

Hands-on Learning Pedagogy in Teaching Concepts Relevant in the Analysis, Design, and Maintenance of Transportation Infrastructure Systems

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Abstract

Learning critical concepts that are centered on the analysis, design, and maintenance of transportation infrastructure systems poses a measure of difficulty for undergraduates in engineering. Therefore, hands-on learning pedagogy should be an excellent precursor to increase understanding of these concepts, since the pedagogy incorporates real-life experience in the delivery. This paper describes how a hands-on learning pedagogy called experiment-centric pedagogy (ECP) has been used to teach these concepts to undergraduate students at a historically Black university. The research questions are as follows: (1) *How well can ECP improve students' understanding of concepts essential to the analysis and design of transportation infrastructure systems?* (2) *How has the ECP facilitated the achievement of the learning objectives of these concepts?* and (3) *Does an ECP increase the engagement of undergraduate students in their transportation infrastructure engineering learning and lead to measurable lasting gains?* To answer these research questions, ECP was implemented and assessed when used to teach the concepts of stress and strain utilized in the analysis of bridges and other transportation infrastructure, sound used in the development and design of noise barriers, moisture content in controlling compaction of highway infrastructure systems, and degradation of infrastructure systems exposed to various environmental settings. Assessment results from 92 undergraduates reveal an increase in students' motivation and cognitive understanding of the relevant concepts, as well as learning gains and an improved success rate compared to the traditional method of teaching.

Keywords

infrastructure, highway maintenance, education and training personnel, education and training, transportation workforce management, university education of future workforce, sustainability and resilience

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The traditional method of teaching and learning, a teacher-directed and teacher-centered approach, has been studied extensively to improve outcomes for students (1). Students may listen to the instructors' lectures, memorize what has been taught, and reproduce the consumed information whether or not understanding has been achieved (2). This in turn does not develop the critical reasoning, problem-solving, or technical skills of the students (2). With time, what had been memorized gets forgotten and there is no ability to transfer the knowledge to other fields of learning. In recent times, research has shown that hands-on pedagogy, a student-centered approach, improves student performance and engagement, increases the interest of students in the subject matter, improves the rate of retention of what is being taught, and develops the capacity of students to transfer the acquired knowledge (3). Learning by doing is a student-centered hands-on approach to learning that allows the students to interact with their environment to actively learn and adapt to the learning environment.

The American Society of Civil Engineers (ASCE) recognizes transportation systems as one of the major critical infrastructure systems in any economy (4). The purpose of this paper is to discover relevant hands-on learning pedagogy in the analysis, design, and maintenance of transportation infrastructure systems. Miller et al. (5) utilized hands-on-learning pedagogy to motivate students, especially minorities and women, by engaging them in solving real-world transportation problems. Connor et al. (6) investigated personal instrumentation tools that supports experimental student centered learning and discovered increased knowledge and greater creativity resulting from hands-on use; increased confidence and more real-world knowledge as theory was tied to practice. ECP is currently being implemented at various historically Black colleges and universities (HBCUs), to allow students of varying learning styles the opportunity to learn at their own pace and in their own environments by providing them with an alternative way to acquire technical skills and knowledge, both in the classroom and outside. An interesting note about ECP is that it allows the true integration of technology with curriculum development and new pedagogies that allows students to learn through hands-on practices, experiential learning, and group work. ECP, a hands-on learner-centered teaching technique that utilizes cheap, portable instrumentations, has been successfully implemented to increase students' engagement and motivation in the electrical engineering field at 13 historically Black universities (7). ECP integrates problem-based activities and constructivist instruction by using a hands-on mobile

multi-function instrument that is designed to replace larger laboratory equipment (7). The hands-on mobile instrument enables the students to practice previously acquired knowledge outside the classroom with their peers or independently. The uniqueness of ECP devices is that they can be easily utilized at different learning settings: in the classroom for demonstration by the instructor; in the laboratory; and at home by students to conduct homework. ECP is also hinged on embodied learning, where bodily activity is integrated into learning tasks with the view of developing meta-cognitive skills and expertise that enhances critical thinking, which promotes students' active participation in rendering and deeply understanding scientific concepts (8, 9).

The use of instrumentations in other science, technology, engineering, and mathematics (STEM) fields facilitates the adoption of ECP in these fields. Although ECP has been successfully implemented in electrical engineering, it had never been implemented in the field of transportation infrastructure engineering. Without employing high-impact pedagogy that utilizes hands-on activities that connect theory with practice, most critical concepts that are relevant in the analysis, design, and maintenance of transportation infrastructure engineering systems may appear abstract and very difficult to grasp. This paper presents the development and implementation of ECP to teach these concepts, which are relevant in the analysis, design, and maintenance of transportation infrastructure systems to undergraduate students at a historically Black university. To demonstrate the efficacy of ECP in transportation infrastructure engineering, active learning experiments were developed, implemented, and assessed in courses where the concepts of stress and strain, sound, moisture content, and other transportation infrastructure systems concepts are taught.

Literature Review

Hands-on Learning Pedagogy

Ekwueme et al. (10) defined hands-on learning pedagogy as "a method of instruction where students are guided to gain knowledge by experience. This means giving the students the opportunity to manipulate the objects they are studying..." When students are given the opportunity to simulate what has been taught, they stand a better chance to recall the teachings and to also transfer gained knowledge. Zha and He (11) equally observed that assigning each member of a group in an online learning setting a specific role was the key to inclusive learning. In their research on "Pandemic Pedagogy in Online Hands-on

Learning for Information Technology & Information Science courses,” it was discovered that after students experienced this role-assigned group learning several times, the introverted students who kept to themselves at the beginning of the class started to raise questions and also voluntarily offered answers. More so, it was revealed that engagement in content learning improved the performance of students in given assignments.

Numerous hands-on learning methods have been designed to encourage self-learning for students in the classroom (5, 10). It cannot be overemphasized that the classroom is no longer a traditional teacher-centered classroom but now a modern student-centered classroom. This change, rather than becoming frustrating to the faculty, should inspire the faculty to learn new ways of knowledge transfer, unlearn old ways that have become outdated, and relearn forgotten methods that are still relevant.

To effectively and efficiently implement ECP in transportation infrastructure engineering, various learning theories must be considered. Learning theories describe different learning processes and models that can be integrated into classrooms. The result of this provides instructors with better teaching methods. In addition, the proper implementation of learning theory results in increased motivation and engagement in students.

Theoretical Framework

The process of learning is one that is dynamic and unique to each individual. It is extremely important for an educator to understand how new skills are developed, how new knowledge is learned, and how new behaviors, morals, attitudes, and values are learned (12). Learning theories give an exposition to the structure of how people learn. Research has been conducted to discover how people learn and theorists have come up with different theories on how learning is achieved (13). Two major learning theories are as follows: (1) behaviorism learning theory, which focuses on what can be learned from the observation of behavior rather than trying to measure or describe a person's internal thoughts, feelings, and experiences; and (2) constructivism learning theory, which examines how individuals can be agents of their own learning.

ECP integrates problem-based activities and constructivist instruction by allowing students to actively participate in the learning process by building on their previous experiences and understanding to construct new knowledge or understanding (14). Constructivism posits that knowledge acquisition occurs amid four assumptions: (1)

learning involves active cognitive processing; (2) learning is adaptive; (3) learning is subjective, not objective; and (4) learning involves both social/cultural and individual processes.

Constructivist Learning Theory Using the 5E Model

The 5E learning model was developed by the Biological Sciences Curriculum Study to promote collaborative, active learning where students work together to solve problems by making observations, questioning, analysis, and drawing conclusions (15). In science education, the 5E model is one of the preferred models since it consists of a gradual process through which knowledge is shared and expounded to learners. Figure 1 shows the pathway the 5E model takes during the learning process. The first stage is the *ENGAGE* stage. Here, the instructor engages students by stimulating their interest through challenging tasks. Finding a solution to the tasks fascinates the students and they begin to activate and connect residual knowledge of the task. Learning then proceeds to the second stage, which is the *EXPLORE* stage. In this stage, previous knowledge is challenged, new ideas are obtained, and the students begin to learn new aspects of the subject or course being taught. The next stage is the *EXPLAIN* stage; here the instructor explains the concepts and contexts of the subject matter, thereby making what seems complex, simple. The students can now connect the knowledge to applicable scenarios. The fourth stage, whose aim is to *ELABORATE* knowledge takes it a notch higher and deeper by showing ways in which the acquired knowledge can be applied to new situations. After going through the first four stages of the 5E model, students will have acquired hands-on experience and knowledge that can be applied to real-life situations. This leads to the final stage, which helps students reflect on their learning and *EVALUATE* their performance.

Experiment-Centric Pedagogy

ECP is a learning process that involves active problem-solving. During the learning process, students are being instructed and allowed to carry out practical activities to enhance their learning. When this pedagogy is applied to teaching and learning activities, students easily utilize the hands-on mobile multi-function instrumentation in a wide variety of hands-on experiments (16). The three objectives of the pedagogy are to apply instrumentation to make measurements of physical quantities, to identify limitations of models to predict real-world behavior, and to develop an experimental approach to characterize and explain the world (7). The benefits of the ECP cannot be

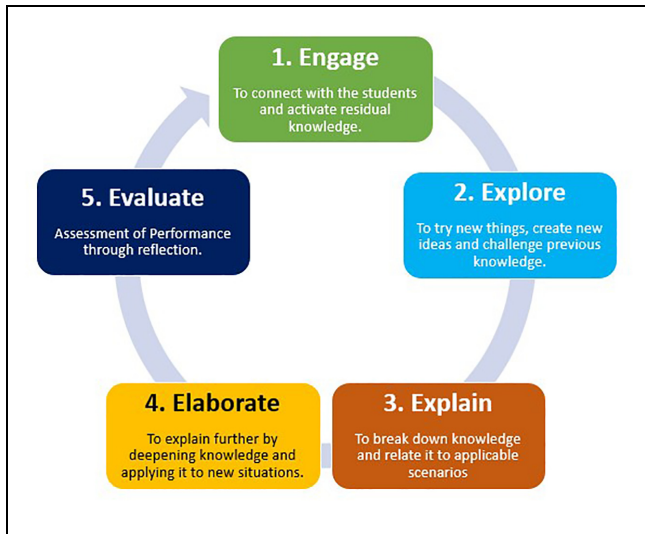


Figure 1. The 5E model of the constructivist learning theory.

overemphasized. It is highly commendable that it allows the students to not only be physically present but also to be actively and mentally present by participating in classroom activities. Figure 2 shows four learning processes using ECP. The process begins with an experiment that exposes learners to the real-life application of what is being taught. Here, students and their peers perform experiments/hands-on activities to aid understanding; they also learn about teamwork, acceptance, and growth. Based on the knowledge and skills acquired during the experiment, students can better draw inferences and make simulations when faced with similar or more advanced situations. The uniqueness of ECP is that the learning process normally commences with the experiment, compared with other traditional methods that commence at the mathematics and science information phase. This is consistent with the study of Emiola-Owolabi et al. (17), where they added a construct to Kolb's (18) experiential learning cycle framework, to increase students' engagement. They added "concrete experience" to Kolb's (18) experiential learning framework to start the process of the engineering students' learning process.

The 5E model was used to deliver ECP to learners in this study. Instructors facilitated learning, beginning with questions or tasks that engage the curiosity of learners, which stirs their exploration of the capabilities of the device in groups, which is consistent with the study of Emiola-Owolabi et al. (17). Afterwards, the tutor picks up the device and demonstrate how to use the device to perform one of the key functions. Learners are then permitted to go home with the device, experiment other functions with it, present a report from their personal

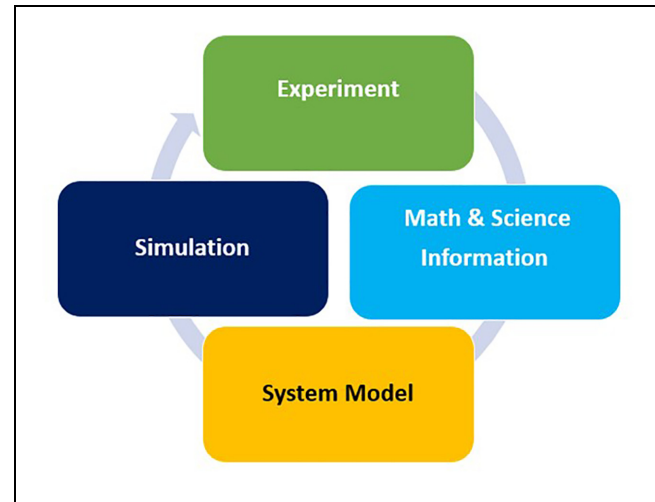


Figure 2. The fundamentals of experiment-centric pedagogy.

experiment, and later, the instructor evaluates them using signature assignments.

Concepts Relevant to Transportation Infrastructure Systems Analysis and Design

Stress and Strain in the Analysis and Design of Bridges and Other Relevant Infrastructure. Stress and strain are very crucial concepts used in the structural analysis of various transportation infrastructure systems, such as bridges, culverts, retaining walls, and so forth. When these experiments are introduced to students, the concepts are usually linked to real-life theory. More information about the experiments are contained in the work by Ikiriko et al. (19).

Sound used in the Development and Design of Noise Barriers. Noise pollution consists of unwanted sounds that can negatively affect psychological health. These negative effects can lead to stress responses, sleep disturbances, and adverse economic effects. To address the effects of noise pollution, noise barriers have been created to absorb and alleviate noise leaks. Noise barrier walls can be implemented in highway traffic and residential areas (20). This noise measurement experiment will help students better understand the planning and design of noise barriers in highway corridors that are situated in densely populated communities. Figure 3 shows the effects that traffic volume, speed, and vehicle type have on noise. Students were able to understand the noise model that governs the observation in Figure 3. Sound data were collected both indoors and outdoors. The voltage reading from an ADALM 100 device was converted

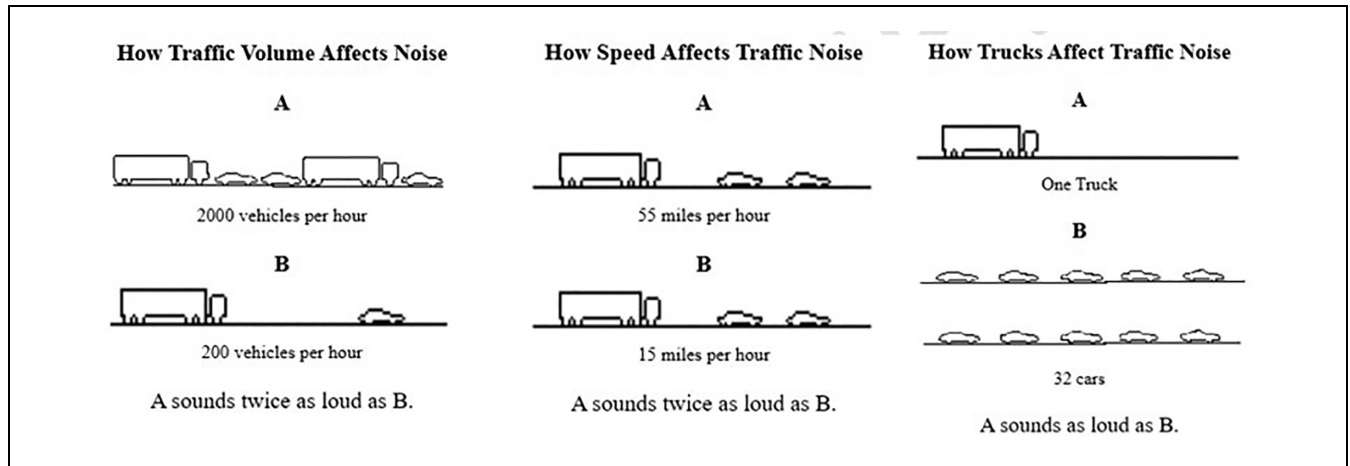


Figure 3. The effects of volume, speed, and vehicle type on noise (21).

to decibels using Equation 1. Details of the experiment are shown in the *Methodology* section:

$$\text{Gain(dB)} = 20\text{Log}_{10}(V_{out} \div V_{in}) \quad (1)$$

where V_{out} is the output voltage and V_{in} is 5 V, which is the input voltage.

Moisture Control in Compaction of Highway Infrastructure Systems. Soil moisture content is an essential parameter used to determine the quality of highway construction and pavement performance. Soil moisture content is defined as the ratio of the weight of water to the weight of dry soil. It is normally expressed as a percentage. Soil moisture content affects the soil's electrical conductivity, which can help to determine the important physical and chemical properties of the soil (22). Moisture content can affect the structural performance and behavior of roadway pavement. This knowledge is also very important for compaction control in highway construction. Another application of moisture content determination is material quality determination and control. An Alice M1K device coupled with a data stream in Microsoft Excel was used to determine the moisture content in eight different soil types.

Degradation of Infrastructure Systems Exposed to Various Environmental Settings. Transportation infrastructure, such as bridges, highway culverts, and stormwater conveyances, can deteriorate based on the chemical nature of the waters they convey and traverse. The infrastructure that comes into contact with water is constructed from a variety of materials and is available in many different shapes and configurations. Culverts, for instance, are necessary to convey water through a roadway embankment, and their service life and material durability is subject to field and environmental conditions. Over time

culverts may deteriorate because of abrasion and corrosion based on the chemical condition of the water (23).

Highways and roads can also be major sources of pollutants that affect water quality. This could have adverse effects on aquatic systems and can also lead to environmental regulatory violations, as waters of the U.S.A. are subject to state and federal protection. Road salt, heavy metals, and other pollutants can contribute to elevated concentrations of total dissolved solids (TDS) that may affect bodies of water that receive stormwater runoff from roads. The interaction between transportation infrastructure and receiving bodies of water can affect the pH. This means that state transportation agencies must be cognizant of the national recommended water quality criteria for the pH of freshwater of 6.5–9. This is within the optimal range to allow aquatic organisms to grow and survive. When activities cause the pH to be outside of this range, organisms can become physiologically stressed, affecting reproduction, and may even cause death. Cementitious materials are often used in the construction and maintenance of transportation infrastructure. These materials can adversely affect water quality, particularly by spiking the pH, caused by hydrolysis of calcium oxide (CaO), which can increase pH to greater than 12 (24). This also may consequently produce caustic alkalinity and increases in pH that can raise the toxicity of other pollutants, potentially affecting aquatic organisms and fragile ecosystems. For example, fish are 10 times more susceptible to ammonia toxicity at pH 8.5 than at pH 7.5, according to Thurston et al. (25). When the pH of the water is low, sediments can release toxic elements and compounds into the water, which can be taken up by aquatic plants and animals. A change in pH can also affect how much phosphate, ammonia, iron, and trace metals are available in the water (26).

Water quality parameters, such as pH and TDS, enable the monitoring of aquatic systems affected by transportation infrastructure. These impacts on water

quality can often come from activities related to the construction, operation, and maintenance of bridges, culverts, highways, and roads. In the ECP laboratory activities, students learned about these common water quality measures used for detecting changes in bodies of water and monitoring water quality. To achieve this, the Alice M1K desktop device was employed using the voltmeter reading to study the pH of different liquids, as explained above.

Methodology

Research Purpose and Questions

The following are the research questions that guided the study: (1) How well can ECP improve students' understanding of concepts essential to the analysis and design of transportation infrastructure systems? (2) How has the ECP facilitated the achievement of the learning objectives of these concepts? and (3) Does an ECP increase the engagement of undergraduate students in their transportation infrastructure development learning and lead to measurable lasting gains? To answer these questions, electronic instrumentations used to make scientific measurements in the transportation infrastructure engineering field are carefully identified. In the transportation infrastructure engineering field, electronic instrumentations are essential in testing and understanding these concepts, which is the reasoning for the adoption of ECP in transportation infrastructure engineering. Critical and difficult-to-understand concepts where electronic instrumentations can be used to make scientific measurements in explaining principles guiding such concepts were identified in the transportation infrastructure engineering field. After the identification of these concepts, experiments that utilize the electronic instrumentations are then developed and implemented. The Motivated Strategies for Learning Questionnaire (MSLQ) tool (27–29) and Litman and Spielberger (30) curiosity assessment instruments were used to measure key constructs associated with student success, such as motivation, epistemic curiosity (EC) and perceptual curiosity (PC), and self-efficacy. Student success was measured by the academic performance of the ECP students compared to the academic performance without ECP. Furthermore, the fundamentals of ECP and the classroom observation protocol are implemented to effectively integrate ECP in transportation infrastructure engineering.

In each of the courses a well-developed course structure with modules where ECP can be easily implemented was developed. The ECP course structure with well-aligned course components are divided into four parts, as described in Figure 4. This structure guides the course delivery.

Quantitative and qualitative data are collected before and after each module. The MSLQ measure includes two

distinct scales, motivational and learning goals. The motivational scale includes three components: value, expectancy, and affective. The value section includes goal orientation for intrinsic and extrinsic, and task value, while the expectancy section includes control beliefs and self-efficacy. The affection section includes test anxiety. The MSLQ measure was utilized to assess the effectiveness of the implementation of ECP. The learning goals scale of the MSLQ is further separated into cognitive and resource management strategies components. The cognitive section includes items for rehearsal, elaboration, organization, critical thinking, and metacognitive self-regulation. The resource management strategies include items for time and study environment, effort regulation, peer learning, and help-seeking. When pre- and post-data are collected to show positive gains, we would expect increases, particularly in intrinsic goal orientation (IGO), task value, control beliefs, and self-efficacy with reduced test anxiety from the motivational scale. As well as increases in critical thinking and metacognitive self-regulation, peer learning goals scale particularly as a function of the active learning strategies and the implementation of ECP (27, 28, 31). The MSLQ uses a 7-point Likert-type scale with statements related to the key constructs.

The Littman and Spielberger (30) curiosity assessment tool, on the other hand, measures students' level of curiosity. The tool is divided into two categories: EC and PC. EC is curiosity that stems from one's motivation to know, to gather knowledge, and to fill in "gaps" in one's knowledge. In contrast, PC is curiosity that leads to increased perceptual experiences of the individual. The curiosity assessment tool is based on a 4-point Likert-type scale. A descriptive analysis is conducted to determine the significance of the pre- and post-test results of all the key constructs.

The classroom observation protocol for undergraduate STEM (COPUS) developed by Smith et al. (32) was used to measure student engagement during the implementation of ECP. COPUS was also used to reliably characterize how faculty and students are spending their time in the classroom. COPUS is also a pedagogical validated evaluation tool that can provide feedback to instructors about the effectiveness of their teaching techniques, so as to identify professional development needs. The classroom observation contains 25 codes in only two categories ("What the students are doing" and "What the instructor is doing") and can be reliably used by university faculty. Velasco et al. (33) further recommended that in analyzing the observation results, bar charts should be utilized that will display the proportion of behaviors, calculated as percentages of 2 min intervals in a class period during which individual behaviors are observed and the proportion of codes describing the

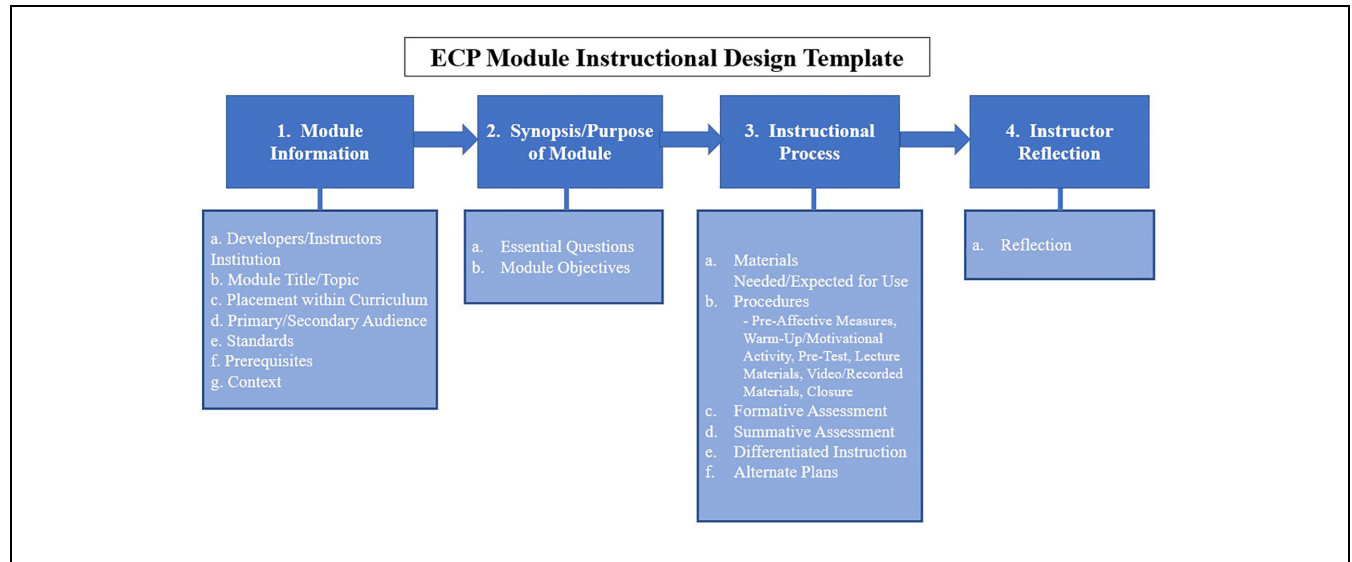


Figure 4. Experiment-centric pedagogy (ECP) module instructional design.

nature of interaction-coded intervals co-coded with codes for the nature of verbal interactions.

A signature assignment was used to determine the measure of knowledge gain in each module; the same assignment was administered before the module and after the module. Instruments were also developed to measure the attainment of student learning outcomes: an ability to develop and conduct experiments or test hypotheses, analyze and interpret data, and use scientific judgment to draw conclusions.

Table 1 shows a breakdown of the courses and experiments where ECP was implemented in the transportation infrastructure engineering field from Fall 2020 to Spring 2022. It is to be noted that when cleaning the data, data points that did not match at pre and post were eliminated; therefore, the number of students in the table reflects the number actually utilized for the analysis. To show the impact of ECP, all courses were combined and following are the socio-demographics: 79.3% were male and 19.6% were female; 87.0% reported ethnicity as African American, 6.5% were Hispanic or Latino, 1.1% White/Caucasian, and 5.4% reported as other racial group. Overall, 4.3% of the students were freshmen, 8.7% sophomore, 33.7% junior, and the remaining 53.3% reported that they were seniors. From the aggregation, 23.9% have a cumulative grade point average (CGPA) of 3.60–4.00, while 32.6% reported a CGPA of 3.1–3.5, 34.8% fell in the range of 2.6–3.0, and 8.7% fell in the 2.10–2.50 range.

Brief Description of the Experiments

Below a brief description of a few of the experiments is presented; details of others can be found in Ikiriko et al. (19).

Noise Measurements Experiment. In Fall 2020, the sound experiment was conducted in the highway engineering class. The experiment involved the use of an ADALM 1000 (M1K) device, an analog sound sensor, three jump wires, and a laptop or personal computer. Figure 5 shows the experiment components.

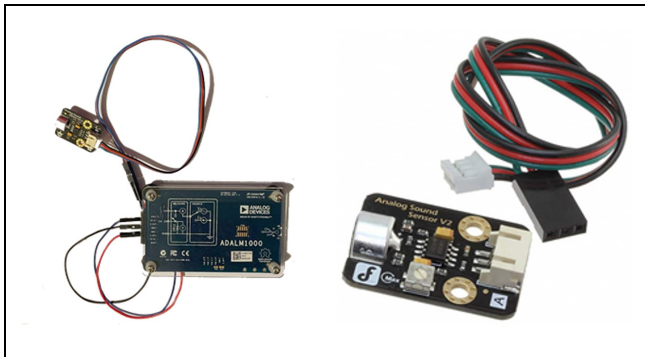
Before the experiment was introduced in class, the students were taught about the fundamental concepts of sound, which include loudness, duration, frequency, and subjectivity. They were shown the different decibel levels for different scenarios. Since noise pollution is very prevalent in urban and densely populated communities, mitigation is necessary.

Moisture Content Determination. The soil sensor measures the soil's EC and the data collected can then be used to determine the moisture content. Six prepared samples of varying soil moisture were used to calibrate the sensor (Figure 6a). The operating voltage range for the soil moisture sensor (Figure 6b) is 3.3–5 V, with an output voltage signal of 0–4.2 V and a current of 3 mA. Moisture content data is collected using the Arduino device with the appropriate transfer function (Figure 6, c and d). There was a chance of problems/technical issues with the software on different laptops and faculty might spend a lot of time troubleshooting all those different machines. Students were asked to use the desktops at the computer laboratory. The code for the Arduino device was uploaded and students did their work on the desktops. Arduino UNO has enabled us to produce consistent results similar to those of Drake (34).

Data Collection and Analysis. The MSLQ was sent to the students virtually before and after the implementation of

Table 1. Courses and Experiments Undertaken with Experiment-Centric Pedagogy with Number of Student Data Points (*N*)

Semester (year)	Course code	Course title	Experiments	Frequency, <i>N</i>	Percentage, %
Fall (2020)	CEGR 324	Structural Analysis and Lab	Bending stress & strain Beam deflection/modulus of elasticity of specimen	5	5.4
Fall (2020)	TRSS 415	Highway Engineering	Sound experiment	22	23.9
Spring (2021)	CEGR 324	Structural Analysis and Lab	Bending stress & strain Beam deflection/modulus of elasticity of specimen	7	7.6
Fall (2021)	CEGR 324	Structural Analysis and Lab	Bending stress & strain Beam deflection/modulus of elasticity of specimen	8	8.7
Fall (2021)	TRSS 415	Highway Engineering	Soil moisture content	3	3.3
Fall (2021)	TRSS 301	Introduction to Transportation Systems	Sound experiment	24	26.1
Spring (2022)	CEGR 324	Structural Analysis and Lab	Bending stress & strain	8	8.7
Spring (2022)	CEGR 338	Environmental Engineering	PH and total dissolved solids	10	10.9
Spring (2022)	CEGR 212	Mechanics of Materials and Lab	Bending stress & strain Beam deflection/modulus of elasticity of specimen	5	5.4
Total students				92	100.0

**Figure 5.** The noise experiment setup.

the ECP module. The MSLQ is a 7-point Likert scale instrument, ranging from “never” true of me (coded as 1) to “very true of me” (coded as 7). The collected data were averaged and reported using the mean and standard deviation (both pre- and post-test) for each subscale. The curiosity data (deprivation EC and interest EC) were collected using a 4-point Likert scale from “never” (coded as 1) to “always” (coded as 4). Box plots were also used to compare the responses of the pre- and post-test data. The overall mean and standard deviation of each subscale were presented. In addition to the above descriptive statistics, the study compared the responses of participants before and after using a non-parametric method because the data failed the assumptions of normality ($p < 0.05$). The confidence level for the non-parametric test was set at a 95.0% confidence level.

Deductive analysis was conducted using the two-cycled format of qualitative investigation on the open-ended question given to the participants. The two-cycled format involves reading, classifying, and theme identification. The first cycle of analysis was that one of the authors read the data and coded it into units with broad themes in a line-by-line format. In the second cycle, the broad themes in the line-by-line analysis were re-analyzed and themes were merged after comparing the line-by-line broad themes that were common sets or repeated. One of the open-ended questions is: “Please describe your class experience of using analog devices (Arduino, M1K, M2k, or others), it may be related to an experiment topic that you enjoyed, or your interest and curiosity/challenges or something.”

Results and Discussion

How Well Can Experiment-Centric Pedagogy Improve Students' Understanding of Concepts Essential to the Analysis and Design of Transportation Infrastructure Systems?

From the results of the descriptive statistics of the for the pre- and post-tests scores of the MSLQ and curiosity scales in Table 2, there is a clear direction toward the improvement of metacognition and peer learning/collaboration, as the results show a significant increase in the students' metacognition, Δ mean = 0.26, and peer learning/collaboration scores, Δ mean = 0.53 ($p < 0.05$). As

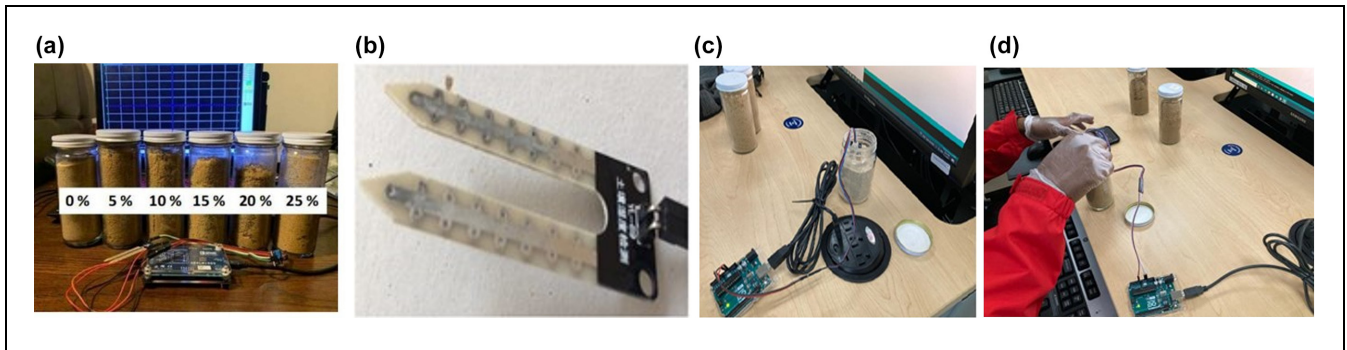


Figure 6. (a) Sample specimens used to calibrate the soil moisture sensor. (b) Soil moisture sensor. (c), (d) Experimental set of the moisture content determination with the Arduino device.

Table 2. Summary Statistics for Students' Motivation and Curiosity Pre- and Post-Test

MSLQ scale	Pre-test, $N=92$, Mean $\pm$ SD	Post-test, $N=92$, Mean $\pm$ SD	Δ mean	Z-test	p-value
Intrinsic goal orientation (IGO) ^a	5.43 $\pm$ 1.17	5.37 $\pm$ 1.05	−0.05	0.64	0.53
Task value (TV) ^a	5.57 $\pm$ 1.32	5.46 $\pm$ 1.15	−0.10	1.31	0.19
Expectancy component (EC) ^a	5.49 $\pm$ 1.3	5.47 $\pm$ 1.12	−0.02	0.38	0.71
Test anxiety (TA) ^a	4.83 $\pm$ 1.81	4.88 $\pm$ 1.42	0.05	0.25	0.81
Critical thinking (CT) ^a	4.84 $\pm$ 1.38	5.04 $\pm$ 1.13	0.20	1.17	0.24
Metacognition (MC) ^a	5.21 $\pm$ 1.22	5.47 $\pm$ 1.07	0.26	1.46	0.03
Peer learning/collaboration (PLC) ^a	4.19 $\pm$ 1.74	4.72 $\pm$ 1.54	0.53	2.97	0.01
Interest epistemic curiosity (IEC) ^b	3.17 $\pm$ 0.66	4.47 $\pm$ 1.48	1.30	0.54	0.59
Deprivation epistemic curiosity (DEC) ^b	2.81 $\pm$ 0.75	2.74 $\pm$ 0.63	−0.08	0.16	0.88

Note: MSLQ = Motivated Strategies for Learning Questionnaire.

^a1–7 Likert scale (note: 1 = not at all true of me, 7 = very true of me).

^b1–4 Likert scale (note: 1 = never, 2 = sometimes, 3 = often, 4 = always).

noted above, the result presented in Table 2 reveals the summary statistics (mean, standard deviation, mean difference) as well as the p -values of the paired t -test of pre- and post-test scores of students under each domain of the MSLQ. Other notable improvements in the domain were in students' critical thinking (subdomains: I often find myself questioning things I hear or read in this course; I try to play around with ideas of my own related to what I am learning in this course; whenever I read or hear an assertion or conclusion in this class, I think about possible alternatives) and interest EC (subdomains: I enjoy exploring new ideas; I enjoy learning about subjects that are unfamiliar to me; I find it fascinating to learn new information; when I learn something new, I would like to find out more about it and I enjoy discussing abstract concepts). Clearly from the results of these constructs it can be seen that ECP has improved students' understanding of the abstract and difficult-to-grasp transportation infrastructure engineering concepts. The result, as shown in Table 2, revealed an improvement in students' intrinsic goals, as the distribution of student scores in the post-test were better in than in the pre-test. However, the Z-test test showed that the 0.05 decrease in the mean score of the

students from pre-test to post-test was not statistically significant ($Z = 0.64$, $p > 0.05$). Although there was a decrease in the mean score of the task value, this was not significant (mean = -0.11 , $Z = 1.31$, $p > 0.05$). The results of this study are consistent with other studies carried out around the globe, where it has been reported that active learning pedagogy increased students' interest, imagination, and motivation to prepare (35–37). It also produced a demanding atmosphere for learning that encouraged the exchange of different viewpoints and the growth of a community of learners (38).

From the qualitative results, the following were expressed by the students when asked to describe their experience using the analog devices (question asked: "Please describe your class experience of using analog devices [Arduino, M1K, M2k, or others]. It may be related to [an] experiment topic that you enjoyed, or your interest and curiosity/challenges or something other").

The students expressed developing interest and curiosity in the courses as they engaged with the instruments (Arduino, M1K, M2k) introduced in the class. The major themes that were obtained from the qualitative data are "engaging," "enlightening," and "insightful." All of these

themes demonstrated that the students became engaged with the instruments, which further leads to a positive learning process for the students. These themes can be linked to the ECP constructs.

The theme “engaging” is linked with the first construct of ECP: experiment. The students were able to use the instruments to perform experiments to aid their understanding and learning process. Sample excerpts of this theme are as follows:

It was very interesting seeing how the Analog Device (M1k-ADALM 1000) worked. It was very simple, and it was intriguing to see how decibel waves formed with sound.

I enjoyed my class experience greatly. my professor always kept us engaged and was very creative with fun but challenging assignments.

The theme “explore” described how the students were able to discover new things as they engaged with the instruments given in the courses. This theme is connected to the ECP construct “explore.” Sample extracts of this theme are as follows:

We used the sound decibel app in my transportation class to record the level of noise for different locations and at different times. It was cool finding out the differences in the level of noise for different sounds.

The decibel: finding the db decibel's was very interesting and enlightening during this course.

The overall experience using the phone app was insightful. It allowed me to better understand and determine safe vs unsafe sound ranges based on the sources. As well as how other factors contribute to sound/noise levels.

The Arduino was used to simulate different soil states with given properties to generate the necessary data for the understanding and analysis of soil properties.

During this experiment the goal was to measure the soil moisture through utilizing the Arduino software. It was a good experiment that exposed me to a soil moisture sensor.

It was pretty cool seeing how the slightest bit of sound could affect the hertz.

Nice experience being able to determine the ppm of random solution with computer software and sensors.

The theme “insightful” is linked to the ECP construct “elaborate.” In this theme, the students described having deeper knowledge of the concepts being learnt as they engaged and gained new insights into the concepts. Sample excerpts of this theme are as follows:

This experiment was extremely informative in knowing what water samples are best to drink pending on its TDS level.

It was very fun to set up. Always a great day learning something new.

It was rather interesting; it gave me a better visual understanding of devices used.

The main themes of the qualitative results are students' interest and engagement with the contents that culminated in better comprehension of concepts essential to the analysis and design of transportation infrastructure systems, subsequently demonstrating the effectiveness of ECP. The general comments and expressions also revealed that students were motivated as they could relate the topics taught during normal class sessions with real-life scenarios. This finding is similar to the report of Yukhymenko et al. (39) where students also reported better engagement with the content as well as peer collaboration with the use of active learning pedagogy.

How has the ECP Facilitated the Achievement of the Learning Objectives of these Concepts?

To demonstrate students' mastery of the learning outcomes of the concepts, the students were assessed through a validated instrument that assesses the ability to develop and conduct experiments or test hypotheses, analyze and interpret data, and use scientific judgment to draw conclusions. The instrument has performance scales of unsatisfactory, developing, satisfactory, and exemplary, respectively. For each performance criteria a targeted performance of 75% has been set, which means at least 75% of the students must either be at the satisfactory or exemplary scale. This means that less than 25% must fall under the unsatisfactory and developing scales, respectively. This was set as a benchmark by the department, as part of the Accreditation Board for Engineering and Technology, Inc. (ABET) accreditation process, to ensure that the considerable majority of students had attained a satisfactory level of mastery of the concepts taught. The outcome assessments were conducted in Fall 2021 (Figure 7a) and Spring 2022 (Figure 7b). Figure 7c shows an aggregation of all the courses assessed in Fall 2021 and Spring 2022. More than 75% percent of students in all these courses met the target performance for the following performance criteria: “describes the hypothesis being tested”; “formulates adequate simulation or experiment and hypothesis”; “understands the functions and limitations of the computer or laboratory tool/equipment used”; and “uses laboratory tool/equipment or computer simulation correctly,” while students failed to meet the targeted performance when “acceptance of reasonable variance between numerical or experimental results and predictions of hypothesis”;

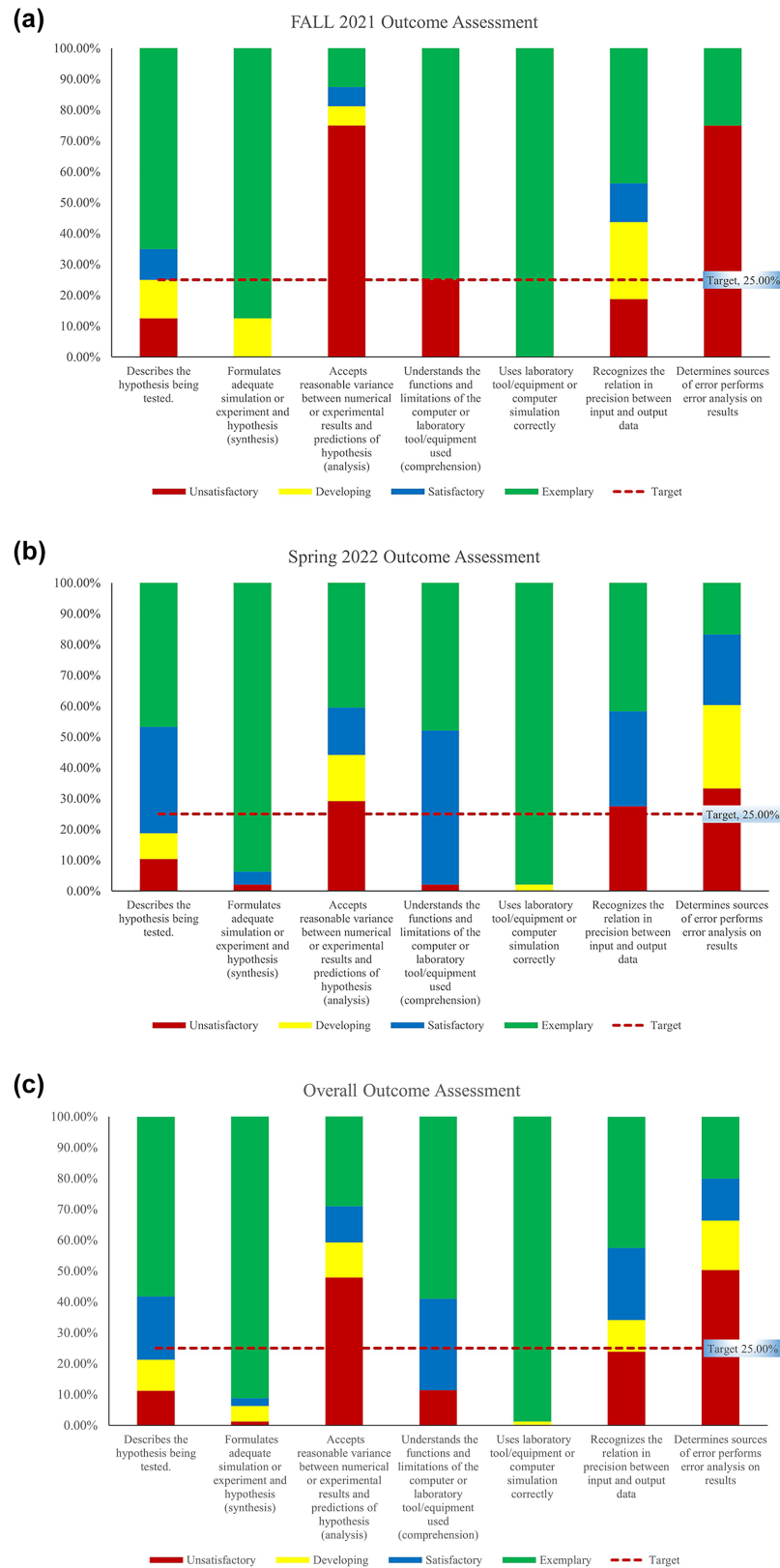


Figure 7. (a) Outcome assessment results for the highway engineering and structural analysis courses in Fall 2021 ($N = 20$). (b) Outcome assessment results for the mechanics of materials, structural analysis, and environmental engineering courses in Spring 2022 ($N = 29$). (c) Outcome assessment results for all courses aggregated for both Fall 2021 and Spring 2022 ($N = 49$).

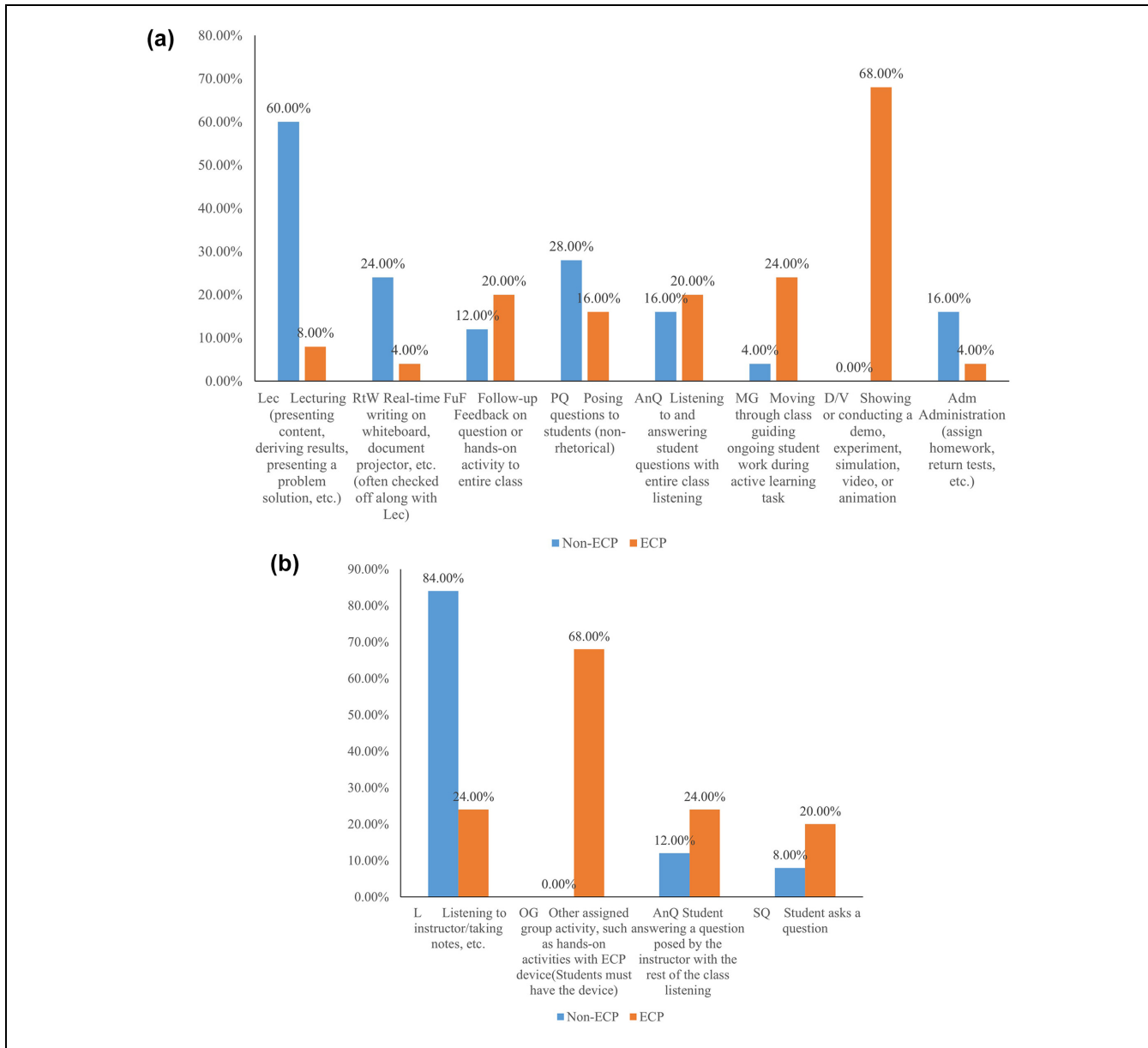


Figure 8. (a) Comparison of instructor behavior with and without experiment-centric pedagogy (ECP) in the structural analysis class. (b) Comparison of student behavior with and without ECP in the structural analysis class.

“recognition of the relationship in precision between input and input data”; and “determination of sources of error” performance criteria were assessed.

Does an ECP Increase the Engagement of Undergraduate Students in their Transportation Infrastructure Engineering Learning and Lead to Measurable Lasting Gains?

The comparison of the classroom observation of instructor and student behaviors when ECP was implemented and not implemented in structural analysis and highway

engineering classes reveals a better student engagement with ECP (Figure 8, *a* and *b*). In classes that were instructed using ECP, it was observed that students had more participation than in the non-ECP classes. Students were able to not just listen more like in non-ECP classes, but were able to work in groups and ask and answer more questions, which informs a deeper level of curiosity and engagement with class content.

As described earlier, to measure lasting gains, signature assignments were administered before and after implementation of ECP in Fall 2021 and Spring 2022. In Fall 2021 (Table 3), students’ minimum score increased from 5 to 51, while the maximum score increased from

Table 3. Students' Signature Assignment (Academic Performance $N = 56$)

	Pre-test	Post-test	% Change	Z-test	p-value
Fall 2021				3.58	0.01
Min.	5.00	53.00	6.00		
Max.	73.00	100.00	71.00		
Mean	52.00	86.56	34.56		
Spring 2022				4.99	0.01
Min.	14.29	28.50	0.00		
Max.	100.00	100.00	67.00		
Mean	50.16	76.70	26.54		
Aggregated				6.03	0.01
Min.	5.00	28.57	0.00		
Max.	100.00	100.00	71.00		
Mean	50.69	79.52	28.83		

Note: Mini. = minimum; Max. = maximum.

73 to 100. The mean difference of the pre-test and the post-test was 34.56. The Wilcoxon Z-statistic showed that there was a significant increase in the students' engagement when ECP was employed in teaching transportation infrastructure courses at an historically Black university ($Z = -3.58$, $p < 0.05$). This was similar to the result observed in Table 3, as there was a statistically significant improvement in students' signature assessment by Spring 2022 ($Z = -4.99$, $p < 0.05$). The result of the aggregated data (Table 3) likewise revealed that there was a significant improvement in students' signature assessment scores at post-test ($Z = -6.34$, $p < 0.05$).

Student success was measured by the academic performance of the ECP students compared to the academic performance without ECP in courses with the same instructor. The results in Table 4 present a comparison of students' performances in Fall 2019 (non-ECP) and Spring 2022 (ECP) in the CEGR 214, CEGR 338, and TRSS 415 courses. These courses are chosen from the poll because the same instructor taught them in Fall 2019 before the implementation of ECP. The classification of the result was students with Grades D–F were classified as failed and students with grades A–C were classified as passed. There was a 100% pass rate among students taught with ECP, and 74.4% of students taught with non-ECP passed in CEGR 214. The Fisher's exact test (FET) result showed that there is a significant association between students' pass rates in civil engineering courses and the method of instruction, where ECP-taught students outperformed students taught traditionally. Also, the pass rate in CEGR 338 was significantly higher in the ECP-taught class than in the non-ECP-taught class, which shows there is a significant association between ECP usage in teaching and learning and students' grades (chi-square = 3.96, $p = 0.047$).

Table 4. Academic Grades in Courses

Course	ECP	Non-ECP	χ^2/FET	p-value
CEGR 214			0.0117	0.012
Fail	0.00%	25.60%		
Pass	100.00%	74.40%		
CEGR 338			3.96	0.047
Fail	4.30%	26.70%		
Pass	95.70%	73.30%		
TRSS 415			0.03	0.850
Fail	26.67%	28.50%		
Pass	73.33%	71.50%		

Note: ECP = experiment-centric pedagogy; FET = Fisher's exact test.

Conclusion

This study investigated the utilization of a novel pedagogy, referred to as the ECP, in transportation education with the aim of improving students' motivation as well as strengthening engagement during classroom and post-classroom activities in different engineering fields. The instructional design of the pedagogy was hinged on the constructivist theory, which shifts attention from instructors to learners and emphasizes learners taking the center stage in the teaching and learning process. This study adopted the use of the motivated learning strategies questionnaire to assess students' motivation, self-efficacy, and learning strategies as well as peer learning and collaboration. From the result of this study, ECP has been demonstrated to improve students' motivation and the achievement of stated learning objectives of transportation infrastructure systems concepts. Equally, ECP facilitated students' demonstration of better mastery of the expected competencies in the modules. Thus, at a historically Black university, ECP has been designed, implemented, and assessed when used to teach the concepts of stress and strain utilized in the analysis of bridges and other transportation infrastructure, sound used in the development and design of noise barriers, moisture control in controlling compaction of highway infrastructure systems, and degradation of infrastructure systems exposed to various environmental settings. The study also found similarity between the current findings about the impact of the use of ECP and the motivation, self-efficacy, curiosity, and peer learning of learners. The results of the 92 undergraduates assessed reveal an increase in students' motivation and cognitive understanding of the relevant concepts, as well as learning gains and a better success rate compared to the traditional method of teaching.

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