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Performance-Based Learning: An Innovative Approach to Teaching Engineering Thermodynamics in a Hybrid Learning Environment

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“Full Paper: Performance-Based Learning: An Innovative Approach to Teaching Engineering Thermodynamics in a Hybrid Learning Environment”

Abstract

A cost-effective, secure, and portable electronic instrumentation equipment is used in Experiment Centric Pedagogy (ECP), formerly known as Mobile Hands-On Studio Technology and Pedagogy, as a teaching method for STEM subjects both inside and outside of the classroom. Since the Spring of 2020, ECP has been integrated into two Industrial Engineering (IE) courses: Thermodynamics and Materials Engineering. This has been done in various ways, including through student use at home and in-class demonstrations and teaching labs. During the most recent academic session (Fall 2021–Spring 2022), the effects of practical home-based experimentation and lab activities on students' attitudes, interests, and performance were examined for the Engineering Thermodynamics course. The outcomes of a survey known as the Motivated Strategies for Learning Questionnaires (MLSQ), which was given to 51 students, demonstrated better improvements in the student's motivation, epistemic, and perceptual curiosity, three crucial characteristics linked to their success. Along with the MLSQ, the Classroom Observation Protocol for Undergraduate Students (COPUS) assesses active learning in Industrial Engineering courses, and quantitative and qualitative data on the significant components of student achievement were gathered. Results obtained show that using ECP has improved students' awareness of material properties and increased their interest in learning about the thermodynamics concept of heat transfer in connection to various solid materials.

1. Introduction

All STEM fields frequently use electronic devices to undertake scientific measurements; hence Experiment-Centric Pedagogy (ECP) is a successful STEM teaching method. Depending on the learning environment and different teaching methods (instructor demonstration, cooperative and independent student settings), ECP implementation may differ (traditional classroom, lab setting, homework). To bring an experiment-based, evidence-based teaching style across different STEM fields, including Industrial Engineering, the National Science Foundation (NSF) awards research grants.

Four STEM fields—Biological Sciences, Physical Sciences, Industrial Engineering, and Civil Engineering piloted the ECP initiative in the Spring term of 2020. The initial effects of the project's adoption in the four disciplines show how learning activities can be improved both inside specific experiments and across a variety of topics [2].

The ECP implementation can also be utilized to assess the successful outcomes for students as a result of its use. Motivation, perceptual and epistemic curiosity, engineering identity, and self-efficacy will be used to gauge student progress [2]. As a result, the Industrial Engineering (IE) department adopted the ECP idea with a focus on implementing home-based hands-on activities for two courses. Learning a specific idea can start at any point, but the ECP concept starts with the presentation of an experiment to teach the students a theory. This greatly improves the student's ability to retain the taught theoretical topic. The ECP concept is based on the Mobile Studio project designed by the Rensselaer Polytechnic Institute to boost students' interest and success in electrical engineering [3]. Since then, many colleges, including 13 HBCUs in the USA [4], have adopted it as a successful teaching strategy.

It can be used in a virtual environment or regular college classroom settings. Active learning teaching approaches have been found to improve student learning, raise retention rates, and close the achievement gap between various student populations in college science, technology, engineering, and mathematics (STEM) courses [4]. Beyond the subject of electrical engineering, active learning pedagogies have been applied extensively in industrial engineering [5-7].

For STEM students, in particular, who learn best in courses with hands-on laboratories, an effective online instructional practice uses a variety of active learning pedagogies as shown in Figure 1. There is a considerable level of discontent with online engineering instruction, according to Mackay and Fisher's [8] observations, which calls for urgent improvement in the delivery methodology.

The traditional technique, in the viewpoint of Aziz and Islam [9], leaves students feeling bored and unmotivated since it is too abstract and fails to interest students. A home-based, hands-on learning strategy should be used while instructing engineering courses online. The goals of integrating ECP into Industrial Engineering disciplines and in various settings, such as traditional classrooms and teaching laboratories, as well as student use at home, are to (1) design affordable home-based hands-on experiments for IE students to teach them laws of thermodynamics, (2) integrate ECP into the IE disciplines, and (3) measure student success outcomes as a result of ECP using key constructs associated with student success, such as motivation, interest in epistemology and perception, engineering identity, and self-efficacy.

The following high-level research questions are addressed in this paper:

1. Does the Experiment-Centric Pedagogy (ECP), which goes beyond electrical engineering, improve student learning, motivation, and curiosity?

2. Does an experimental-centric pedagogy boost undergraduate students' interest in Industrial Engineering (IE) and result in quantifiable and long-lasting learning gains?

3. How is student learning in the IE department affected by using the Experiment-Centric Pedagogy?

In order to respond to the research questions, the concept of ECP was implemented in two IE courses for four consecutive semesters (Fall 2021 - Spring 2022) by creating a set of hands-on learning experiments and using affordable equipment to actively engage the students in "though active demonstration with the hands-on engagement learning platform." The inclusion of the ECP concept in the two IE undergraduate courses was done to show better how scientific theories like the theories of thermodynamics and Hooke's law are applied in actual situations. According to Cox's research [5], a standard set of tools is frequently utilized in an undergraduate engineering curriculum to give students practical experiences with basic machine science theories that serve as the foundation for automation and robotics. Theories presented in class are integrated with tangible tools used in the lessons to support conceptual ideas and further pique students' interest in and learning about the material.

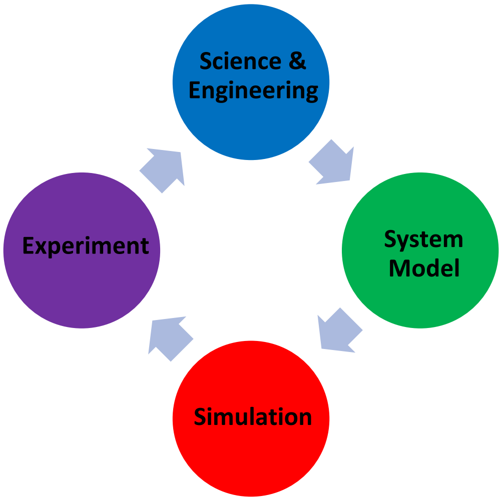


Fig.1 ECP Implementation Model

2.0 Theories of Learning

By incorporating several learning theories, including behaviorism, cognitivism, constructivism, and others, ECP into IE classes tries to improve student achievement. Different fields of cognitive theory have developed over time, concentrating on various facets of learning and comprehension. At its core, the cognitive theory holds that internal and external influences significantly influence the cognitive process. Cognitive learning theory affects pupils since awareness of one's mental process may help with learning [10].

Teachers that are knowledgeable in learning theories are better able to relate to a wide range of students. To reach diverse students, teachers might concentrate on different learning styles, resulting in instruction specifically tailored to each student's requirements and abilities. Contrariwise, the constructivism hypothesis is predicated on the notion that students design their learning based on prior knowledge.

Kolb's learning theory, which emphasizes experiential learning, was created in 1984. The hypothesis has received a substantial study from numerous educators and academics, but results about its impact on learning have been mixed, partly because of a dearth of data [11]. For comprehensive, long-term learning, Kolb created a four-step model learning cycle. The steps are known as active experimentation, reflecting observation, abstract conceptualization, and concrete experience (doing) (using the ECP approach) as shown in Figure 2. It is anticipated that students will retain more information after taking courses that follow all these procedures [12, 13]. Students directed through the learning cycle are also exposed to more excellent educational opportunities and chances for individual thought and self-discovery.

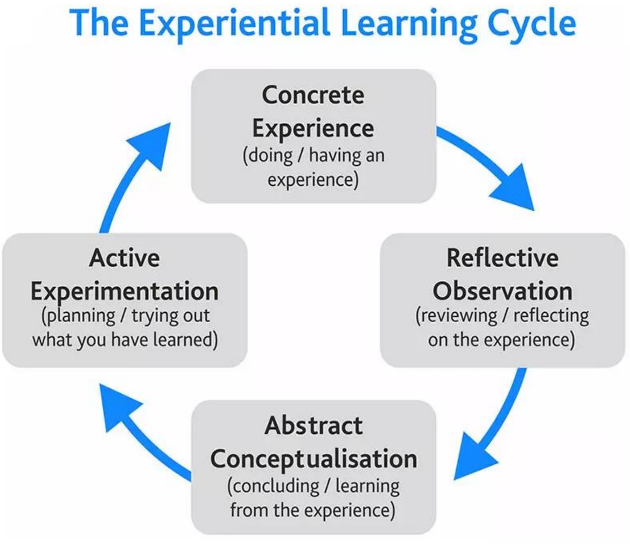


Fig.2 Kolb’s Learning Theory

3 Methodology

3.1 The Use of Experimentation and Teaching

To implement the hands-on, inexpensive experimentation in STEM online learning suggested by [16], the instructors chose the 3E model for best practices. Expectations, Experimentation, and Engagement make up the 3E model. The three areas of knowledge—cognitive, psychomotor, and effective—must be considered in the laboratory learning objectives and expectancies. Through lab tasks that actively engage students in scientific investigations, experimentation aims to support the development of the necessary technical and critical thinking abilities. For the ECP implementation at Morgan State University, the inexpensive portable device used is the M1K shown in Figure 3. Synchronous technologies must be employed in the online environment to help students' conceptual understanding, advance their capacity to design and carry out effective experiments, and create opportunities to connect observations with theory.

Fig.3 ADALM1000 (M1K) ECP Analog Device

3.2 ECP Implementation in Engineering Thermodynamics (IEGR 305)

Experiment Title: Specific Heat of Solids

Introduction

The amount of heat needed to increase the temperature of one gram of a substance by one degree Celsius is known as the specific heat of a substance, which is typically denoted by the sign ‘c’. The amount of heat needed to raise the temperature of an object formed of a material with specific heat equal to "c" is provided as follows:

$$\Delta Q = (mass\ of\ object)\ (c)\ (\Delta T) \qquad (1)$$

Utilizing the idea of energy conservation presented by the first law of thermodynamics, the specific heat capacities of various solids (such as steel and brass) was determined. During the fall 2021 semester, students were first exposed to the experiment on the specific heat of solids to understand the concept of heat transfer. To get temperature data, an analog temperature sensor was added to the circuit architecture of the ADALM1000 device. The temperature was connected with the temperature readings of the refined experiment utilizing analog sensors.

The students were instructed to build a low-cost calorimeter out of a set of Styrofoam cups, attached the analog temperature sensor to the ADALM1000 (M1K) device, and obtained the temperature reading via the graphical user interface (GUI) built into a Python programming and record their readings with other parameters in Table 1. The heat capacities of the two solidmetals -brass and steel having same weight of 50g, were determined using equation 2 which expresses that heat lost by the hot metal is equal to heat gained by water having achieved equilibrium point with the same final temperature of water and metal. The students then determined the percent uncertainty for potential explanations of variations between theoretical and experimental specific heat values as given by equation 3 and record both the heat capacities and percent uncertainties in Table 2.

$$MmCm\Delta Tm + MwCw\Delta Tw = 0 \tag{2}$$

$$Percent\ Uncertainty = \frac{|Cm{,}theory - Cm{,}\exp|}{Cm{,}theory} * 100\% \tag{3}$$

Where subscripts ‘m’ stands for metal and ‘w’ stands for water

Figures 4 and 5 show the setup of the heat capacity experiment for both the virtual simulation experiment and in-lab experimentation by the students. To analyze the students’ learning outcome for the heat capacity experiment, three evaluation metrics were used – Signature assignment, Classroom Observation Protocol for Undergraduate Stem (COPUS), and Motivated Strategies for Learning Questionnaire (MSLQ).

Now that the experiment is complete, you can opt to show/hide the graph and/or microscopic views for subsequent runs.

Click the Replay button to run the experiment again.

Click the Reset button to start a new experiment.

Aluminum - Al

Mass (g) 50.0

Temp (°C) 100.

☒ Show specific heat (J/g°C) 0.903

Water - H_2O

Mass (g) 75.0

Temp (°C) 20.0

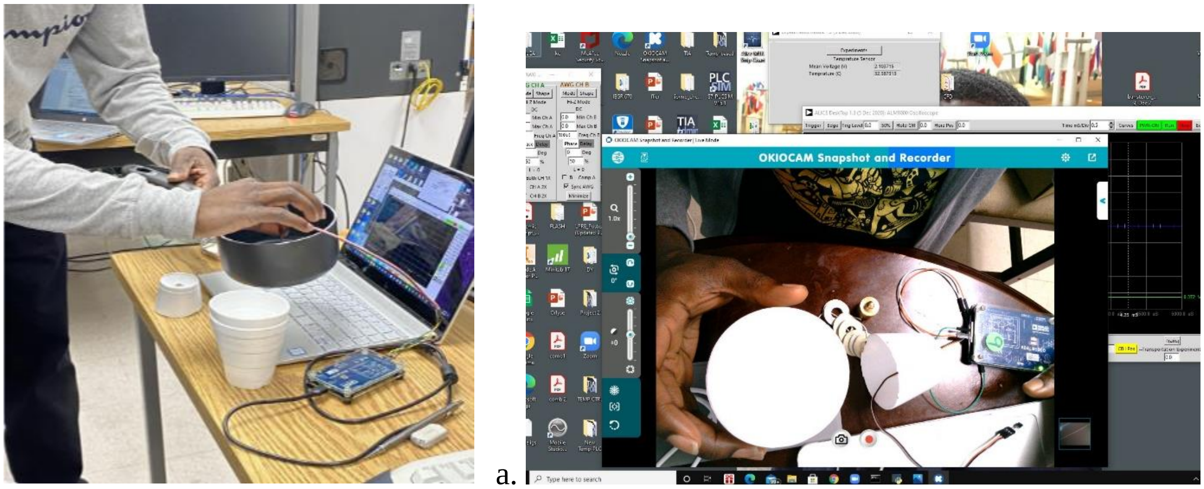
☒ Show specific heat (J/g°C) 4.184

RUN EXPERIMENT

☒ Show graph view

☐ Show microscopic view

Fig.4 Home-based Virtual Lab Set Up for Specific Heat of Solids



a. b.

Fig. 5(a&b). Experimental Measurement of Hot and Cold Fluid Temperature

Table 1: Mass and Temperature Measurements

Trial	Materials	Initial Temp (^{o}C)	Final Temp (^{o}C)	Change in Temp (^{o}C)
1.	Water			
	Steel Washers			
2.	Water			
	Brass ball			

Table 2: Specific Heat Capacities

Materials	Specific Heat Capacity (cal/g^{o}C)	Theoretical Specific Heat Capacity (cal/g^{o}C)	Percent Uncertainty (%)
Steel		0.122	
Brass		0.091	

4. Result and Analysis

The effect of ECP on students' performance in the Industrial Engineering class was evaluation using the three specified metrics.

4.1 Signature Assignment

Before conducting the experiment, the students were given a pre-survey form and a pre-signature assignment in order to assess their prior comprehension of the experiment and theoretical knowledge of the first law of thermodynamics. Upon the completion of the experiment, a post-survey form and the same questions from the pre-signature assignment were presented as a post-signature assignment to assess overall comprehension and knowledge gained by the students.

From the grade sheet, it was observed that the majority of the 16 students’ performances improved following the experiment as shown in Figure 6 by the blue bars which indicates the score variations for individual. For four students, there were no change in their results; three students received perfect scores of 100 (out of 100) on the pre-and post-signature assignment, while the remaining seven students received an identical pre- and post-score of 85.0. On comparison, the mean scores of the pre- and post-signature assignments are 74.66 and 93.85, respectively, a 25% improvement in score is typically seen which indicates a positive knowledge gain by the students.

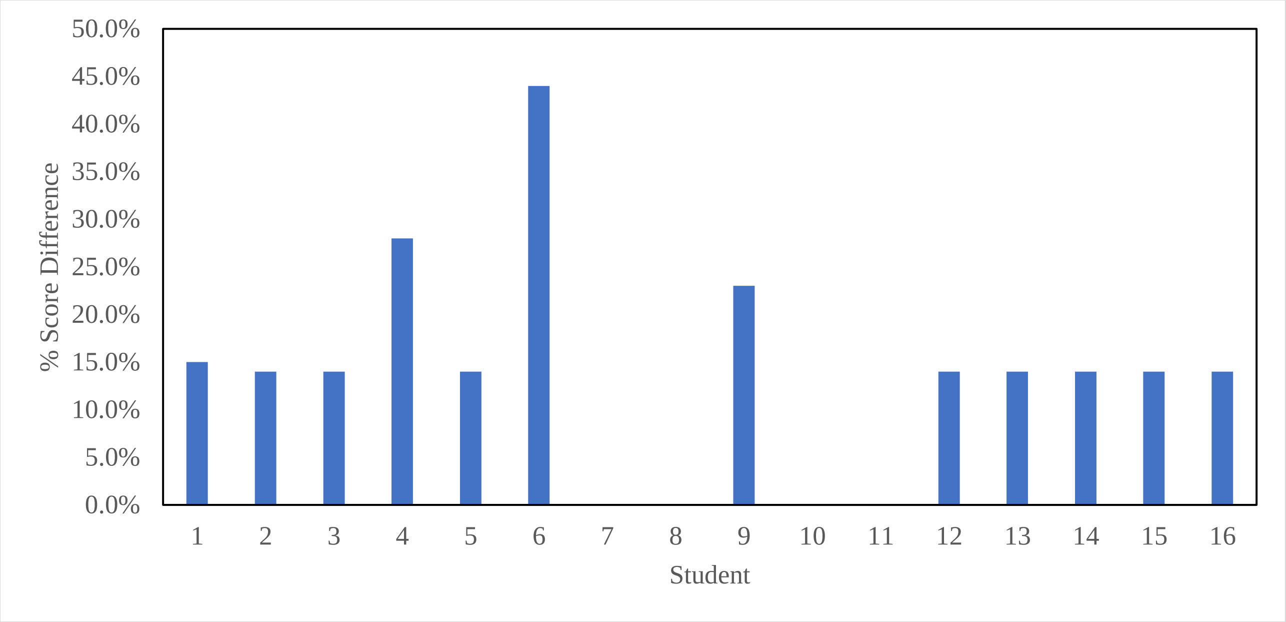


Fig.6 Difference in Pre-and Post-Signature Assignment Scores.

According to the previous implementation's results during the Fall 2020- Spring 2021 COVID-19 period, the students who participated in the Hands-On Lab (HOL) exercise scored higher than those who completed the equivalent heat experiment virtual lab exercise. As seen in their submitted lab report, the students in the HOL class also demonstrated a superior knowledge of the heat transfer subject being taught. A similar result was recorded in this study.

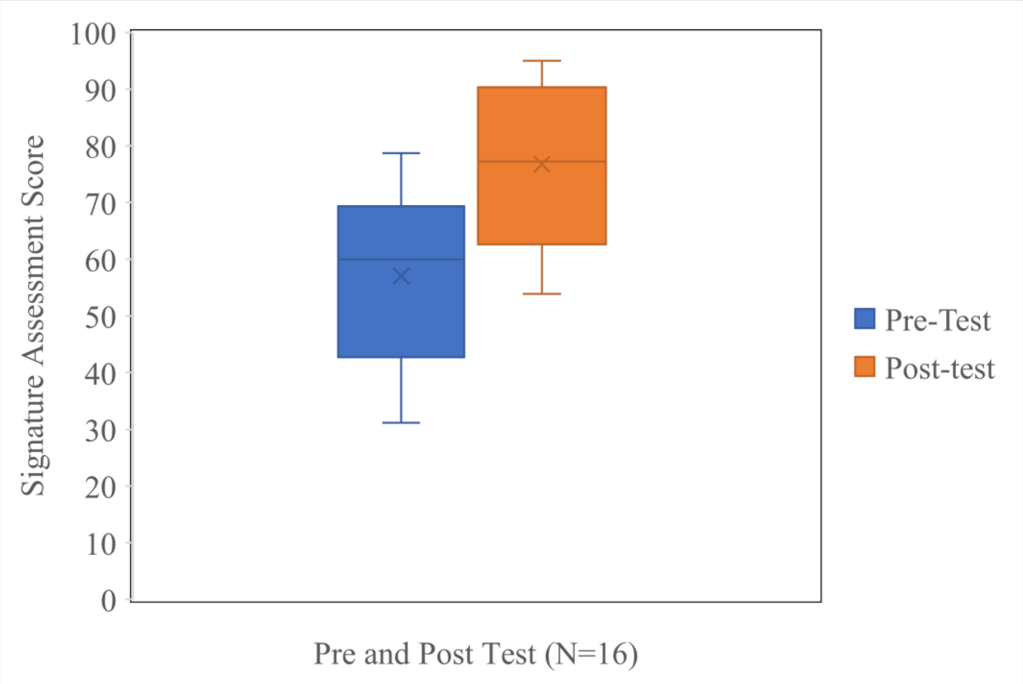


Fig.7 Boxplots of Pre- and Post-Test Signature Assignment

The boxplots in Figure 7 include information about the quartiles of the student's scores on the pre-and post-signature assignments. Furthermore, when the performance is compared to the pre- and post-signature results, it is clear that the student's performance has improved, as evidenced by the interquartile range (IQR), which moved from 45 – 65 percent to 65 – 90 percent. It demonstrates that following the experiment, the students could better remember and comprehend the fundamentals of digital logic.

2. Student Engagement

A Classroom Observation Protocol for Undergraduate STEM (COPUS) developed by Smith et al. [17] for observing students and instructor’s interactions in a typical instructional learning mode was adopted for this course. The COPUS concept was created to assist STEM educators in streamlining the procedure of gathering data on the variety and frequency of teaching methods at the departmental level and institution-wide sizes. University teachers can dependably use classroom observation, which has 25 codes and only two categories ("What the students are doing" and "What the instructor is doing"). From the students’ activities and instructor’s activities shown in Figure 8 and 9, it was observed that the students were actively engaged in the experiment at 51.3% of the class time with 15.4% of the time spent on answering the quizzes. The instructor used several active learning pedagogies during the class experiment, moved around the classroom having one-on-one conversations with the students as shown in Figure 9. This is similar to the findings obtained by Smith et al. (2013) for an ECP class unlike the traditional teaching class where students' sole activity is listening and instructor's sole activity is teaching. The students' participation in the hands-on experiment demonstrates how eager and interested they were in learning the concept of heat transfer in Engineering Thermodynamic course.

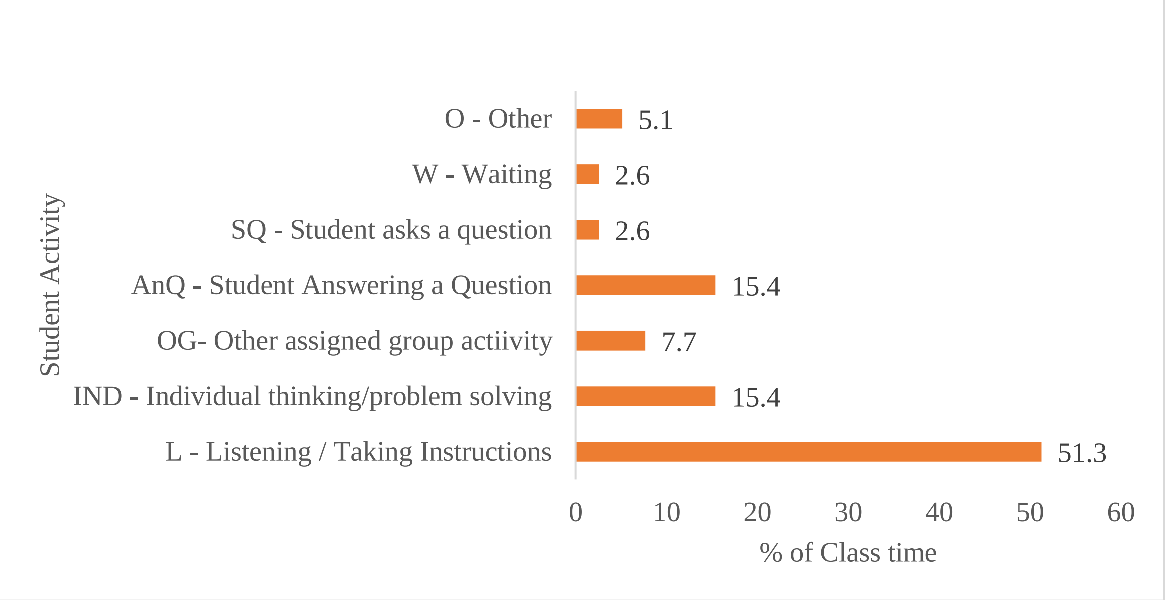


Fig.8 Student's activities during the class experiment

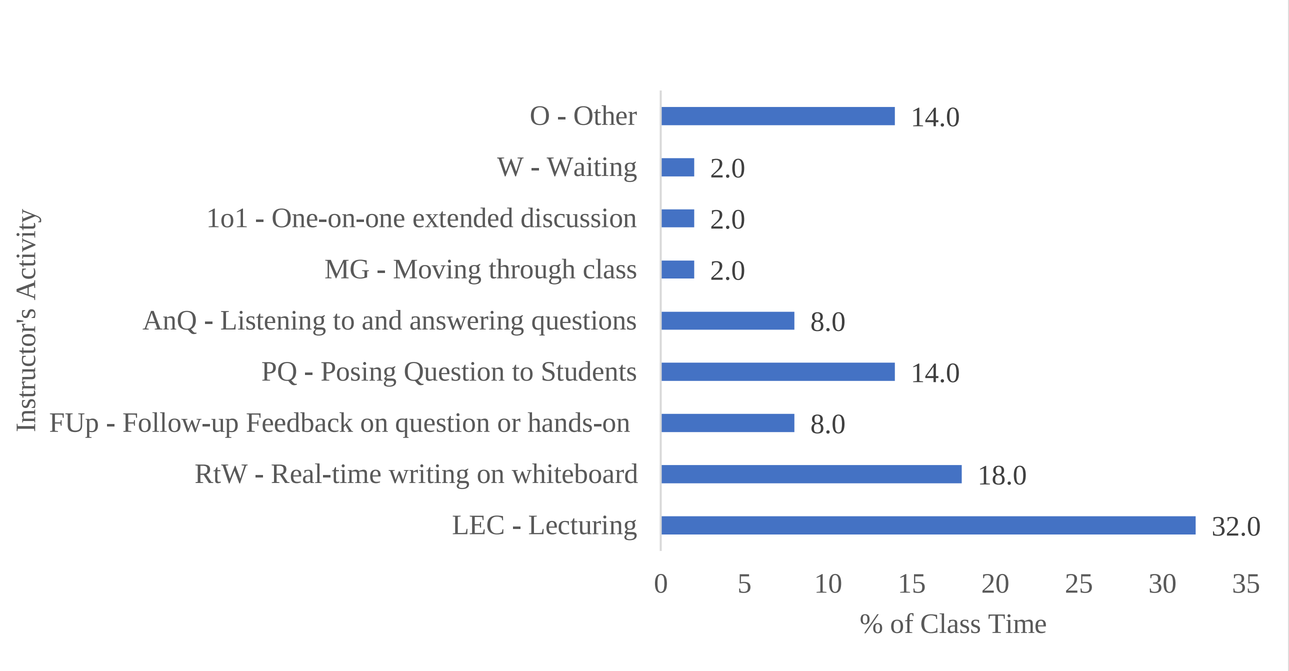


Fig.9 Instructor’s activities during the lab session

3. Outcome Assessment

The ABET student’s learning outcomes for Fall 2021 and Spring 2022 were shown in Figures 10 and 11. In 2021 and 2022, the learners were able to demonstrate an exemplary level of formulating adequate simulation or experiment and hypothesis which indicated that learners gain synthesis skill. More so, in 2021 and 2022 as well as, the learners were able to understand the functions and limitations of the computer or laboratory tool/equipment used which reveals the ECP made comprehension possible for learners. However, the learners struggle to demonstrate a good grasp of understanding errors associated with using tools and equipment as well as the precision of those tools in both years.

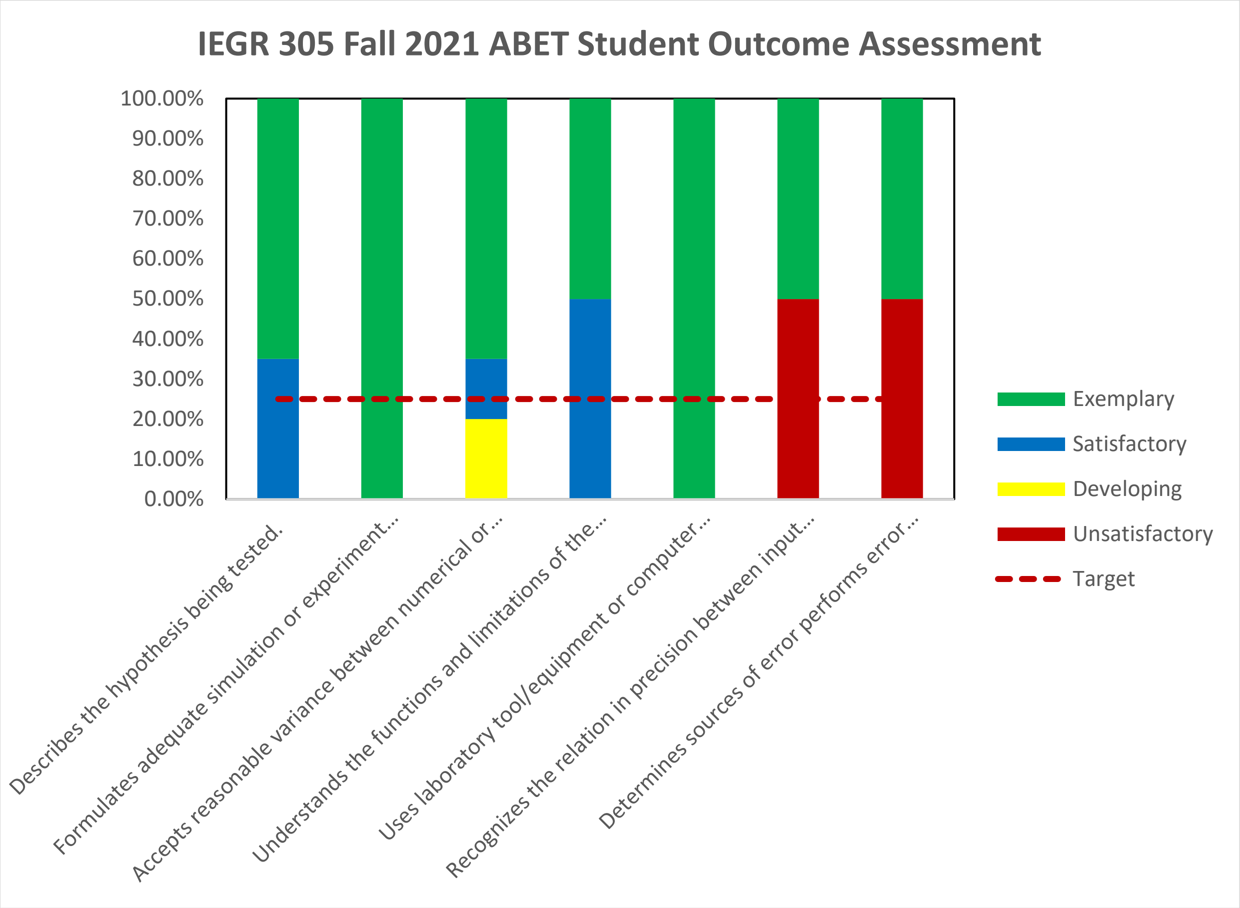


Fig.10 Students' Class Assessment Outcome for IEGR 305 Fall 2021

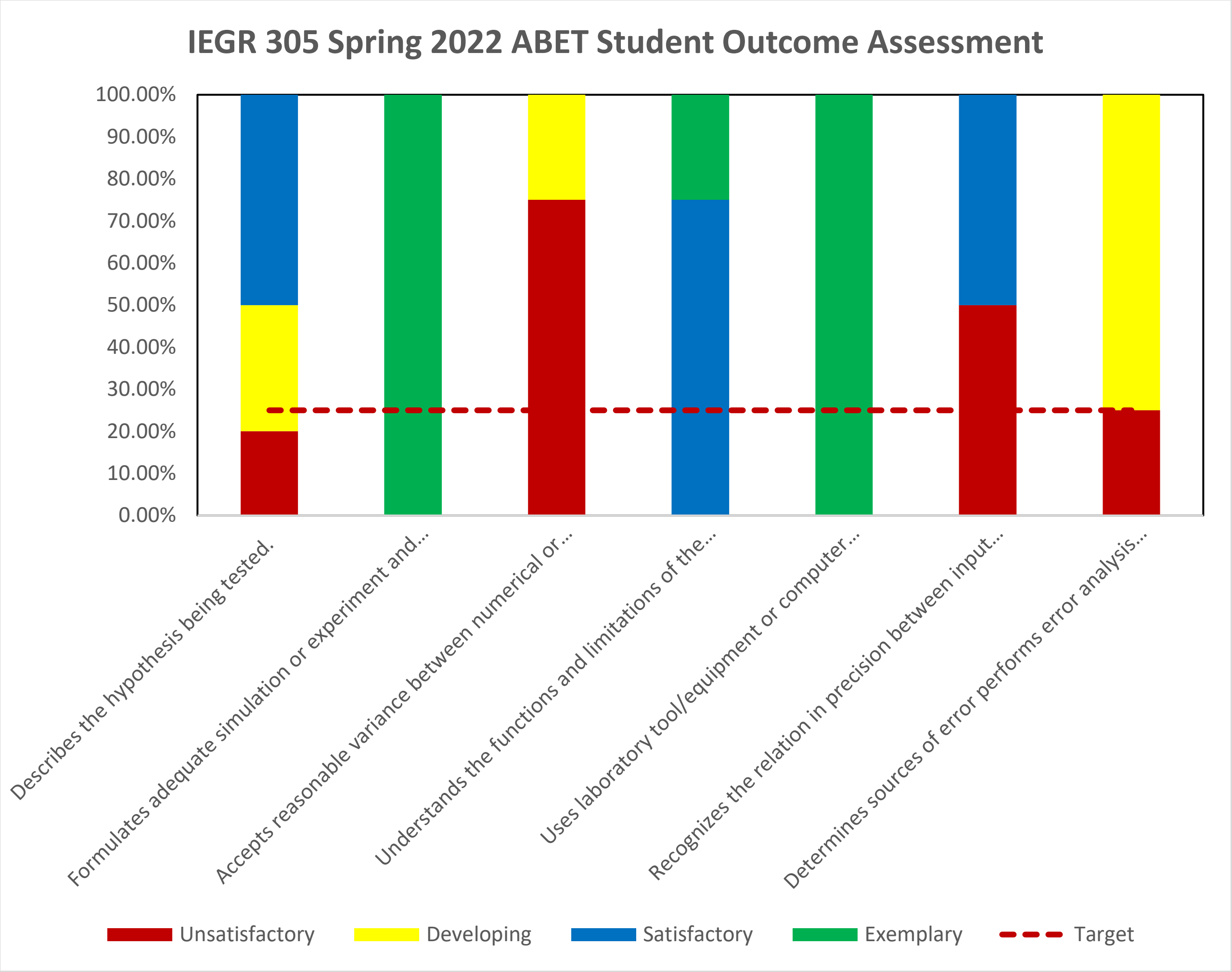


Fig.11 Students' Class Assessment Outcome for IEGR 305 Spring 2022

Conclusion

This study described the use of ECP to teach an industrial engineering course- Engineering thermodynamics class successfully used a home-based hands-on lab and a virtual lab for the two semesters (Fall 2021 –Spring 2022 academic session). For Engineering Thermodynamics (IEGR 305) during the two semesters, a hybrid educational strategy was employed to involve students in both home-based hands-on lab and virtual simulation lab, which led to higher motivation and retention by the students. According to the COPUS observations, students actively participated in the various instructional strategies employed in both the fall and spring semesters. The overall intrinsic goal orientation and learning techniques of pupils have increased because of the employment of ECP. In addition, the study found that students develop the ability to use laboratory tools and gain better understanding of the concepts.

Acknowledgment

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