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Best Practices for the Implementation of Home-based, Hands-on Lab Activities to Effectively Engage STEM Students During a Pandemic

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 assistant 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.

Dr. Jumoke 'Kemi' Ladeji-Osias, Morgan State University

Dr. J. 'Kemi Ladeji-Osias is Professor and Associate Dean for Undergraduate Studies in the School of Engineering at Morgan State University in Baltimore. Dr. Ladeji-Osias earned a B.S. in electrical engineering from the University of Maryland, College Park and a joint Ph.D. in biomedical engineering from Rutgers University and UMDNJ. Dr. Ladeji-Osias' involvement in engineering curricular innovations includes adapting portal laboratory instrumentation into experiments from multiple STEM disciplines. She enjoys observing the intellectual and professional growth in students as they prepare for engineering careers.

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.

Mr. Oludayo Samuel Alamu, Morgan State University

Mr. Alamu is a Graduate Research/Teaching Assistant at the Department of Industrial and Systems Engineering, Morgan State University where he conducts qualitative and quantitative research works leading to development. He has participated and led several innovative research works and he is a member of the rocketry team at Morgan State University. He has authored and co-authored several publications with the recent one on the use of additive manufacturing in building a liquid propellant rocket engine nozzle.

Dr. Seong W. Lee, Morgan State University

Dr. Lee is currently Professor & Lab Director of Industrial & Systems Engineeing Deparment at Morgan State University.Dr. Lee has been actively involed in development of laboratory hands-on experimental projects using his ongoing research projects to be implemented and used in his teaching classes and capstone design projects.

Dr. Gbekeloluwa B. Oguntimein P.E., Morgan State University

Dr. Gbekeloluwa B. Oguntimein received his B.S. and Ph.D. degrees in Chemical Engineering from Iowa State University in 1974 and 1979 respectively. He has over 30 years teaching and research experience having taught at in the departments of chemical engineering, Iowa State University, Ames Iowa, department of food technology, University of Ibadan, Nigeria and conducted research at Institute Nationale Polytechnique de Lorraine in Nancy, France, at Gesselschaft Biotechnologie Forschung in Braunschweig, Germany and Industrial Biotechnology Center, University of Waterloo in Waterloo, Canada. He currently teaches Environmental Engineering, Water and Wastewater treatment, Environmental Impact and Risk Assessment and Project Management and Sustainable energy development courses at the undergraduate and graduate levels at Morgan State University. His research areas are application of biological systems in the solution and prevention of environmental problems and development of sustainable energy.

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 Dr. Ariyibi (Nee Akintola) 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.

Ms. Hye Jeong Lee, Morgan State University
Dr. Krishna Bista, Morgan State University

Krishna Bista is an Associate Professor at Morgan State University, Maryland (USA).

Dr. Mulugeta T. Dugda, Morgan State University
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 journals and conferences across the United States.

Dr. Celeste Chavis P.E., Morgan State University

Celeste Chavis is an Associate Professor in the Department of Transportation & Urban Infrastructure Studies in the School of Engineering at Morgan State University in Baltimore, MD. Dr. Chavis is a registered professional engineer in the State of Maryland. Her research focuses on transportation operations, safety, and performance metrics for multimodal transportation systems through an equity lens. Dr. Chavis specialized in instructional technology, STEM education, and ABET accreditation.

Best Practices for the Implementation of Home-Based Hands-On Lab Activities to Effectively Engage STEM Students During a Pandemic

Abstract

The current COVID-19 pandemic has forced many colleges and universities to remain on a completely online or remote educational learning environment for the 2020 Spring and Fall semesters, however there is a growing concern in STEM fields about how students will be able to achieve one of the major ABET learning outcomes without conducting physical, hands on laboratory exercises as many STEM disciplines are switching to virtual laboratory; an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering/scientific judgment to draw conclusions. In addition to the limited achievement of the ABET outcomes, roughly half of the population of a historically black university communicated their anxieties during the pandemic to the University President via Change.org. The students' main anxiety is portrayed in a statement culled from the petition as follows**:** "Most classes are very hands-on, and we are not able to do those from home because of the limited resources available at home". This paper highlights the best practices for the implementation of home-based hands-on activities across multiple STEM fields. The paper further elaborates on the impact of remote and virtual labs on students' attitude, interest, and performance in STEM over the home-based hands-on experimentation. Home-based hands-on laboratory activities were performed in biology, electrical engineering, industrial engineering, transportation system, and civil engineering. The results of a Motivated Strategies for Learning Questionnaires (MLSQ) survey that was administered to about 100 STEM students revealed better gains in key constructs associated with student success, such as motivation, critical thinking, and metacognition.

Introduction

The ongoing COVID-19 pandemic has forced colleges and universities to a completely online educational learning environment. However, there is a growing concern in STEM fields about how students will be able to achieve one of the major learning outcomes (an ability to develop and conduct appropriate experimentation, analyze, and interpret data, and use engineering/scientific judgement to draw conclusions [1]) without conducting physical hands-on laboratory exercises as many STEM disciplines are switching to virtual laboratories. According to Deboer et al [2], despite the potential for at-home lab kits to serve as a blended learning supplement in online environment, the literature on best practices for adoption in STEM online environment is very scanty. Subsequently, to bridge the gap in the current hands-off virtual laboratory simulations, as well as provide more insight into best practices for adoption of home-based hands-on activities in STEM, this research seeks to develop, implement, and assess the home based, hands-on, in-expensive laboratory experiments across five STEM disciplines at a historically black university. According to the Accreditation Board for Engineering and Technology (ABET) [3], experimental experiences should include the following: knowledge of the objectives and procedures associated with an experiment; conducting an experiment, including setup, measurement and data collection; observing and documenting error and uncertainties in data collection procedures; offering critical analysis of data points; making application of experimental procedures and analysis of results consistent with a real-world STEM problems or situations; and drawing interpretation of the experimental results, with appropriate conclusions and recommendations [3]. There have been major flaws with hands-off virtual laboratories ranging from the accuracy of simulations by the subject matter, ability of the simulation to replicate actual experiences of physical set up, measurements, errors, and data collection, to nature of students' interaction with and the abilities acquired with the simulations coupled with the satisfaction with the knowledge gained [3]. All these flaws are poised to have a drastic impact on students' attitude, interest and performance during this pandemic or any other time that in lab is impracticable.

Virtual labs and online instructions are helpful for students to learn basic science information as well as to achieve the learning outcomes, but they are not equated to substitute onsite lab environment because of the instrumental limitations [4]. Researchers experimented with virtual labs at Amrita University and Helwan University using existing resources with organic chemistry classes where students were encouraged to participate using virtual chemistry laboratories. In another study, Wolski and Jagodzinski [5] used a virtual laboratory while teaching chemistry where they analyzed the gestures and movements of students to measure student learning and effectiveness of chemical education. Although their study indicated students remembered information while using virtual labs, there were concerns regarding the level of course objectives, types of experiments to teach higher level lab skills, and logical thinking which may not be replaced in such online labs. Truchly et al. [6] used virtual labs along with a set of self-tests in a STEM education project, their learning approach was enhanced by a developed virtual lab and a set of self-tests with directions where students reported higher levels of their learning motivation and course satisfaction. Past studies also indicated that take-home STEM experiments practices or "science backpacks" that students would be doing with their families foster meaningful conversations and connections with fun and entertainment [2], [7]. For example, DeBoer et al. [2] integrated hands-on activities into online classrooms and they found that students in the treatment group had significantly higher exam scores and levels of self-efficacy to perform in the topic area. These home-based labs are highly recommended in online courses in engineering and other science, technology, engineering, and math areas that traditionally have laboratory components. Such an education program that includes home-based tools can be effective in preparing African American students for post-secondary education and to pursue degrees in technical disciplines [8].

In this work, in order to address these concerns/gaps, the home-based, hands-on, in-expensive, experimentation was developed by the instructors in their various STEM disciplines. Laboratory kits were shipped to students at their respective homes (since students are now restricted to their homes during the pandemic) and instructional videos were produced on how students will conduct the experiments at their own homes. Instructors seek to synchronously engage the students using the online platform in conducting the experiments. The developed system ensured that students have the proper lab equipment to conduct the experiments correctly while also following lab safety protocols [9]. The major research question addressed in this paper are: "Given the unplanned switches to a completely online educational format in-order to minimize the spread of COVID-19 (coronavirus), can home-based hands-on in-expensive laboratory exercises enhance student learning outcomes, attitudes, and performance? With two sub-questions: (1a.) How do the different STEM fields integrate and customize the home-based hands-on in-expensive laboratory pedagogy to meet the learning objectives within their disciplines? (1b.) What is the impact of virtual laboratory on student attitudes, interest, and performance in STEM over the lab experimentation? At the authors' institution, each STEM discipline adopted a well-practiced active online approach in the integration of the home-based hands-on in-expensive laboratory experiment pedagogy as shown by the Classroom Observation Protocol for Undergraduate STEM presented by [10].

The objective of this paper is to present the best practices for implementing home-based teaching and experimenting pedagogy which is geared towards improving students' learning and retaining abilities. The practices contained in this article came out of the ongoing project (Adapting an Experiment-centric Teaching Approach to Increase Student Achievement in Multiple STEM Disciplines-ETA-STEM) that centered on active online learning pedagogy in the diffusion of home-based hands-on in-expensive experimentation across multiple STEM disciplines in an online environment at the institution. Some home-based hands-on inexpensive experiments conducted during the Spring, Summer and Fall 2020 semesters in various STEM fields are discussed.

Teaching and Experimentation Approach

At the institution, two major approaches were introduced to the STEM disciplines for effective teaching and experimentation during the ongoing pandemic. Since Zoom was largely used by the university instructors, the STEM faculty participating in the ECP implementation adopted the teaching approach proposed by [11] to effectively engage the students in online learning environment. In a synchronous class meeting, the lower-level cognitive skills of remember and understanding can be enhanced through the interactive features of microphone and share screen as well as the nonverbal feedback icons and chat features that checks for attention and the polls features that check for understanding. While the higher-level cognitive skills of apply, analyze, evaluate, and create can be facilitated through the collaborative features of chat, screen sharing, private chat, whiteboards, and breakout rooms.

All the participating STEM disciplines have laboratory sections in the courses being taught during the Summer 2020 and Fall 2020 semesters. Faculty adopted the 3E model for best practices for adoption of the home-based hands-on in-expensive experimentation in STEM online learning as proposed by [12]. The 3E model comprises of:

(i) Expectations: Laboratory learning objectives must be clearly stated which take into consideration the three domains of knowledge; cognitive, psychomotor, and effective

(ii) Experimentation: To facilitate the development of the required technical and critical thinking skills, laboratories exercises which would actively engage students in scientific investigations, and

(iii) Engagement: Synchronous tools must be used in the online environment to facilitate students conceptual understanding, promote ability to develop and conduct appropriate experimentation as well as foster opportunities to link observations with theory and practice.

Home-based Hands-On Lab

Hands-on Labs for the past 25 years have been providing tactile lab experience for distance learners in over 10 disciplines [13]. The digital cloud platform of Hands-on Lab comprises of exploration, experimentation and evaluation sections. The exploration section prepares students to conduct the experiment, while the experimentation section contains the lab instructions, the materials list, and instructional videos. The evaluation section consists of an integrated grade tool for assessment and report generation that are aligned with the learning objectives.

Safety Concern: The HOL inc. company assumes 100% liability for students when conducting the experiments at home and there are prerequisites safety training that students must perform before getting access to the experiment platform. In other STEM disciplines like civil engineering, transportation systems, and industrial engineering, where HOL does not have existing lab kits and associated digital cloud platform, Hands-On Labs is committed to working with our Subject Matter Expert (SME) in the pedagogy development by assisting in sourcing for laboratory materials that would be safe and appropriate for students to use while off campus and providing logistics for distributing the kits to the students. As generally done through the company's webinar series, they are equally committed to providing professional development and training for faculty in the developing the HOL in their various disciplines. The pre-existing curriculum can be hosted on HOL's cloud platform and also can be incorporated in Canvas.

Spring 2020 Pilot Study

In response to the pandemic at its early stage, the participating department obtained laboratory kits from HOL Inc and distributed to the students in civil engineering while M2K circuit boards were distributed to the students in electrical engineering department.

Civil Engineering

The laboratory experiments conducted in civil engineering and the number of registered students are as follows: Beer's law (23 students), determination of water (11 students) and water quality (11 students). From the studies conducted in the Department of Civil Engineering (for an environmental engineering lab), it was discovered that a few students had challenges in effectively following the laboratory instructions which are a precursor to successfully achieving the experimentation objectives. Subsequently, it was suggested to change the pedagogical format in diffusing the home-based hands-on experimentation by adopting a synchronously online laboratory experimentation pedagogy that effectively engages the students while conducting the home-based hands-on laboratory exercise as proposed by [12].

Electrical Engineering

The experiments conducted during the Spring semester are: multiplexer and decoder (17 students), shift register and gray code (16), sequence detector (16) and ADALM2000 experiment for 12 students. For the Department of Electrical and Computer Engineering, an ADALM2000 (M2K) circuit board alongside color coded wires and resistors were distributed to the students for conducting home-based hands-on experiment. Upon the successful completion of the experiment, MSLQ was administered to the students in both departments to evaluate the students' motivation to conduct home-based experiment.

Summer 2020 Hands-On Home-based Lab Study

During the initial pilot study carried out in Spring 2020, it was discovered that a few students had challenges in effectively following the laboratory instructions which are precursor to successfully achieving the experimentation objectives. In order to enhance best practices in diffusing the home-based pedagogy, a synchronously online laboratory experimentation that effectively engages the students during the conduction of the home-based hands-on laboratory exercise as proposed by Mawn [12] was adopted for Summer 2020 implementation.

Civil Engineering

To synchronize online learning with hands-on home-based experiment, lab kits were obtained from HOL Inc. and were distributed to 23 students enrolled in the environmental engineering course. The lessons covered in the experimental course are: acid-base chemistry, water quality, determination of water hardness using a titrator, Beer's law, analysis of phosphate in water, and carbon footprint and sustainable living. Two international students currently residing outside the U.S were provided the HOL kits code and data sets to perform virtual lessons. A setup of an experiment on the analysis of phosphate in water is shown in Figure 1.

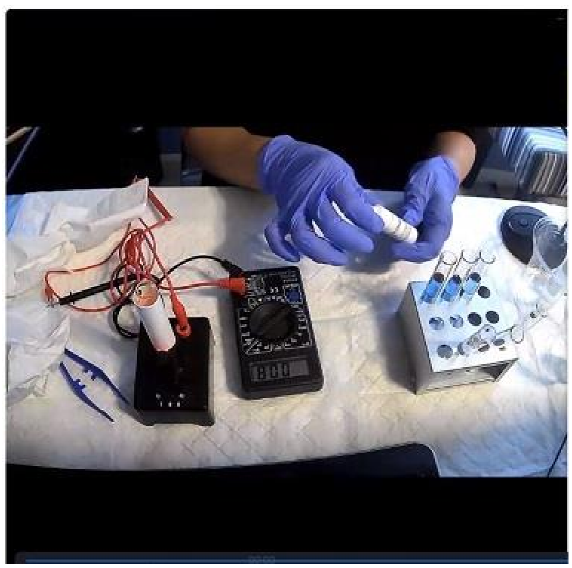
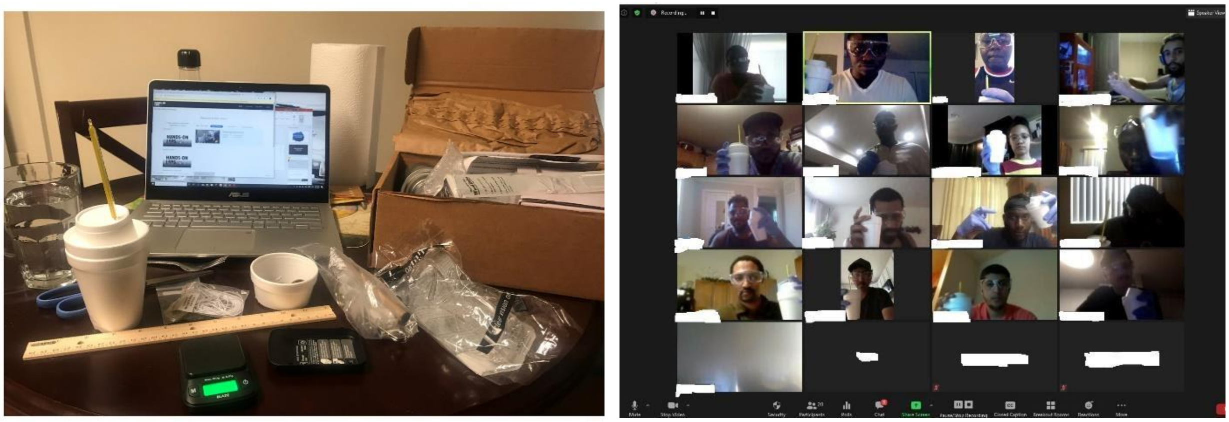


Figure 1. Home-Based Lab Experiment for Environment Engineering

Industrial Engineering

The second pilot study incorporating the active synchronous online laboratory experimentation pedagogy was implemented through an experiment focusing on the determination of the specific heat of solids by 24 engineering students taking the Thermodynamics engineering course in Summer of 2020. The laboratory kits for the Specific Heat of Solids Lab were shipped to the 19 students residing in the U.S. to conduct the experiment as shown in figure 2, while the remaining 5 students that were oversees completed their experimentation through a virtual lab simulation. The HOL students were made to go through the three (3) stages of hands-on home-based learning: exploration, experimentation and evaluation. During the synchronous online laboratory experimentation, the 19 students were highly motivated in conducting the experiment. Students that conducted the hands-on lab scored higher than the rest of the students that did the virtual lab exercise of the same specific of heat experiments. Similarly, the students in the HOL class displayed a better understanding of the heat transfer concept being taught as observed in their submitted lab report.



2a. Home-based Lab Set Up 2b. Home based Lab Activity

Figure 2. Home-based Lab Experiment for Engineering Thermodynamics

Fall 2020

In fall 2020 home-based labs were implemented in Biology, Industrial engineering, Physics and Transportation Systems courses and added new courses in implementing the ECP (i.e., hands-on devices) (Table 1).

Table 1: The Synchronous Online Laboratory Experimentation Pedagogy Courses Implemented in Fall 2020 Semester

Courses	**No of Students**	**Experiment Title**
BIOL 103 Introductory Biology for Nursing Major (Sec. 1)	25	Heart rate Measurement
BIOL 103 Introductory Biology for Nursing Major (Sec. 2)	25	Heart rate Measurement
BIOL 201 Anatomy and Physiology I	25	Heart rate Measurement
CEGR 324 Structural Analysis and Lab (Sec 1)	9	Stresses and Strains
CEGR 324 Structural Analysis and Lab (Sec 2)	6	Stresses and Strains
IEGR 305 Engineering Thermodynamics (Sec 1)	10	Specific Heat Capacity
IEGR 305 Engineering Thermodynamics (Sec 2)	23	Specific Heat Capacity
PHYS 206 University Physics II	23	Sound/Reflection and Refraction of Light
TRSS 414 Traffic Engineering	30	Sound

MSLQ Analysis

The Motivated Strategies for Learning Questionnaire (MSLQ) is a self-report instrument designed to assess college students' motivational orientation and their use of different learning strategies for a college course. According to [14], the instrument is a measure of student self-efficacy, intrinsic value, test anxiety, self-regulation, and use of learning strategies. Constructs from this survey center on measures of the types of learning strategies and academic motivation used by college students. This instrument uses 44-items with a 7-point likert-type scale with statements focused on student motivation, cognitive strategy use, metacognitive strategy use, and management of effort. Additionally, a number of researchers have also utilized the MSLQ to examine whether there is a predictive relationship between motivation, self-regulated learning, and academic achievement (i.e., GPAs) at the college level; however, based on changes in class format due to COVID-19, this relationship was not investigated as was proposed, but will be addressed in the near future.

Classroom Observation

Smith et al., [10] presented a new observation protocol known as the Classroom Observation Protocol for Undergraduate STEM or COPUS. This protocol allows STEM faculty, after a short 1.5-hour training period, to reliably characterize how faculty and students are spending their time in the classroom. The COPUS idea was developed to help STEM instructors in facilitating the process of collecting information on the range and frequency of teaching practices at departmental level and institution-wide scales. According to the authors, the faculty at both the University of British Columbia (UBC) and the University of Maine (UMaine) created classroom observation programs to collect information about the nature of STEM teaching practices. The results of such observations were needed to: (1) characterize the general state of STEM classroom teaching at both institutions, (2) provide feedback to instructors who desired information about how they and their students were spending time in class, (3) identify faculty professional development needs, and (4) check the accuracy of the faculty reporting on the teaching practices survey that is now in use at UBC. The classroom observation contains 25 codes in only two categories ("What the students are doing" and "What the instructor is doing") as shown in Table 2 and can be reliably used by university faculty.

Results and Discussion

MSLQ Result and Outcomes

Results from the MSLQ as well as the outcomes of the implementation of the home-based lab activities are reported below. Sections of questions focused on specific motivational, critical thinking and metacognition constructs. For Spring and Summer 2020, the results of the outcomes of the implementation are presented (only post survey), while for the Fall 2020 implementation, the results of the pre and post of the MSLQ survey are presented.

Spring 2020 Outcomes

In May 2020 after the first pilot test of the home-based lab activities due to unplanned switch to online mode resulting from COVID-19 pandemic in Spring 2020, an online survey was sent out to the participating students, where 47 students completed it: 41 males, 6 females. Students who participated in the home-based lab projects were seniors (31), juniors (14), and (2) sophomores. As shown in Table 3 after the completion of the Spring 2020 semester, 97.82% of the students expressed their interests in learning more and more concepts in the field of engineering, 95.74%

stated that they understood the concepts being taught in engineering and a very good number of the students said that the experiment they were taught was helpful in developing skills in the subject area.

Table 2: Descriptions of the COPUS Student and Instructor Codes [10]

Students are Doing	
L	Listening to instructor/taking notes, etc.
AnQ	Student answering a question posed by the instructor with the rest of the class listening
SQ	Student asks a question
WC	Engaged in whole class discussion by offering explanations, opinion, judgment, etc
Ind	Individual thinking/problem solving.
CG	Discuss clicker question in groups of 2 or more students
WG	Working in groups on worksheet activity
OG	Other assigned group activity, such as responding to instructor question
Prd	Making a prediction about the outcome of demo or experiment
SP	Presentation by student(s)
TQ	Test or quiz
W	Waiting
O	Other – explain in comments
Instructor is Doing	
Lec	Lecturing
RtW	Real-time writing on board, doc. projector, etc.
Fup	Follow-up/feedback on clicker question or activity to entire class
PQ	Posing non-clicker question to students (non-rhetorical)
CQ	Asking a clicker question
AnQ	Listening to and answering student questions with entire class listening
MG	Moving through class guiding ongoing student work during active learning task
1o1	One-on-one extended discussion with one or a few individuals
D/V	Showing or conducting a demo, experiment, simulation, video, or animation
Adm	Administration (assign homework, return tests, etc.)
W	Waiting when there is an opportunity for an instructor
O	Other – explain in comments

During the synchronous online laboratory experimentation in industrial engineering, the 19 students were highly motivated in conducting the experiment (Figure 2b). Students that conducted the hands-on lab scored higher than the rest of the students that did the virtual lab exercise of the same specific of heat experiments. Similarly, the students in the HOL class displayed a better understanding of the heat transfer concept being taught as observed in their submitted lab report. In terms of percent uncertainty, i.e. measuring the difference between the theoretical and experimental values of the specific heat capacity of different solid materials (brass and steel washer), the students in the HOL category reported the errors observed and were guided to know if they have conducted the experiment correctly or not based on their values. Percent uncertainty >20% indicated the presence of errors in reading the thermometer or during the process of heat transfer from hot solid to cold body, therefore necessitating the need to repeat the experiment.

The qualitative responses gotten from the students in electrical engineering when asked to describe their experiences in conducting experiment at home indicated their overall satisfaction. The students said that it was interesting especially learning how to use the software Scopy for M2K analog device. Similarly, the students in civil engineering said that it was very interesting, and they learned a lot with regard to environmental engineering. Overall, the students said they did not know it is possible to conduct an experiment at home without a designated laboratory and lab instructor. Thus, they expressed their confidence in conducting more labs at home accurately.

Below are few sample responses: (i) "It was interesting especially learning how to use the software Scopy. It was challenging at first, understanding Scopy and the functions that can be performed to a circuit". (ii) "It was very interesting, and I learned a lot in regards to environmental engineering. However, in one of the experiments, I was expected to have a toothpick but I did not have this so I had to use something else. I couldn't go to the store at the time due to the severity of COVID19". (iii)"I did not know it is possible to do experiment at home without a designated laboratory room and lab instructor. Now, I have the confidence to conduct more lab experiment accurately". Participants reported that they found the home-based experiments "interesting" (19 students), "useful" (6 students), and "relevant" (5 students).

However, one or two expressed issues and challenges while conducting the experiments; one student opined that" It was very exhausting and difficult. If I got lost or stuck, I did not have the assistance of a lab coordinator." This comment, with others informed a change to the synchronous online laboratory experimentation pedagogy in Summer 2020.

Table 3: Outcomes of Students' exposure to Home-based Hands-on Lab (Spring 2020)

Outcome Items	% Agree * n = 47
The experiment provided me opportunities to practice content	93.61
The experiment helped me increase my understanding about the topic	91.49
The experiment helped me develop skills in the subject area	95.65
I know the steps of conducting an experiment	95.74
I can apply the results of experiment in everyday life	78.73
I am further motivated to conduct other experiment	78.72
I developed confidence in content area	87.23
I developed interest in the subject area	85.1
I enjoy exploring new ideas	95.74
I am interested in learning more about engineering	97.82
I can do well on exams in engineering	89.36
I understand concepts I have studied in engineering	95.74

**% agree= strongly agree and agree combined using a five-point Likert scale*

Summer 2020 Home-based Experiment Outcomes

In Summer 2020, only 37 students complemented the survey from Civil Engineering (23 enrolled) and Industrial Engineering (22 enrolled) due to low enrollment. Thirty of the respondents were male while seven were female students, out of which 35 were seniors and two were juniors. Table 4 shows the results of the survey after the completion of the home-based labs. Students' experiences in the summer were similar to the Spring 2020 results in that 97.30% of the students expressed their interests in learning more concepts in the field of engineering (vs. 97.82% in the spring), 97.14% stated that they understood the concepts being taught in engineering (vs. 95.74% in the spring) and a very good number of the students said that the experiments were helpful in developing skills in the subject area. However, when students were asked about their knowledge of conducting experiments, there was an increase in agreement from 95.74% in Spring to 97.14% in the summer. This shows that the synchronous online laboratory experimentation pedagogy adopted in the summer was effective. An additional qualitative question was added in-order to gauge the effectiveness of the synchronous online laboratory experimentation pedagogy: "Did the live session with the lab instructor enhance your achievement of the lab objectives? Share your experiences". Below are few of the student's responses:

> "Yes, the live session, helped a lot. Seeing exactly how to carry out the experiment is more helpful than doing it on your own and constantly wondering if you are doing right or not".
>
> "The lab session helped us to achieve our goal. That made us understand what we were supposed to do".
>
> "These are new experiments with new ideas. They are useful for our skills".

Table 4: Outcomes of Students' exposure to Home-based Hands-on Lab (Summer 2020)

Outcomes Items	% Agree * n = 37
The experiment provided me opportunities to practice content	89.19
The experiment helped me increase my understanding about the topic	88.89
The experiment helped me develop skills in the subject area	88.89
I know the steps of conducting an experiment	97.14
I can apply the results of experiment in everyday life	75.67
I am further motivated to conduct other experiment	69.44
I developed confidence in content area	81.08
I developed interest in the subject area	67.57
I enjoy exploring new ideas	97.22
I am interested in learning more about engineering	97.30
I can do well on exams in engineering	100.00
I understand concepts I have studied in engineering	97.14

**% agree= strongly agree and agree combine using a five-point Likert scale*

Classroom Observation

The following reveals the classroom observation of the homebased lab activities in civil and industrial engineering in Fall 2020.

Industrial Engineering

The thermodynamics lab requires learning basic heat transfer, introducing concepts, such as heat exchange, determining properties of the material, calculating heat, and the law of thermodynamics. In this hands-on lab experiment, a simple experiment was set-up using a temperature sensor, solid materials (Steel and Brass), water (cold and hot) and Styrofoam cup (as calorimeter) to teach the concept of first law of thermodynamics. In this hands-on lab virtual session, students were actively engaged in setting up the experiment apparatus, installing software, conducting the experiment, and collecting data. In addition, they were very curious and mostly exchange questions and answers with the instructor the whole session and were not aware of the time flying as shown in Figure 3. They really appreciated the hands-on lab activity that was performed during the session with the instructor.

In comparison, the COPUS result in Figure 3 is similar to the chart presented by [10] for a course that utilizes several active learning instructional practices. In this hands-on lab activity, the instructor engaged the students using several active learning pedagogies in the thermodynamics experiment. Students were fully engaged during the lab-experiment.

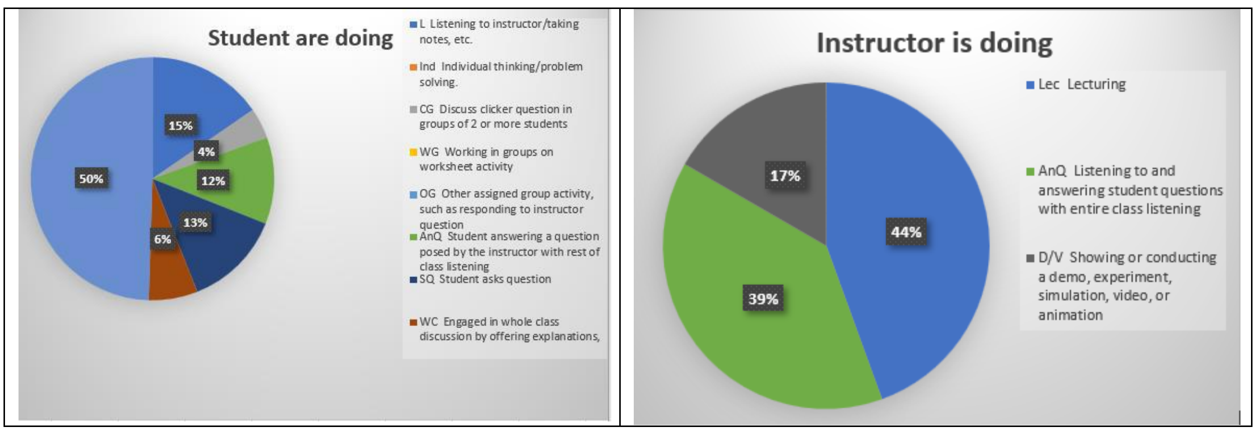


Figure 3. Observation results of Hand-on activity using ECP learning in Industrial Engineering

Civil Engineering

Figure 4 shows the COPUS result of ECP implementation during a lab session on structural analysis. It was observed that the lab session was very interactive with the use of ECP, the instructor was able to demonstrate, followed up with the students to ensure that the students were carried along as shown in the chart. A great similarity was seen in the results of the classroom observation when compared with other courses that utilize several active learning instructional practices in [10]. Overall, the instructor effectively implemented the beam experiment using several ECP active learning techniques.

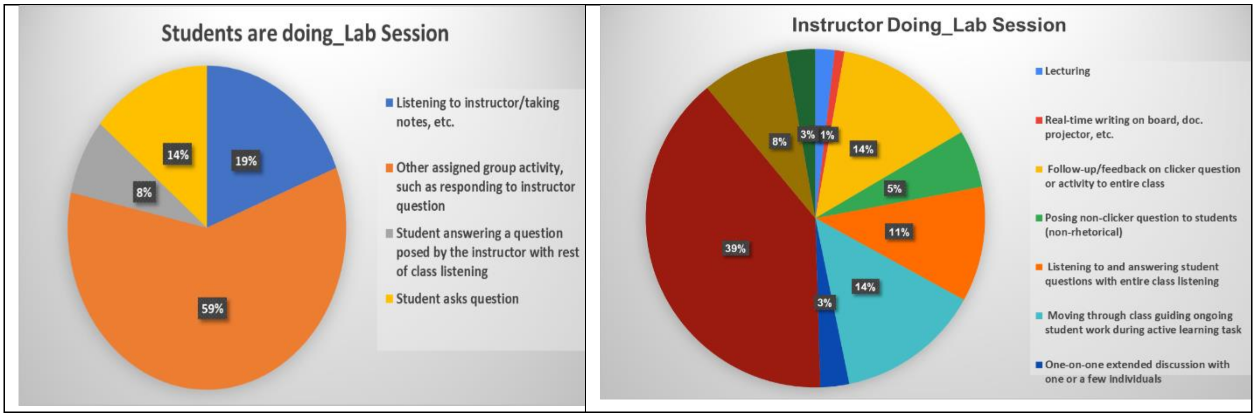


Figure 4**.** Observation results of Hand-on activity using ECP learning in Civil Engineering

Fall 2020 Results of Implementation of Homebased Lab Pedagogy

A pre-post design was used to measure change in undergraduate engineering students' perceptions of motivational learning strategies and epistemological beliefs as they relate to learning and overall academic success. Items from the Motivated Strategies for Learning Questionnaire (MSLQ), as well as items from several other instruments measuring critical thinking and metacognition were included on both the pre- and post-survey instrument. The purpose of this survey was to evaluate the experience for students as they participated in course work that had been enhanced with the synchronously online laboratory experimentation pedagogy. Table 5 shows the results of the pre- and post-tests for students' motivation strategies. The outcomes of the constructs under intrinsic goal expectations for STEM majors showed an increase in their preference for and challenges with content and materials in the home-based lab pedagogy courses; while non-STEM majors decreased their agreement for these constructs from pre to post. The non-STEM majors are students that enrolled in STEM courses as a general education course in Fall 2020. There was a general supported interest in the content and task value of the courses at pre-test and indication of less interest in the tasks at post. STEM students indicated a high consistency in expectation of the success in course grades, etc. Most non-STEM students indicated a reduction in test anxiety, pre to post while STEM students remained consistent or increased their test anxiety pre to post. Overall, comparisons of STEM and non-STEM responses to motivational constructs indicated that STEM students remained consistent in most motivational perspectives, while Non-STEM majors revealed that they had less motivation from pre to post for most activities. In the intrinsic goal orientation category, there was a +22% increase in the students that agreed that home-based activities made them prefer course material that really challenges them so they can learn new things.

Table 6 shows the results for the critical thinking and metacognition strategies. Generally, STEM students had a change in their critical thinking capability after the implementation of the home-based pedagogy, with a maximum of +10% change with the first construct in the critical thinking category. There is also an increase in the metacognition of STEM students with the maximum increase of +10% for the second item of the construct: "Before I study new course material thoroughly, I often skim it to see how it is organized". Non-STEM students' responses to critical thinking and metacognition constructs decreased after participating in the courses.

A descriptive analysis was performed on the key constructs; intrinsic goal orientation, task value, text anxiety, critical thinking, meta cognition and peer learning/collaboration for each of the discipline where homebased pedagogy was implemented in Fall 2020. Table 7 shows the mean (maximum desirable score is 7 on seven Likert scale for all constructs in exception of test anxiety which is 1), standard deviation and mean difference that displays an improvement in students' construct due to the implementation of the hands on pedagogy. A paired sample t-test was used to determine the significance between the pre and post results, a p-value of <0.05 in Table 7 demonstrates a significance different in the construct. Generally, across all disciplines there is an increase in the peer learning/collaboration construct. Additionally, in all the engineering disciplines there are positive mean differences for most of the students' constructs, while in the science courses majority of the mean difference between the post and pre constructs is negative. In biology, there is significant difference in test anxiety and peer learning and collaboration, while civil engineering students reported a significant difference in intrinsic goal orientation and critical thinking. The home-based hands lab activities resulted into significance difference in intrinsic goal orientation, critical thinking, meta cognition and pear learning capabilities of the students in the industrial engineering course. Students that took the physics courses only reported a significance different in the expectancy component of the MLSQ constructs, while transportation systems students reported a significant difference in metacognition and peer learning. When all the disciplines were aggregated, the descriptive analysis reveals a significance difference in expectancy component and peer learning/collaboration constructs.

Conclusion

As shown in this paper, best teaching and experimenting practices for developing and implementing active home-based hands-on activities across multiple STEM fields have been discussed as effective tools for increasing students' motivation and learning abilities during unprecedented times as this (COVID-19 era). It was observed that implementing home-based hands-on activities into the coursework of various STEM disciplines lead to increased intrinsic goal orientation and learning strategies used by students. The results of a Motivated Strategies for Learning Questionnaires (MSLQ) survey that was administered to about 129 STEM and non-STEM Students.   Results revealed gains in key constructs associated with student success, such as motivation, critical thinking, and metacognition for STEM students.

The Classroom observation protocols indicated several active learning instructional practices implemented at the authors institution during the 2020 academic session. It was also shown that the hands-on lab activities have more gains that the hands-off virtual lab.

Overall, most of the undergraduate engineering students reported that the home-based experimentation helped them in learning the course content, recall course material and information, and motivated them to learn course. Additionally, the most notable pre to post changes in participants' motivation occurred in the subareas of critical thinking, peer learning/collaboration, and expectancy, as personal learning preferences and responses remained consistent in the positive direction from pre to post.

Table 5: Student Motivation Strategies

MSLQ Items	MSLQ Constructs	**Pre % Non-STEM True of me***	**Post % Non-STEM True of me***	**% Diff**	Pre % Non-STEM True of me*	Pre % Non-STEM True of me*	%Dif
In a class like this, I prefer course material that really challenges me so I can learn new things	Intrinsic Goal Orientation	**65**	**62**	**-3**	57	79	+22
In a class like this, I prefer course material that arouses my curiosity, even if it is difficult to learn	Intrinsic Goal Orientation	**75**	**66**	**-9**	70	75	+5
The most satisfying thing for me in this course is trying to understand the content as thoroughly as possible	Intrinsic Goal Orientation	**82**	**67**	**-15**	77	79	+2
I am very interested in the content area of this course	Task Value	**81**	**63**	**-18**	77	79	+2
I like the subject matter of this course	Task Value	**77**	**67**	**-10**	82	72	-10
It is important for me to learn the course material in this class	Task Value	**85**	**80**	**-5**	73	74	+1
I believe I will receive an excellent grade in this class	Expectancy Component	**81**	**65**	**-16**	84	83	-1
I expect to do well in this class	Expectancy Component	**84**	**73**	**-11**	80	78	-2
I'm confident I can do an excellent job on the assignments and tests in this course	Expectancy Component	**79**	**67**	**-12**	83	79	-4
I have an uneasy, upset feeling when I take an exam	Test Anxiety	**84**	**69**	**-15**	80	80	0
I feel my heart beating fast when I take an exam	Test Anxiety	**79**	**64**	**-15**	65	69	+4

Table 6: Student Critical Thinking and Metacognition

MSLQ Items	MSLQ Constructs	**Pre % Non-STEM True of me***	**Post % Non-STEM True of me***	**% Diff**	Pre % Non-STEM True of me*	Pre % Non-STEM True of me*	%Dif
I often find myself questioning things I hear or read in this course to decide if I find them convincing.	Critical Thinking	**72**	**62**	**-10**	64	74	+10
Whenever I read or hear an assertion or conclusion in this class, I think about possible alternatives.	Critical Thinking	**64**	**63**	**-1**	67	66	-1
I try to play around with ideas of my own related to what I am learning in this course.	Critical Thinking	**68**	**64**	**-4**	65	66	+1
If course materials are difficult to understand, I change the way I read the material.	Metacognition	**76**	**72**	**-4**	73	73	0
Before I study new course material thoroughly, I often skim it to see how it is organized	Metacognition	**73**	**68**	**-5**	69	79	+10

Table 7: Descriptive Analysis of Students Key Constructs in all Disciplines

Constructs / Department		Intrinsic goal orientation		Task Value		Expectancy Component		Test Anxiety		Critical Thinking		Metacognition		Peer Learning/ Collaboration	
		Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
BIO Pre-N=149 Post-N=105	Mean	5.517	5.200	5.881	5.394	5.687	5.178	5.919	5.410	5.137	5.054	5.414	5.293	4.516	5.098
	SD	0.211	0.094	0.313	0.173	0.129	0.080	0.074	0.067	0.116	0.009	0.184	0.071	0.213	0.104
	Δ	-0.317		-0.487		-0.509		-0.509		-0.083		-0.121		+0.582	
	P-Val	0.156		0.145		0.014		0.037		0.419		0.350		0.042	
CE Pre-N=8 Post-N=8	Mean	5.384	6.000	5.704	6.083	5.815	5.750	4.667	5.125	4.148	5.389	5.278	5.500	4.593	4.667
	SD	0.046	0.000	0.189	0.118	0.052	0.000	0.000	0.125	0.189	0.079	0.255	0.306	0.189	0.118
	Δ	+0.616		+0.379		-0.065		+0.458		+1.241		+0.222		+0.074	
	P-Val	0.003		0.086		0.222		0.170		0.005		0.372		0.667	
IE Pre-N=27 Post-N=27	Mean	4.630	5.333	5.037	5.346	5.317	5.765	5.288	5.148	4.577	5.272	4.896	5.519	4.000	5.049
	SD	0.121	0.000	0.416	0.254	0.286	0.076	0.212	0.111	0.152	0.122	0.096	0.150	0.157	0.063
	Δ	+0.703		+0.309		+0.448		-0.140		+0.695		+0.623		+1.049	
	P-Val	0.014		0.431		0.149		0.633		0.008		0.002		0.005	
PHY Pre-N=56 Post-N=18	Mean	5.372	5.212	5.846	5.455	5.628	4.970	5.115	5.000	5.205	5.303	5.731	5.477	4.846	4.909
	SD	0.455	0.343	0.191	0.223	0.127	0.155	0.077	0.000	0.048	0.043	0.202	0.075	0.220	0.074
	Δ	-0.160		-0.391		-0.658		-0.115		+0.098		-0.254		+0.063	
	P-Val	0.714		0.134		0.010		0.374		0.099		0.114		0.732	
TRS Pre-N=15 Post-N=11	Mean	5.289	5.528	5.667	5.917	5.222	5.500	5.300	5.750	5.133	5.500	5.383	5.979	4.556	5.444
	SD	0.506	0.039		0.136		0.245		0.250		0.068		0.069		0.039
	Δ	+0.239		+0.2500		+0.278		+0.450		+0.367		+0.596		+0.888	
	P-Val	0.573		0.505		0.419		0.429		0.070		0.046		0.013	
ALL Pre-N=255 Post-N=169	Mean	5.387	5.283	5.770	5.459	5.676	5.315	5.581	5.324	5.063	5.158	5.394	5.388	4.528	5.085
	SD	0.258	0.058	0.292	0.177	0.135	0.085	0.089	0.076	0.038	0.034	0.164	0.063	0.170	0.076
	Δ	-0.104		-0.311		-0.361		-0.257		+0.095		-0.006		+0.557	
	P-Val	0.630		0.281		0.042		0.163		0.059		0.954		0.028	

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