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Fostering Curiosity among Industrial Engineering Undergraduates through Experiment-Centric Pedagogy

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Abstract

In engineering education, cultivating a sense of curiosity among undergraduates is imperative for nurturing innovative thinkers and problem solvers. This study proposes an innovative approach, termed Experiment-Centric Pedagogy (ECP), an experiential and learners-centered approach of learning, aimed at enhancing curiosity of industrial engineering undergraduates. ECP integrates hands-on experimentation with traditional coursework to provide students with a dynamic and engaging learning experience. The study proposes to stimulate transformational shift in classroom dynamics by stirring learners' curiosity through experiential learning.

The methodology utilized a pre-and post-investigative design. The study conducted a survey with the validated and globally accepted Litman and Spielberger curiosity assessment tool to investigate the interest epistemic curiosity and the deprivation epistemic curiosity of the learners electronically. Quantitative analysis was carried out and results were presented using frequency, simple percentages, mean, and standard deviation. Impact of the pedagogy and other mediating factors to improving curiosity of learners were investigated using a t-test and the confidence level was set at 95% using the Statistical Package for Social Scientists (IBM SPSS v25.0)

The findings of this study reveal a positive impact of ECP on students' curiosity levels. Through pre- and post-assessment surveys, it was observed that students exposed to ECP demonstrated a marked increase in their interest in exploring complex industrial engineering concepts. Moreover, class observation results indicated a heightened sense of engagement and participation during classroom sessions.

In conclusion, experiment-centric pedagogy offers a promising approach to enhancing curiosity in industrial engineering undergraduates. This innovative teaching methodology not only ignites students' interest in the subject matter but also equips them with critical thinking skills necessary for success in the dynamic field of industrial engineering. This research sets the stage for a transformative shift in pedagogical practices among industrial engineering educators, ultimately empowering the next generation of industrial engineers to drive innovation and progress in the industry.

Introduction

Curiosity is a primary motivator of learning, invention, and innovation. Curiosity is essential in engineering education for fostering critical thinking, problem-solving, and lifelong learning skills required to face 21st-century issues [1], [2], [3]. Lindholm [4] posited strongly that modernity is fundamentally rooted in curiosity, which serves as a catalyst for knowledge acquisition, fresh perspectives, and creative thinking in both individuals and groups. In the opinion of Pluck and Johnson [5], curiosity is an aspect of intrinsic motivation with great potential to stimulate learning and comprehension. In addition, According to Litman [6], curiosity can be summed up as the drive to discover, perceive, or feel anything that answers the unanswered by gathering new information. Curiosity is therefore one of the keys to learning, creativity, invention, and the poise needed to tackle problems of the twenty-first century.

Traditional engineering curriculum, on one hand, frequently prioritizes theory over application and passive learning overactive participation [7]. This can only serve to reduce learners' natural curiosity and motivation to seek and gain deeper insights which often leads to lesser comprehension, lowered educational outcomes, low retention, as well as lessen workforce development. More hands-on, inquiry-driven techniques that promote curiosity and involve students as active participants in the learning process have been advocated in recent times [8], [9], [10], [11].

Experiment-centric pedagogy (ECP), which combines traditional coursework with flexible, non-complex, hands-on activities and experiments, is one pedagogical strategy that induces a paradigm shift in learning whether in classrooms or laboratories, as well as educational outcomes. [12] define ECP as a practical, learner-centered teaching approach that uses affordable and portable devices to demonstrate STEM concepts. By giving learners' the chance to engage directly with engineering phenomena, build knowledge via first-hand experience, and connect theory to practice, these immersive, hands-on components stimulate curiosity. This creates a stimulating learning atmosphere that encourages in-depth exploration of the underlying technological concepts and piques curiosity. When compared to more passive learning methods, experiment-centric pedagogy has been demonstrated to boost motivation, peer-learning, and retention [13]. Following a study on learners' experiences after exploration and experimentation, Connor et al. [14] emphasized that project-based pedagogy frequently contains implicit biases that limit learning, either in terms of the procedures followed or the expected results. This would result in predictable outcomes that do not promote divergent thinking and creativity [14]. This leads to the authors providing evidence that promotes student-driven pedagogy in which experiment-centric pedagogy stands.

Still, there are a lot of unanswered concerns about how hands-on and project-based learning pedagogies should be implemented with increasing learners' curiosity as a focus. Systematic research is also required to determine how various kinds of hands-on activities affect curiosity and related outcomes based on variables such as the student demography and social characteristics, learning goals, and available resources. Successfully incorporating curiosity focused experiment-centric learning into the engineering and other STEM curriculum will depend on the development, testing, and improvement of evidence-based teaching strategies and policies. For instance, Paruntu et al [15] in a study on the analysis of mathematical curiosity through project-based learning models with scaffolding among junior high school learners found out that higher level learners were more likely to develop curiosity than lower-level learners. In another investigation of the impact of problem-based learning on curiosity in Indonesia, Prayogi et al [3] found that the pedagogy significantly improved the curiosity of learners. These findings suggest that a shift from traditional ways of teaching and learning could potentially lead to improvement in learners' curiosity and therefore strengthen the learning process and yield better outcomes. Experiment-centric pedagogy (ECP) distinguishes itself from other active learning or project-based learning activities through its emphasis on hands-on experimentation integrated seamlessly with traditional coursework. While various pedagogical approaches encourage active participation, ECP places experimentation at the forefront, allowing students to directly engage with industrial engineering phenomena. In addition, the ECP is not confined within the laboratory setting but extends to the classroom setting making it a unique approach to active learning, participation, and increased curiosity among learners. This dynamic involvement fosters a deeper connection between theoretical concepts and practical applications among the students.

Despite the overwhelming body of data supporting the importance of curiosity in the advancement of science and engineering education, little is known about the critical role that transformative pedagogy may play in fostering curiosity of students. The current study therefore seeks to examine the impacts of an experiment-centric pedagogy on curiosity and the learning outcome of learners in terms of performance over two academic semesters. Experiment-centric pedagogy has been implemented in other STEM fields and has been reported to improve motivation and self-efficacy. The choice of industrial engineering was made because of its strong emphasis on practical problem-solving abilities in addition to theoretical understanding. In addition, ECP aligns seamlessly with the objectives of industrial engineering education and through its interactive and immersive nature, there is a promotion of a holistic understanding of complex concepts and nurturing the skills necessary for success in this dynamic and progressive field. Nonetheless, the ideas and conclusions are meant to contribute to a broader understanding of engineering education. Another gap the study proposed to fill is the dearth of evidence of the level of curiosity of learners at higher education as well as pedagogy that stirs curiosity at higher levels of education in response to the recommendation of Jirout et al [16]. One hypothesis was tested in the current study: "There is no significant difference between the epistemic-curiosity scores of learners before and after the implementation of ECP."

Epistemic Curiosity – EC

Berlyne [17] defined epistemic curiosity as a person's "drive to know" that propels learning and intellectual growth. Litman [18] further describes epistemic curiosity as an innate appetite for knowledge that leads to closing knowledge and information deficiency among learners. While Litman and Jimerson's investigation of curiosity using a Feeling-of-Deprivation Scale (CFDS) focuses on lowering uncertainty and negative affectivity, Litman and Spielberger's epistemic curiosity scale was later introduced as a measure of positive emotional-motivational states. After an extensive study on curiosity of learners, Litman [18] found that there are two major classifications of EC which are I-EC and D-EC which represent Interest epistemic curiosity and deprivation epistemic curiosity. IEC refers to the process of expanding one's knowledge base by incorporating novel ideas and concepts, encouraging a diversified approach to learning, and involving positive emotions stemming from the desire to enhance one's cognitive abilities [18]. DEC goes into an unfulfilled need-like condition that energizes specialized investigation focused at solving difficulties and relates to developing performance-oriented learning goals [18].

In recent years, the focus of STEM professionals, social analysts, and education researchers is drifting to understanding these two dimensions of curiosity. Kim and Lee [19] examine the effects of two types of epistemic curiosity on mobile game retention: D-type (information-seeking) and I-type (exploration). The results indicated that switching costs and continuous play intention are considerably influenced by both types, with the combined effect having greater explanatory power than either type alone. To better understand the behavior of mobile gamers, I- and D-type curiosity provide perceptive alternatives to classic demographic indicators. Applying this to engineering education showed a clear understanding of pedagogical processes that can potentially stimulate learners' retention and even workforce development. In another study by Cui et al [20] which represented how hands-on invention activities affected Taiwanese students' interest in STEM careers, using the attitude-behavior-outcome framework. Positive and causative relationships between hands-on activities and epistemic curiosity (EC) of the problem-solving (DEC) and exploration types (IEC) were found using structural equation modeling. STEM career interest was significantly predicted by both types of EC, with problem-solving EC having a larger effect. Notably, EC mediated the association between STEM interest and hands-on activities, implying that the pursuit of inventions stimulates curiosity, which in turn feeds aspirations in STEM fields. It is therefore noteworthy that hands-on activity plays a significant role in aiding learners' development of curiosity, and this can support learning outcomes, retention, workforce pipeline development. A mixed-method study examined how well learner's types of curiosity were considered when determining the efficacy of hands-on activities combined with discovery learning to enhance critical thinking in mathematics. The results demonstrated that whereas students with perceptual curiosity (PC) only improved in question formulation, those with epistemic curiosity (EC) exhibited a considerable improvement in critical thinking due to the model. Compared to PC students, EC students had greater levels of critical thinking overall, indicating that curiosity type moderates the impact of learning [21].

Discovering Learning Model (DLM)

Discovery-based learning (DBL) has the transformative power to awaken students' natural epistemic curiosity. DBL, as opposed to passive lectures, forces students to actively dissect complex phenomena and create their own paths to solutions by throwing them into difficult challenges and, in this case, hands-on experiments with inexpensive, safe devices. Students' interest is piqued by this process of self-driven inquiry, which gives them the freedom to delve deeper, challenge presumptions, and learn new information at an engaging pace of their own.

Curiosity and DBL have a mutually beneficial relationship; while DBL gives freedom to satisfy this need for knowledge, curiosity gives the unwavering motivation to venture into undiscovered intellectual realms. With the help of this student-centered method, aspiring engineers may connect on a personal level and combine new ideas with preexisting mental models to create a richly meaningful narrative. DBL classrooms are hotbeds of infectious curiosity, where students' passion to methodically solve the world's riddles is spread by the spirit of inquiry.

Discovering Learning Model hinges on 5 principles that aid in the experiential learning process. These principles include problem solving, learners’ management, integrating and connecting, information analysis and communication, and failure and feedback. Considering figure 1, the learning process began with a problem which can come in the form of hands-on experiments or questions. The instructor utilized this experience to investigate the minimum knowledge of students prior to demystifying the course content. This inquiry approach enables learners to probe their past understanding. However, this can lead learners outside of the intended learning scope hence the next level of learned management comes into play where the instructor takes the learners through the experiment to solidify the and gain insight into the concept that the module is focused on. effortlessly, the instructor begins the connect and integration phase which involves linking the experiences and knowledge gained during the preliminary sessions to the core concepts. Information analysis and communication represents the evaluation level of the model where the learners demonstrate the level of comprehension and reproducibility of the lessons learnt. The failure and feedback are geared towards enabling the learners to fill knowledge gaps that could be found post learning.

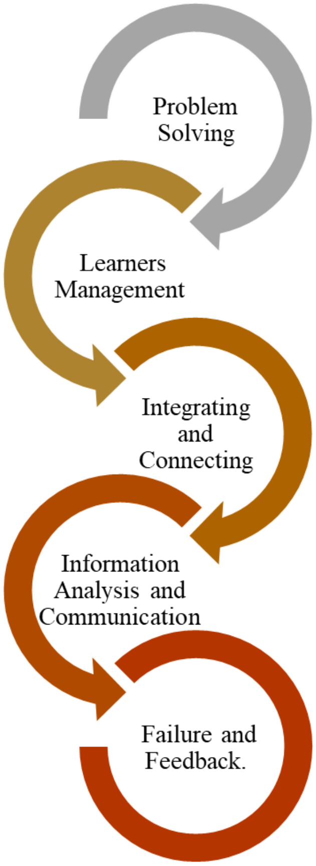

Figure 1: Discovery Learning Framework

This paper explores the transformative potential of Experiment-Centric Pedagogy (ECP) in industrial engineering education. ECP stands out from other pedagogical approaches by emphasizing experiential and learner-centered learning through hands-on experimentation integrated with theoretical coursework. The unique features of ECP are discussed, highlighting its ability to bridge the gap between theory and practice. The alignment of ECP with the goals of industrial engineering education is emphasized, as it fosters critical thinking skills and addresses core principles and challenges in the field.

Methodology

Our study aims to explore the impact of experiment-centric pedagogy (ECP) on fostering curiosity and improving learning outcomes among industrial engineering undergraduates. Specifically, the authors seek to test hypotheses related to changes in curiosity scores. This study was carried out at one of the United States oldest Historically Black Colleges and Universities

(HBCUs). The participants were recruited from academic levels which were post first-year, as well as ensuring representation across socio-demographic variables such as gender, age, and academic standing in the course. Our experiment-centric pedagogy involves integrating hands-on activities and experiments within the traditional curriculum.

The ECP sessions were carried out in the spring term of 2022 and covered in separate courses. The experiments created for modules taught in IE are as published by the authors [authors]. In this quantitative research, a pre-post-test design was adopted in each semester, employing the validated quantitative tool of Litman and Spelberg [22]. The total number of completed experiments was two (2) as described by authors in [author]. The first course where ECP was implemented was Thermodynamics (IEGR 305) which is a 3 credit hours course and has a total of 7 modules spanning topics like Fundamental thermodynamic concepts, zeroth law of thermodynamics and temperature measurements; work and heat; First law of thermodynamics; properties of pure substances; First Law analysis of some thermodynamic systems; and power and refrigeration systems. The second course where ECP was implemented was Materials Engineering (IEGR 309) and some of the modules within the course include Fundamentals of materials including the structure of metals, mechanical behavior, testing, manufacturing properties, and physical properties; Metal alloys including their structure and strengthening by heat treatment; Production, general properties, and use of steels, nonferrous metals, polymers, ceramics, graphite, diamond, and composite materials. At the end of the module implementation, a total of 10 learners met all the criteria and data required for the study. The number of students in the class during the terms was between 6-8 and hence revealed we had about 72% participation in the pedagogy implementation. The instrument used for collecting data for this study was electronically sent to the students. The instrument was a 4-point Likert scale that learners responded with 1 (never) through 4 (always). The interest epistemic curiosity and the deprivation epistemic curiosity questionnaire had 5 items on each subscale. The minimum obtainable score for each item was 1 and the maximum was 4. In total, the minimum obtainable score for IEC or DEC was 4 and the maximum was 20. Using the university standard of academic performance rating, the scores of the learners in each of the DEC and IEC scores was rated in low (4-11), average (12- 16) and high level (17-20). This categorization was carried out to aid in defining the levels of learners' curiosity pre- and post-implementation of ECP.

Normality test was conducted on the curiosity scores received and observing the small sample size (less than 50), the Shapiro-Wilk test was used, and the result is presented in Table 1. Therefore, the current study failed to reject the null hypothesis, and parametric test statistics was adopted for the inferential analysis ($p>0.05$). Simple percentages, mean and standard deviation were used for the presentation of the result of this quantitative study. Specifically, the inferential statistics was carried out using the paired sample t-test. The confidence level was set at 95.0% and the Statistical package for Social Scientists (IBM SPSS 25.0) was used for the data analysis.

Table 1: Normality Test using Shapiro-Wilk

	Shapiro-Wilk		
	Statistic	df	Sig.
IEC	0.873	10	.109
DEC	0.910	10	.282

p is greater than 0.05, hence, accept null hypothesis

Results

The interest epistemic curiosity (IEC) scale has 5 items and the rating of the learners of each item are presented using box and whisker plots on Figure 3. Box and whisker plots show the mean (mid-line within the box) and the mean (the star within the box). The result showed that there was an increase in the interquartile range on the item "I enjoy exploring new ideas". This indicates that students' ability to explore new ideas was impacted post-implementation of the hands-on pedagogy. Similar increase among the learners on the items, "I enjoy learning about subjects that are unfamiliar to me", and "I find it fascinating to learn new information." There was no obvious increase in the distribution of the interest in epistemic curiosity scores on items, "When I learn something new, I would like to find out more about it" and "I enjoy discussing abstract concepts." Figure 3 showed the distribution of scores on the deprivation epistemic scale among the learners using box and whisker plots. The result showed that there was change in the average and interquartile ranges of the responses of the learners at the post-test across the items. Comparing the mean interest epistemic curiosity scores as shown in Table 2 indicated that the changes in the mean range from 0.1 - 0.3 (figure 4a showed percentage increase. and that of the deprivation epistemic curiosity range from 0.1 - 0.6 (figure 4b showed the percentage range from 5.3% - 30.0%).

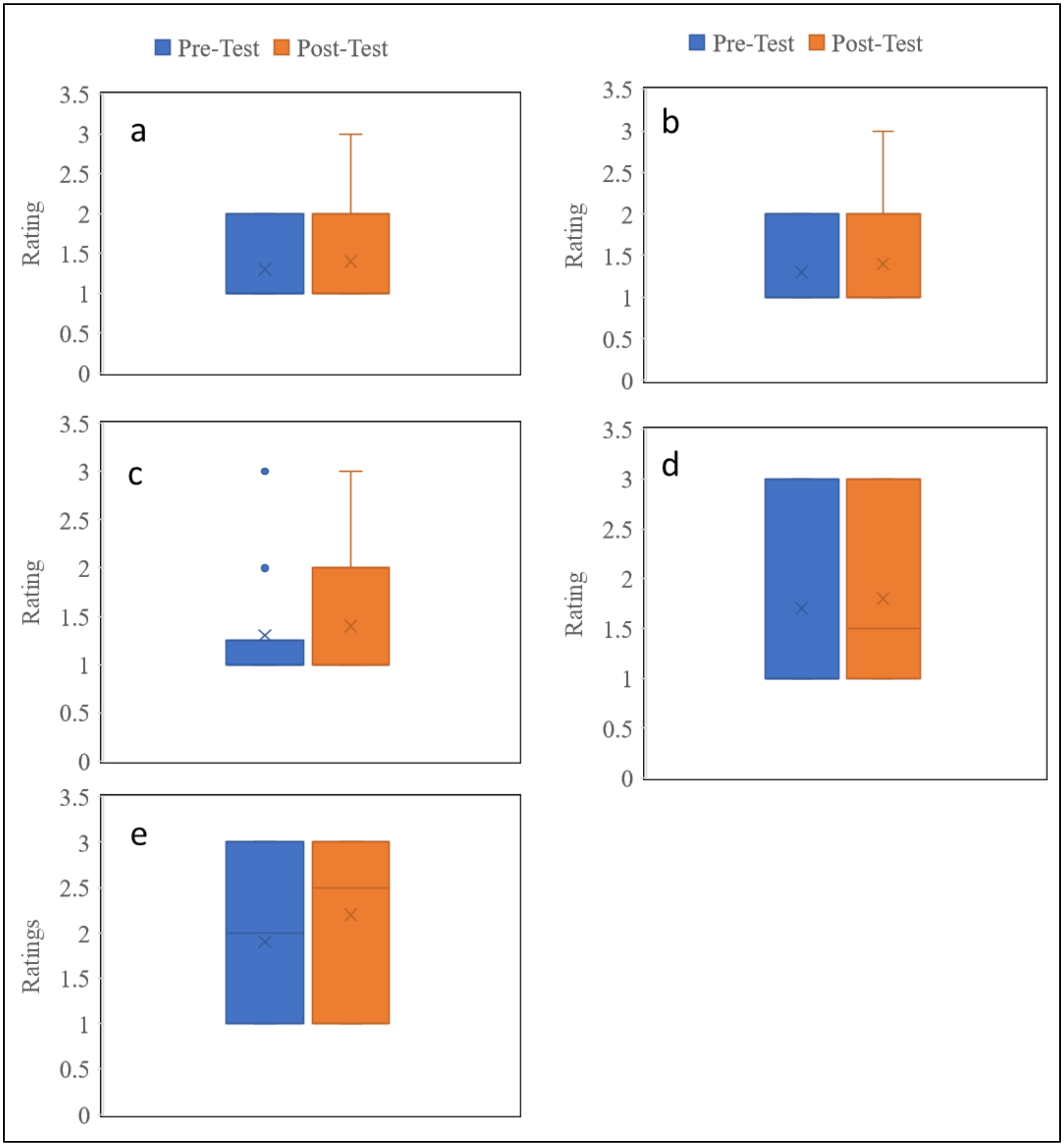

Figure 2: Box and Whisker Plots of Interest Epistemic Curiosity items where (a) I enjoy exploring new ideas. (b) I enjoy learning about subjects that are unfamiliar to me (c) I find it fascinating to learn new information. I find it fascinating to learn new information. (d) When I learn something new, I would like to find out more about it.(e)I enjoy discussing abstract concepts.

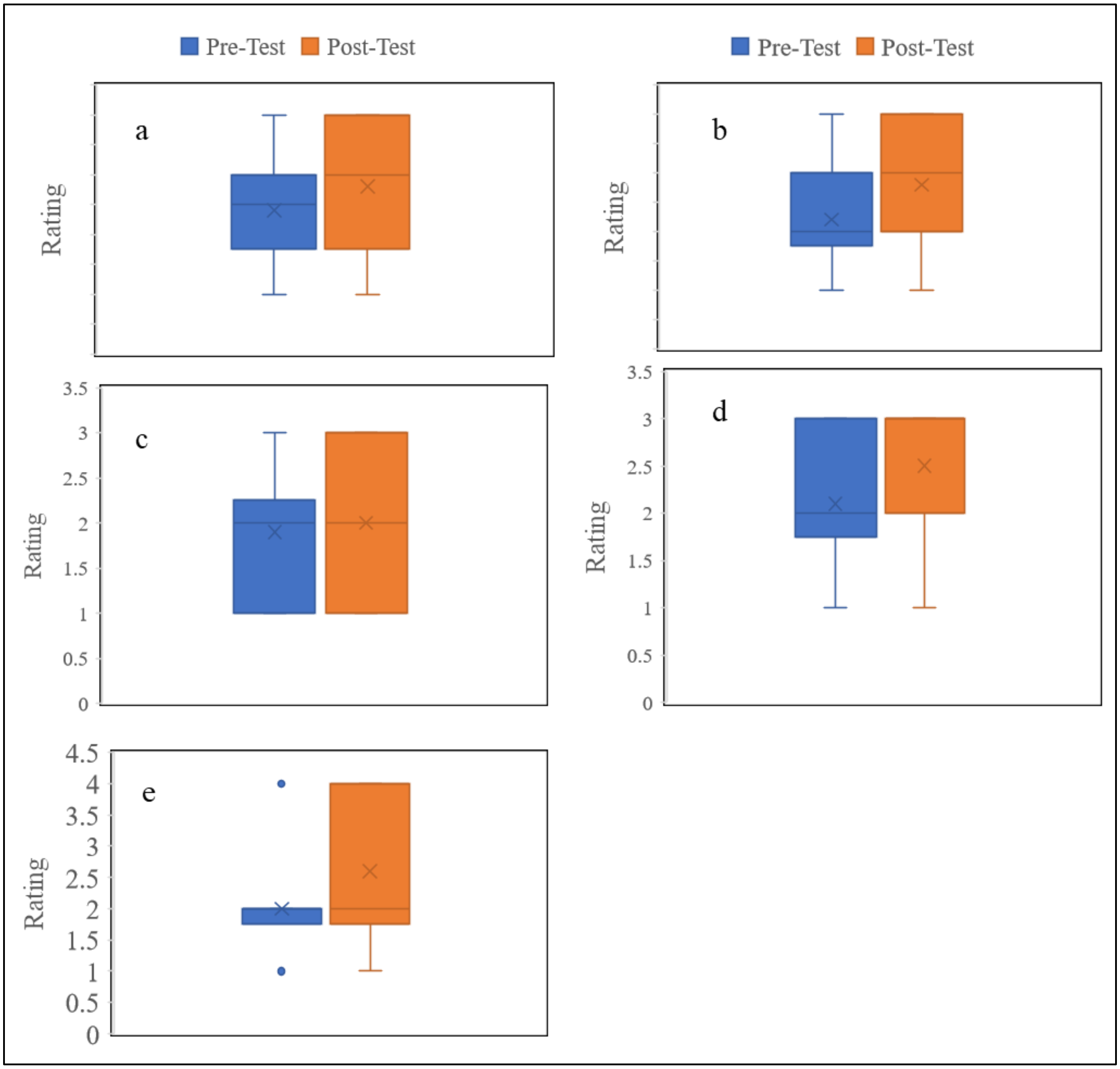

Figure 3: Box and Whisker Plots of Deprivation Epistemic Curiosity items where (a) Difficult conceptual problems can keep me awake all night thinking about solutions. (b) I can spend hours on a single problem because I just can’t rest without knowing the answer.(c) I feel frustrated if I can’t figure out the solution to a problem, so I work even harder to solve it.(d) I brood for a long time in an attempt to solve some fundamental problems..(e) I work like a fiend at problems that I feel must be solved.

Table 2: Mean Score and Mean Change of Interest Epistemic Curiosity

Interest Epistemic Curiosity	Pre-Test	Post-Test	Δ Mean
I enjoy exploring new ideas.	1.3	1.4	0.1
I enjoy learning about subjects that are unfamiliar to me.	1.5	1.8	0.3
I find it fascinating to learn new information.	1.3	1.4	0.1
When I learn something new, I would like to find out more about it.	1.7	1.8	0.1
I enjoy discussing abstract concepts.	1.9	2.2	0.3
Deprivation Epistemic Curiosity			
Difficult conceptual problems can keep me awake all night thinking about solutions.	2.4	2.8	0.4
I can spend hours on a single problem because I just can’t rest without knowing the answer.	2.2	2.8	0.6
I feel frustrated if I can’t figure out the solution to a problem, so I work even harder to solve it.	1.9	2	0.1
I brood for a long time in an attempt to solve some fundamental problems.	2.1	2.5	0.4
I work like a fiend at problems that I feel must be solved.	2	2.6	0.6

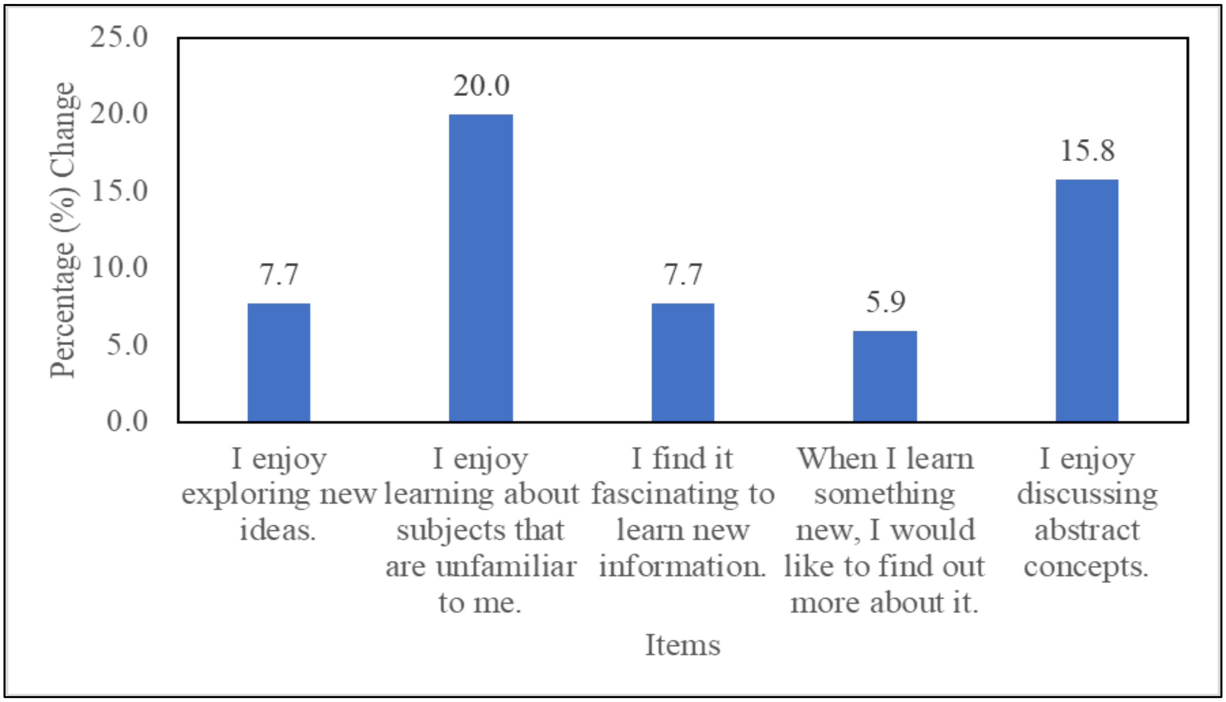

Figure 4a: Percentage Changes in the Interest Epistemic Curiosity Items

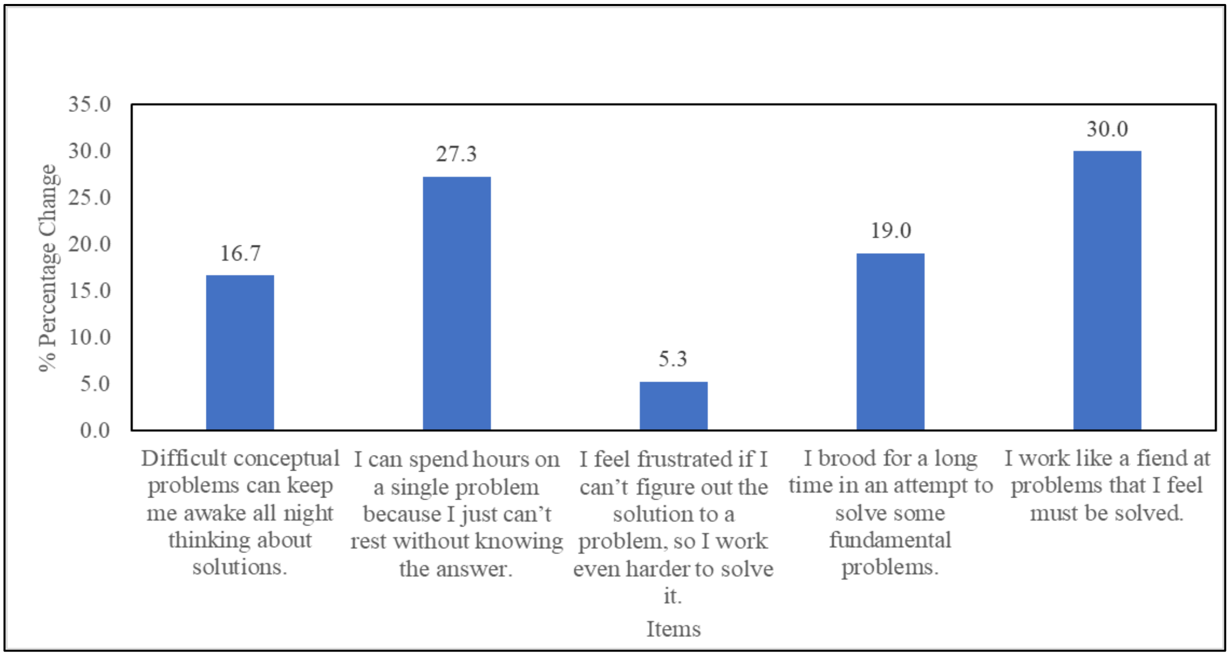

Figure 4b: Percentage Changes in the Deprivation Epistemic Curiosity Items

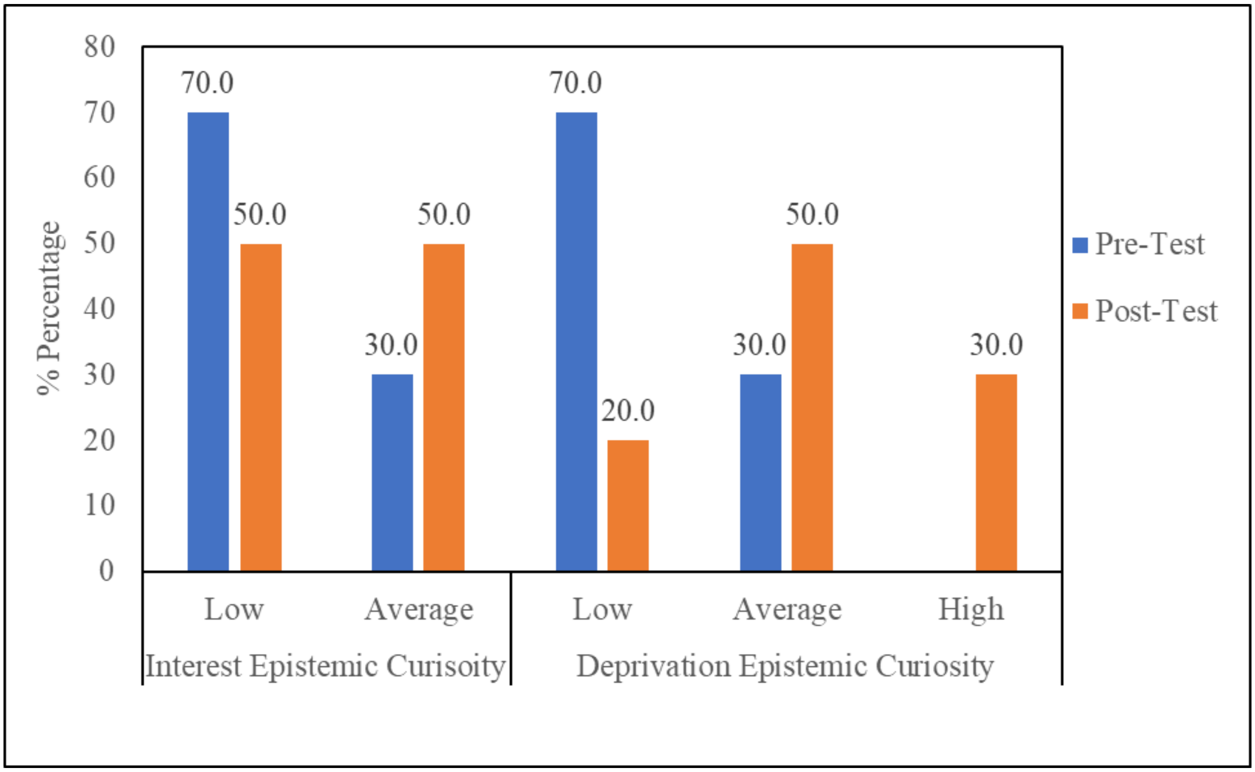

Figure 5: Summarized Level of Curiosity

The overall epistemic curiosity summary presented in figure 5 above revealed the levels of the learners. The result revealed that overall, at pre-test, 70% of the learners had a low level of curiosity (I-type) and a similar result was obtained for the D-type of curiosity. At post-test, 30.0% were found to have a high level of D-type epistemic curiosity and 50.0% average level of D-type of curiosity. This result presents that there was a positive impact of the experiment-centric pedagogy.

Hypothesis Testing:

Ho: There is no significant difference between the epistemic-curiosity scores of learners before and after the implementation of ECP.

Table 3: Pre and Post-Test Mean Comparison of IEC and DEC using Paired Sample T-Test

Item	Test	Mean	Mean Difference	t-test	Sig
Interest Epistemic Curiosity	Pre-Test	7.70	0.90	1.13	0.29
	Post-Test	8.60			
Deprivation Epistemic Curiosity	Pre-Test	10.60	2.10	1.40	0.20
	Post-Test	12.70			

The result presented in Table 3 revealed that there was no significant difference between the pre- and post-test scores of the interest and deprivation type of epistemic curiosity ($p>0.05$).

Discussion

The current study investigates the epistemic curiosity of learners in industrial engineering at one the nation's historical black colleges and universities. The findings of this study provide preliminary evidence that an experiment-centric approach can stimulate curiosity among industrial engineering undergraduates. While the quantitative analysis revealed no statistically significant variations in pre- and post-test curiosity scores, the descriptive data indicate potentially substantial increases in both interest and deprivation forms of epistemic curiosity. Specifically, the box plots show larger distributions and higher mean scores on various IEC and DEC scale items following the experiment-centric training module. This is consistent with previous studies demonstrating that active learning approaches that involve students in inquiry and discovery can spark interest [23], [24].

Hands-on experiments allow students to experiment with new ideas, absorb unfamiliar topics, and solve problems directly. This direct experience may arouse greater attention, fascination, frustration, and a need for explanation. However, the lack of substantial pre-post differences indicates that the module's influence was limited. Curiosity is a multifaceted concept impacted by individual characteristics and contextual influences [25]. A one-time intervention may not be effective in changing pupils' trait-level curiosity. Furthermore, some topics, such as abstract debate, may be less influenced by hands-on learning. Sustained exposure to active experimentation across the course or curriculum may be required to change curiosity [26].

More study is needed to determine the ideal design of experiment-centric pedagogies to stimulate curiosity across engineering disciplines. More open-ended issues, exploration tasks, and student ownership of experimental processes may increase curiosity and learning [23], [25]. Individual differences in prior knowledge and curiosity are also worth investigating [24]. Tailoring instruction to meet the requirements of students may help them grow their curiosity. Finally, the role of group interactions is worth investigating, as collaborative discovery can boost interest [23].

One of the limitations of the current study is the sample size which indicates that the study findings are not generalizable. However, the study has set the stage and calls for IE faculties to reinvent the wheel for a more curiosity focused pedagogy. Overall, this first of its kind study among IE undergraduate students provides promising evidence that active learning through experiment-centric pedagogy can promote curiosity in engineering classes. While momentary exposures may not significantly alter interest, prolonged experiential learning can foster the curiosity required for lifetime learning and innovation. Further study into experiment-centric pedagogy and individual factors can assist to transform this potential into more consistent, significant increases in engineering students' curiosity.

Conclusion

This study investigates how to cultivate students’ curiosity in industrial engineering through an experiment-centric pedagogy. Pre- and post-test surveys were used to measure changes in interest and deprivation curiosity after the study's implementation of practical activities incorporated into coursework. The mean curiosity scores increased, according to descriptive data, but statistical analysis did not reveal any significant differences. The study offers some evidence that incorporating innovative, less complex and hands-on experimentations in active learning might pique the curiosity of engineering students. Short-term interventions might not be enough to change trait-level curiosity, though. Research on ideal designs and prolonged exposure are required. All things considered, the study suggests that experiment-centric pedagogy has potential for increasing the curiosity necessary for learning and creativity in engineering education. To turn this potential into consistent, noteworthy effects on students' curiosity, more work and data is certainly required across the engineering fields.

Acknowledgement

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