer by conduction per unit area, by means of conduction for a furnace wall made of fire clay. Furnace wall thickness is 6" or half a foot. Thermal conductivity of the furnace wall clay is 0.3 W/m·K. The furnace wall temperature can be taken to be same as furnace operating temperature which is 650^0C and temperature of the outer wall of the furnace is 150^0C.



Problem 2: A rectangular fin has a width of 4.1 cm, a thickness of 0.5 cm and a length of 3 cm. The fin material has thermal conductivity of 237 W/m ºC. The base of the fin is at 100 ºC and it is transferring heat to air at 30 ºC. The heat transfer coefficient is 35 W/m^2 ºC. Would the heat transfer improve if this fin were replaced by four cylindrical fins of the same length with a diameter of 0.5 cm equally spaced in the same base area as the rectangular fin?

Table 1: ETA-STEM curriculum development steps

Steps	Description	Documentation/Output
Requirements	• Identify learning outcomes of module or course • Examine current instrument or laboratory setup • Determine range of physical measurements • Determine expectations for GUI	• Laboratory handout or manual • ETA-STEM ECP Module • Pictures
Research	• Identify sensors and signal conditioning • Build and test circuit using M1K or M2K	• One- or two-page summary of sensor research • Parts list for prototyping • Circuit diagram and analysis
User Input	• Demonstrate to instructor(s) and obtain feedback • Discuss improvements, permanent structure and schedule for classroom implementation	• One-page or two-page summary of meeting with date and attendees
Permanent Structure	• Design PCB for circuit • Determine need for sensor or circuit enclosures	• Identify learning outcomes of module or course • Parts list for prototyping • Circuit diagram and analysis • Laboratory handout (draft)
User Input	• Demonstrate to instructor(s) and obtain feedback • Agree on improvements or schedule for classroom implementation	• One-page summary of meeting
Prepare for delivery	• Determine course configuration – number of stations.	• Parts list for classroom • Technology needs for classroom • Laboratory handout
Classroom implementation	• Pre-survey (MSLQ and device exposure) • Pilot ETA-STEM module • Pre-survey (MSLQ and device exposure)	• Summary of observation

Physics: In the physics course selected for the pilot semester, most of the concepts are related to circuits and the use parallels that of electrical engineering. Thus, most experiments are not being redesigned, instead, the personal electronic instrument (M2K) is utilized as source and measurement units to allow for data collection.

Preliminary Results

Table 2 provides a summary of the courses in the which modules are being piloted in the Spring 2020 semester and the number of students impacted. It is expected that the ECP will improve students' motivation and achievement in each of their disciplines. It is envisaged that students will effectively achieve the stated learning objectives as well as demonstrate mastery of the expected competencies at each phase.

Table 2: Data on course implementation in four disciplines

Disciplines	# of Modules Developed	# of Courses (# of sections)	# of students	Pre-Test Students	Post-Test Students
Biology	1	2 (3)	76	53	22
Civil Engineering	2	1 (1)	30	--	--
Industrial Engineering	1	1 (1)	37	30	4
Physics	2	2 (2)	11	6	6

As a part of this larger project, we collected preliminarily data from three classes (N =89 pre-test vs. N = 32 post-test). In the pre-test, 81 students identified as African Americans; 50 as female students and 39 as male students. All students reported that they had not heard of or seen or used the personal electronic instruments (ADALM1000 or ADALM 2000) before. Among 12 students, there were eight juniors, two sophomores, one freshman and one senior from a wide range of disciplines including health education, social work, screen writing and animation, civil engineering, psychology, hospitality management, and business administration. Students indicated a higher level of curiosity where they said “I enjoyed exploring new ideas” (40%), “I enjoy learning about the subject test” (40%), “I find it fascinating to learn new information” (40%), and “I enjoy discussing abstract concepts” (50%). This small sample from one class also indicated important information regarding student success (see **Error! Reference source not found.**), such as intrinsic goal motivation e.g. the most satisfying thing for me in this course is trying to understand the content as thoroughly as possible, 40%; extrinsic goal orientation e.g., Getting a good grade in this class is the most satisfying thing for me right now, 90%; and task value e.g., It is important for me to learn the course material in this class, 60%.

Does Experiment-Centric Pedagogy enhance student learning, motivation and curiosity beyond the field of electrical engineering?

Analog devices (ADALM1000 or ADALM 2000) were integrated into the courses during the Spring 2020 semester and 32 students completed the post-test survey to share their lab experiences. The students who took post-test surveys were enrolled in Biology, Industrial Engineering and Physics courses. There were disruptions due the outbreak of COVID-19 in the delivery of the civil engineering experiments as well as data collection. Of the 32 participants who completed the post-test, 21 were female students and seven were male students. The responses to the survey show a slight increase in learning and motivation (Table 3).

This preliminary sample indicated areas related to student success that require further investigation such as intrinsic goal motivation e.g. *The most satisfying thing for me in this course is trying to understand the content as thoroughly as possible*, 2.17 mean vs. 2.43 mean in post-test; extrinsic goal orientation e.g., *Getting a good grade in this class is the most satisfying thing for me right now*, 1.45 vs 2.43 in post-test; task value e.g., *It is important for me to learn the course material in this class*, 2.06 vs. 2.25 in post-test. Students had a disrupted semester and these items will be observed in future administrations of the survey.

Table 3. Mean differences in Pre-test (N =89) and Post-Test (N = 32) on Learning and Motivation Scales. Note: 1 = always, 2= often, 3 = sometimes, 4 = never.

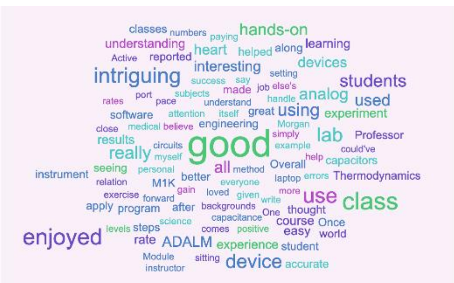
Items	**Pre-test Mean**	**Post-test Mean**
I enjoyed exploring new ideas	1.66	1.50
I enjoy learning about subjects that are unfamiliar to me.	1.98	1.82
When I learn something new, I would like to find out more about it.	1.78	1.79
I find it fascinating to learn new information	1.55	1.61
I enjoy discussing abstract concepts	1.92	1.93
Mean Total	**1.78**	**1.73**

How does the implementation of ECP impact students' learning in the various STEM fields?
We report a clear direction towards the improvement of peer-learning and collaboration (Table 4). For example, the students reported improvements (lower score) in post-test in the areas such as explaining materials to a classmate or friend, or discussing course materials in a group. Table 5 shows that students' persistence level and purposefulness did not grow much but an increase is visible in the dynamism and strategic performance in their study. Students also reported lower test anxiety mean score, for example in the post-test, "I feel my heart beating fast when I take an exam" (mean 3.39 in post-test vs. 2.93 in post-test).

Table 4. Mean value of pre-test (N =89) and post-test (N -32) in peer-learning and collaboration. Note: 1 = very true of me, 7 = not at all true of me.

Items	**Pre-Test Mean**	**Post-test Mean**
When studying for this course, I often try to explain the material to a classmate or a friend.	3.89	3.50
I try to work with other students from this class to complete the course assignments.	3.04	3.25
When studying for this course, I often set aside time to discuss the course material with a group of students from the class.	3.74	3.36

When asked to share their lab experiment experience in an open-ended question, 28 students reported positive experiences of using devices, particularly the "heart rate" experiment being "interesting," many experiments being "easy" and "fascinating" and most of them "enjoyed" the class. While they mentioned the supportive role of professors and teacher/research assistants available all the time in those lab classes, they really appreciated the use of devices in the opportunity of hands-on experiments. One student reported a positive experience and a supportive professor: "*The instrument was very easy to handle and use. Professor ___ made the class very interesting*". Another student reported how this lab helped her course understanding: *"My class experience when it comes to using the analog*



devices has been quite helpful in me understanding the subjects in class. For example, in class when we discussed the capacitors section of class, the analog device helped in my understanding of how to apply capacitors in building circuits."

Table 5. Mean Scores on metacognition during pre-test (N =89) and post-test (N -32). Note: 1 = very true of me, 7 = not at all true of me

Items	**Pre-Test Mean**	**Post-Test Mean**
When I become confused about something I'm reading for this class; I go back and try to figure it out (persistence)	2.24	2.61
If course materials are difficult to understand, I change the way I read the material (dynamism)	2.90	2.54
Before I study new course material thoroughly, I often skim it to see how it is organized (strategy)	3.08	2.89
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 (purposefulness)	3.02	3.14

Conclusion

Although this work is in the early stages, the adoption in four courses illustrates the potential to enhance learning activities within individual experiments and across multiple topics. Preliminary pre-test and post-test data show a slight improvement in the mean scores in the selected courses. Analysis of pre/post surveys for the MSLQ in all courses could not be available at this point due to delay in data collection caused by COVID-19. This personal electronic instrument is expected to contribute toward increasing retention and graduation rates of women and underrepresented minorities in these courses in the long term. It has potential not only to increase public scientific literacy, but will also contribute to the development of a diverse, globally competitive STEM workforce [25-26].

Acknowledgements

This material is based upon work supported by the National Science Foundation under Grant No. 1915614. The opinions, findings, and conclusions or recommendations expressed are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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