Enhancing Chemistry Undergraduates' Peer Learning Collaboration and Curiosity Through Hands on Pedagogy

Mr. Temileye Omopariola Ibirinde, Morgan State University

Mr. Temileye Ibirinde is a Master's student at Morgan State University School of Community Health and Policy. He works as a graduate assistant under an NSF-funded ETA - STEM project.

Mr. Pelumi Olaitan Abiodun, Morgan State University

Pelumi Abiodun is a current doctoral student and research assistant at the department of Civil Engineering, Morgan State University, Baltimore, Maryland. Pelumi got his BSc and MSc degree in Physics from Obafemi Awolowo University, where he also served as a research assistant at the Environmental Pollution Research unit, in Ile-Ife, Nigeria. As part of his contribution to science and engineering, Pelumi has taught as a teaching assistant both at Morgan State University and Obafemi Awolowo University. With passion to communicate research findings and gleaned from experts in the field as he advances his career, Olaitan has attended several in-persons and virtual conferences and workshop, and at some of them, made presentation on findings on air pollution, waste water reuse, and heavy metal contamination.

Adebayo Iyanuoluwa Olude, Morgan State University

Adebayo Olude is a doctoral student and research assistant at Morgan State University's Department of Civil Engineering in Baltimore, Maryland. Adebayo formerly worked as a Graduate Research Assistant at Eastern Mediterranean University in North Cyprus, where he earned his master's degree in civil engineering. He also worked as a project Analyst with AgileP3 after graduating with a Bachelor of Engineering (B.Eng) in civil engineering from Covenant University, Nigeria. Adebayo has taught courses in Transportation and Chemistry at Morgan State University as part of his commitment to the STEM profession. He has attended conferences across the Transportation engineering field.

Dr. Oludare Adegbola Owolabi P.E., Morgan State University

Dr. Oludare Owolabi, a professional engineer in Maryland, joined the Morgan State University faculty in 2010. He is the assistant director of the Center for Advanced Transportation and Infrastructure Engineering Research (CATIER) at Morgan State Universit

Dr. Niangoran Koissi, Morgan State University

EDUCATION/TRAINING University of Turku (Finland) Ph.D. 03/2007 Bioorganic Chemistry University of Maryland Baltimore County (USA) Post-doc 10/2007-08/2013 Chemistry/Toxicology

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Abstract

This abstract presents a study that explores the utilization of hands-on pedagogy as a means to enhance peer learning collaboration and curiosity among chemistry undergraduate students. The research seeks to instill confidence and competence in students' grasp of fundamental chemical principles, collaborative skills, and problem-solving abilities, while also nurturing their curiosity through the integration of active learning techniques, laboratory experiments, and interactive teaching methodologies. The study discusses an examination of the impact of hands-on pedagogy on students' peer learning collaboration and curiosity. The study was carried out among undergraduate students taking foundations in chemistry, which includes engineering and other STEM majors. The study adopted a pre-post-test design method where data on curiosity, peer learning and collaboration were collected via the use of the Motivated Strategies for Learning Questionnaire (MSLQ) and the Litman and Spielberger curiosity scale. A descriptive quantitative data analysis was conducted using SPSS v25.0, and the confidence interval for inferential statistics to compare pre-and post-test scores was set at 95.0%. The average difference between the pre and post test scores of the subscales ranged from 0.12 – 0.57, and there was a significant increase in peer learning, and collaboration ($p<0.05$). There was also a significant increase in one of the curiosity scales that was adopted ($p<0.050$). There was also a major difference in the grades of students who took courses where hands-on pedagogy was implemented compared to courses where the pedagogy was not implemented. The results indicate an increase in curiosity as a result of active engagement in hands-on activities, as well as the enhancement of peer learning and collaboration and the academic performance of chemistry undergraduates. These findings provide substantial implications for educators, curriculum developers, and educational institutions striving to enhance the educational journey of foundational chemistry STEM undergraduates. Recognizing the value of hands-on pedagogy in fostering collaboration, educators can better prepare students for academic success and prosperous careers in chemistry-related fields. Ultimately, this research underscores the significance of innovative teaching methods in nurturing the curiosity of chemistry undergraduates, thus advancing scientific knowledge, and fostering innovation in the field.

Introduction

In higher education, creating a productive learning environment for chemistry undergraduates still stands as a major challenge [1]. It is impossible to overestimate the value of curiosity and collaboration in the academic and professional development of students in this field [2], [3]. The traditional learning method, which is based mainly on the instructors transferring knowledge to students, often falls short of fully engaging students and fostering critical abilities like collaboration, peer learning, and curiosity [4]. An exciting new area in educational research is the meeting point of these educational needs and the innovative field of experiment-centric pedagogy (ECP) which utilizes inexpensive mobile devices. This study explores the growing field and shows how chemistry undergraduates' educational journeys can be transformed through visual, interactive learning experiences, particularly when it comes to historically black colleges and universities (HBCUs).

Over the past 20 years, one of the major trends in higher education has been the emphasis on students learning with and from each other [5]. Peer learning and collaborative learning are both based on the idea that in undergraduate education, there is significant educational benefit in students working together, often independently of teachers, to teach and learn from one another [6]. Multiple empirical studies [7], [8] conducted over several decades have shown that student achievement and motivation have a positive relationship with collaborative learning.

Cognitive scientist Elizabeth Bonawitz [9] posits that curiosity is a natural response to information, acting as a filter that helps the mind decide what information to attend to. Curiosity plays an important role in higher education, acting as a driving force for learning and academic achievement [10]. Inquiry-based learning, which involves posing a problem or setting up an experiment, can stimulate a student’s curiosity. Experimental learning, which can include hands-on laboratory experiments, is an essential element of higher education, allowing students to put theoretical knowledge into practice in real-life scenarios [11]. Higher education institutions are increasingly adopting experimental learning methods, such as project-based learning and work-integrated learning, to enhance the effectiveness of education both inside and outside the classroom [12].

A deep learning approach is essential in STEM education to comprehend concepts and intricate processes [13]. Linton et al. [14] in their study concluded that the process of conceptual change required to understand these concepts is especially triggered by collaborative learning, in which students engage by critically explaining and questioning one another. Although it may not be feasible to cultivate curiosity as an inherent characteristic, educators have the ability to generate circumstances that stimulate and direct a student's curiosity [15]. This process involves highlighting unclear information, assisting students in identifying gaps in their existing knowledge, and encouraging students to formulate predictions and challenge assumptions about the world [16].

Conventional approaches often place an emphasis on memorization and individual achievement, ignoring the advantages of peer learning and the innate curiosity that motivates study [17]. The gap is especially noticeable in basic chemistry classes, where the intricacy of the material can occasionally mask the growth of collaborative and curious abilities [18]. Therefore, this study is using an instructional strategy that not only explains the fundamentals of chemistry to students but also actively involves them in a way that encourages curiosity and peer interaction.

This study aims to answer the question: How does the incorporation of hands-on pedagogy in foundational chemistry courses at HBCUs affect the peer learning and collaboration, as well as the curiosity, of undergraduate students? It seeks to measure how these interactive teaching and learning approaches affect students' capacity for peer collaboration, group problem-solving, and sustaining curiosity throughout the learning process. This research aims to provide strong evidence for educators and curriculum developers to improve the educational experience of chemistry undergraduates by concentrating on the quantifiable results of such pedagogical interventions.

Theoretical Framework

Using the Cognitive Load Theory (CLT) to build the work described can offer valuable insights into optimizing learning experiences for students. Cognitive load refers to the quantity of information that our working memory can handle simultaneously [19]. By ensuring that the presented information is within their capacity to process and assimilate into schemas, cognitive load theory in education helps prevent learners from feeling overwhelmed, thereby facilitating long-term memory storage and subsequent recall [20].

The Cognitive Load Theory is based on the human information processing model shown below.

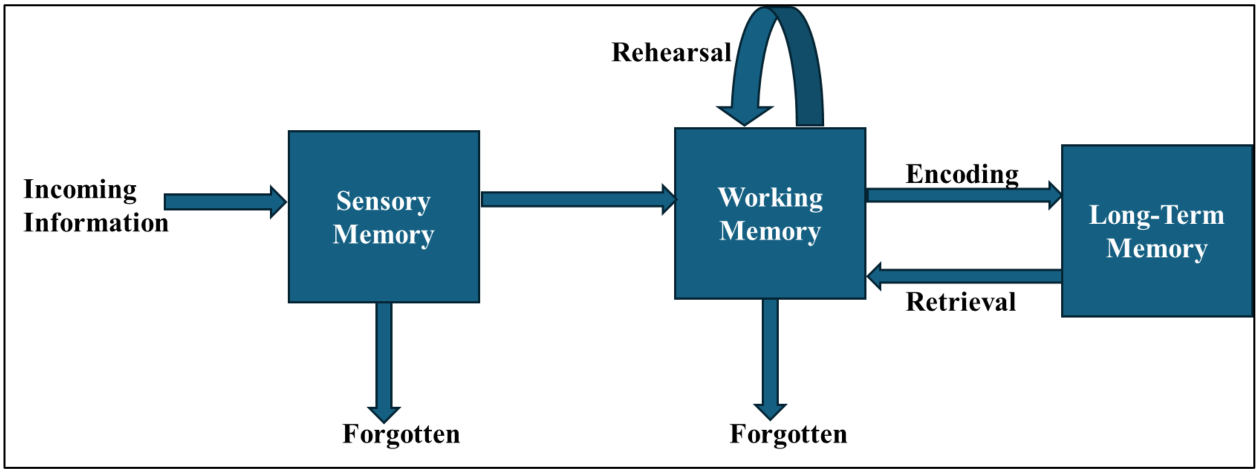

Figure 1: Cognitive Load Framework

This model divides memory into three categories: sensory, working, and long-term. Sensory memory works by filtering out the majority of surrounding sensory input and directing specific information to our working memory for further processing [21]. Working memory can typically process 5-9 pieces of information, or chunks, at any given time [22]. Working memory either discards information or categorizes it for long-term memory storage [23]. Long-term memory stores information in structures known as "schemas," which organize information based on how people use it. The more these schemas are used, the more they develop and become easier to recall [24].

Intrinsic cognitive load [25] addresses the material's inherent difficulty. Chemistry, particularly at the undergraduate level, can be inherently difficult [26]. Hands-on pedagogy should aim to break down complex concepts into more manageable parts while aligning with students' existing knowledge and skills. This perfects the intrinsic load, allowing students to grasp fundamental chemistry principles more effectively.

Extraneous cognitive load [27] comes in the form of an instructional design. The presentation of information to students is a crucial aspect of CLT. Traditional lecture-based approaches may inadvertently increase extraneous loads by presenting information in difficult-to-process formats [28]. The study's emphasis on hands-on pedagogy, interactive teaching methodology, and laboratory experiments has the potential to reduce extraneous cognitive load by providing more engaging, clear, and contextually relevant learning methods. Students can process information and engage with the material more easily without feeling overwhelmed.

Collaborative learning strategies can distribute the cognitive load among peers, allowing students to benefit from each other’s strengths and perspectives [29]. This can potentially reduce the load on individual students while enhancing understanding through discussion and collaboration.

Germane cognitive load refers to the mental resources required for schema processing, construction, and automation [30]. This study aims to engage students in higher order thinking and problem-solving through the study's hands-on activities and peer collaboration activities. This active participation will encourage students to develop and solidify mental models of chemistry concepts, which is our desired result of the relevant cognitive load.

This theory was used in designing the instructional modules for the course where experiment-centric pedagogy was implemented, as shown in Figure 2.

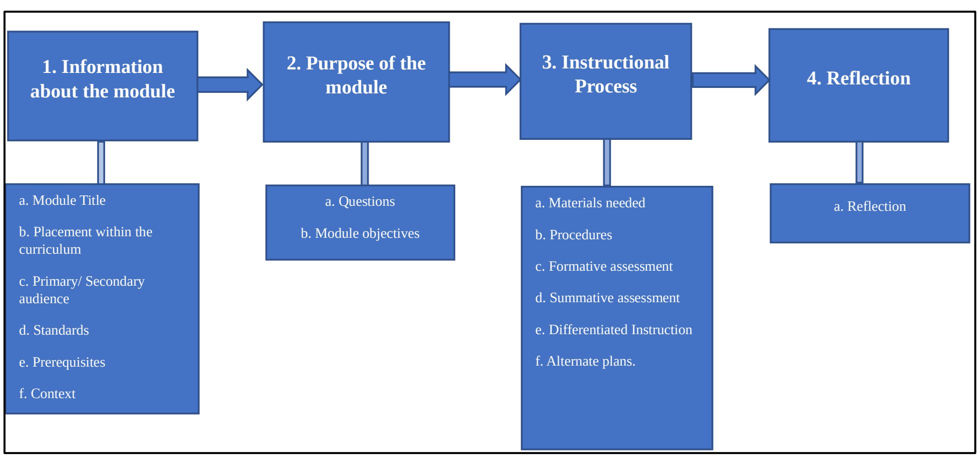

Figure 2: The ECP Module Instructional Design

Additionally, by incorporating active learning techniques that seek to develop student self-found learning techniques, the pedagogy should pique students' interest, which can lead to deeper engagement with the material. This increased learning capacity and engagement can promote deeper cognitive processing, enhancing schema formation and automation.

Methodology

This study provides an overview of the investigation in the chemistry department a HBCU using hands-on mobile devices consisting of an input and output board. The purpose of this approach is to replace the traditional laboratory experiments in the chemistry laboratory by extracting data through electronic measurements (voltmeters) from sensors attached to a board. This quantitative descriptive study employed a pre- and post-test design. Purposively, two foundation classes in the chemistry department were selected for the implementation of ECP to teach chemistry concepts.

Chemistry Hands-on Experiment: pH Meter (Potentiometry)

The potentiometry experiment was conducted in general chemistry for engineering students (CHEM 110) and organic chemistry (CHEM 203) classes. The aim of this laboratory experiment is to estimate the pH value of an unknown solution (buffer) through the calibration curve. In this experiment, a calibration curve was developed from standard pH buffer solutions (4, 7, and 10). It was then used to determine the potential pH scales of other solutions. This module implementation was introduced to the general chemistry laboratory courses, and this adaptation will allow students to participate in hands-on laboratory work and carry out experiments outside the laboratory. The complete laboratory setup consists of pH buffer solutions, the pH probe (Gravity Analog pH sensor), which is used to measure the pH of the different solutions, and the ADALM 1000 instrument. The ADALM 1000, an instrument with an embedded system, is easy to use for students in the laboratory and is portable, allowing them to conduct experiments anywhere, even in the comfort of their own homes. The ADALM 1000 consists of important tools like a signal generator and a voltmeter, which the students can use to better understand chemistry principles and may be adopted in other disciplines and at different levels of academia.

Figure 3: pH Meter

There is also an additional function in the ADALM 1000 board that uses an application to transfer function equations to convert voltage and frequency readings from the device into the desired measurement units.

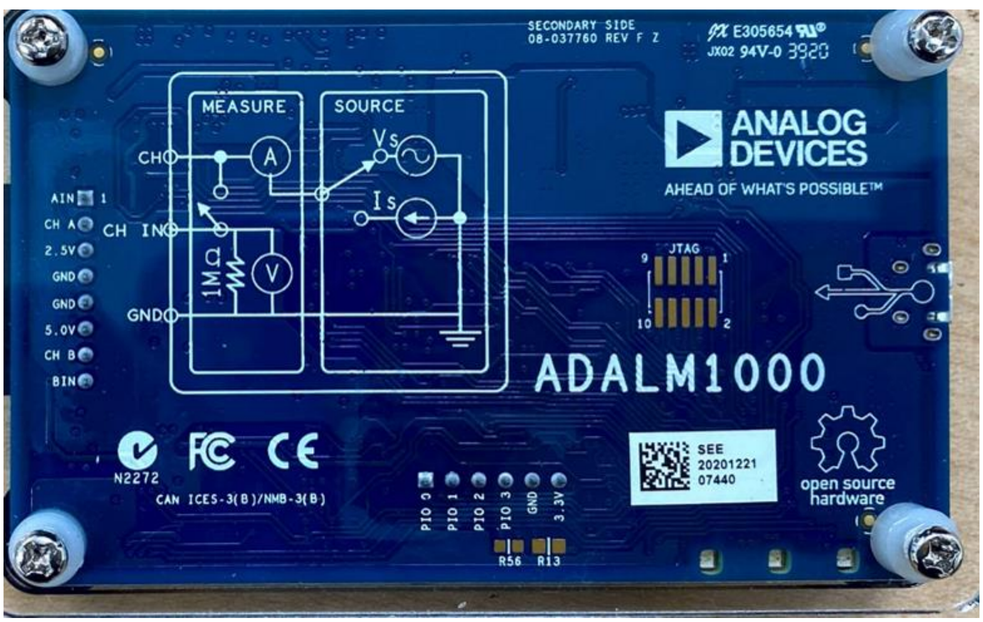

Figure 4: ADALM 1000 Analog Device

In this study, the experiment-centric pedagogy module was implemented between fall 2021 to fall 2022 and the Motivated Strategies for Learning Questionnaire (MSLQ) was adopted, which comprised of 1-7 Likert scales and has 8 subscales [26]. To measure the curiosity of the students, this study adopted the Litman and Spielberg curiosity scales [27] consisting of 1-4 Likert scales. In total, there were 54 students over the course of the three semesters. The students completed and submitted the Motivated Strategies for Learning Questionnaire (MSLQ) both before and after a laboratory experiment, and a comparative analysis between the pre-test and the post-test was conducted. This study, examined the Peer Learning and Collaboration (PLC), as well as two scales that assessed the learners curiosity: the Deprivation Epistemic Curiosity (DEC), and Interest Epistemic Curiosity (IEC) [28]. The items in each subscale are shown in Table 1.

Table 1: PLC, IEC, and DEC items

Construct	Sample Questions
Peer Learning and Collaboration (PLC)	When studying for this course, I often try to explain the material to a classmate or a friend. I try to work with other students from this class to complete the course assignments. When studying for this course, I often set aside time to discuss the course materials with a group of students from the class
Interest Epistemic Curiosity (IEC)	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. I enjoy discussing abstract concepts.
Deprivation Epistemic Curiosity (DEC)	Difficult conceptual problems can keep me awake all night thinking about solutions. I can spend hours on a single problem because I just can't rest without knowing the answer. I feel frustrated if I can't figure out the solution to a problem, so I work even harder to solve it. I brood for a long time in an attempt to solve some fundamental problems. I work like a fiend at problems that I feel must be solved.

Data was collected electronically and safely secured in multi-factor authentication storage. A Wilcoxon signed-rank test was then used to compare the related items after matching them because the MSLQ data failed a Kolmogoro-Smirnov normality test ($p > 0.05$). Descriptive statistics were conducted to present the distribution of the scores obtained by the students in the study. Comparing the pre-test and post-test data, this study examined the impact of the experiment-centric pedagogy, and the differences were estimated and reported using Z-score. The population mean rank difference was examined at a confidence level of 95.0%. All the analysis was carried out using the Statistical Package for Social Scientists SPSS (IBM 25). In addition, this study also obtained the students' institutional data to compare the academic achievements of the students that enrolled in classes where ECP was implemented to those of the students that didn’t enroll in ECP classes.

Results

Boxplots were made to visually depict and compare the distribution and variability of the data for Pre and Post MSLQ scores of PLC, IEC, and DEC. This allows for a clear understanding of any changes or trends in the data from the pre to the post.

The box is the range of values between the 25th and 75th percentiles, known as the interquartile range (IQR). The box is of considerable size, suggesting a substantial dispersion of data within the interquartile range. The median value within the box is approximately 10. The whiskers in the box plot represent the data range that falls within 1.5 times the interquartile range (IQR). The size of the PLCPost box is smaller than that of the PLCPre, suggesting a more compact distribution of the middle 50% of the data. The median value, approximately 15, indicates an increase in the PLC metric from the Pre-test to Post-test. To summarize, the box plot shows that the PLC scores of the students have experienced an increase from the pre-test phase to the post-test phase and that the data in the post phase exhibits less variability. In Figure 7, the box plot for IECPost exhibits a greater height, suggesting that both the median and quartiles are higher in comparison to IECPre. This shows a general rise in the IEC from the pre-to-the-post test. To summarize, the boxplot indicates that the IEC metric has shown an increase from the pre to the post test. The DECPost boxplot displays a higher vertical position, suggesting that both the median and quartiles are higher in comparison to DECPre. This shows a general rise in the DEC metric from the pre to the post.

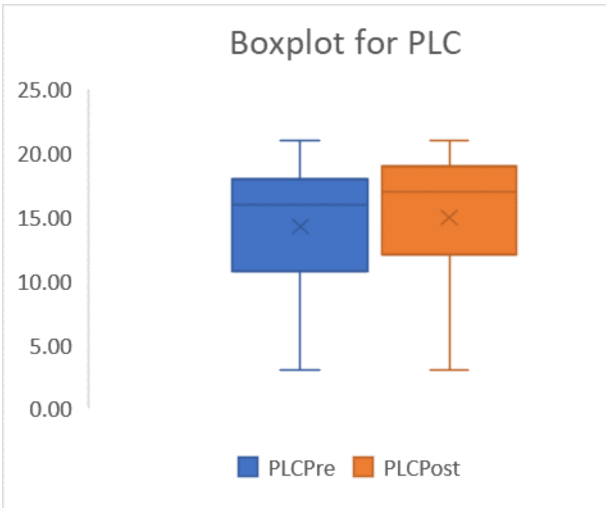

Figure 5: Box plot for Peer Learning and Collaboration

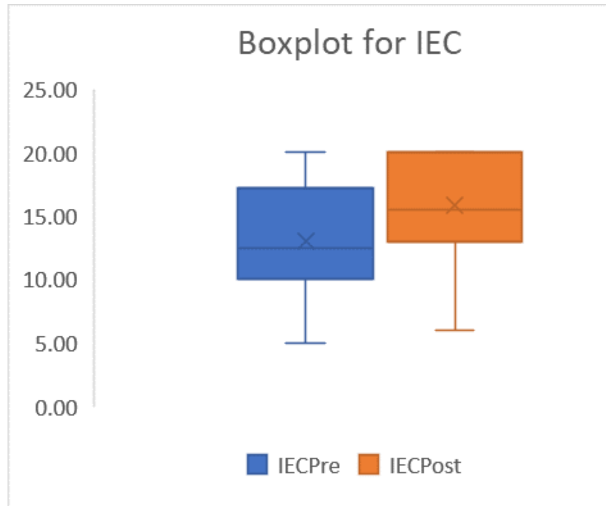

Figure 6: Box plot for Interest Epistemic Curiosity

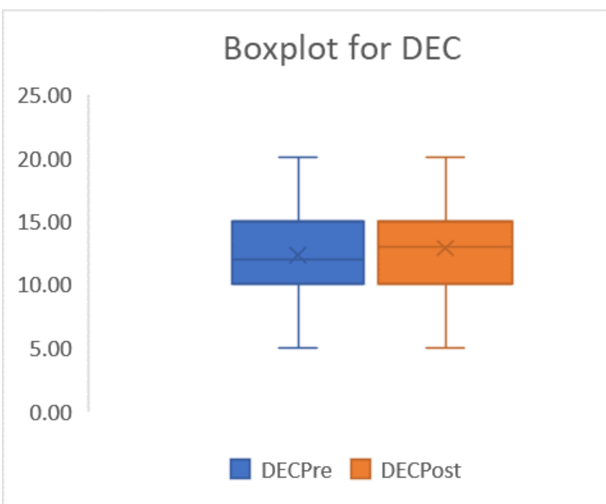

Figure 7: Box plot for Deprivation Epistemic Curiosity

Table 2 is structured to present the findings on the changes in three different scales under investigation: Peer Learning/Collaboration (PLC), Interest Epistemic Curiosity (IEC), and Deprivation Epistemic Curiosity (DEC). For each of the scales, the table shows mean scores with standard deviations (SD), the change in mean scores (Δ Mean), Z-scores, and p-values.

Table 2: Summary statistics for students' peer learning and collaboration and curiosity pre and post-test.

MLSQ Scale	Maximum Obtainable Score	Minimum Obtainable Score	Mean Obtainable Score	Pre-test N=54	Post-test N=54	Z-score	Δ Mean	p-value
				Mean ± SD	Mean ± SD			
PLC	7	1	4	4.75±1.73	4.99±1.68	2.28	0.25	0.048*
IEC	5	1	2.5	2.61±0.94	3.17±0.69	3.65	0.57	0.007*
DEC	5	1	2.5	2.46±0.73	2.57±0.73	0.86	0.12	0.906

* Significant difference at 0.05

For Peer learning & Collaboration, the pre-test mean score was 4.75 (±1.73) and the post-test mean score was 4.99 (±1.68), indicating a slight improvement (0.25 increase in mean).The Z-score of 2.28 indicates a significant increase, as supported by the p-value of 0.023 (less than 0.05), which confirms the statistical significance of the increase (*p*< 0.050).The aspect of the Interest Epistemic Curiosity showed a notable increase from a pre-test mean of 2.61 (±0.94) to a post-test mean of 3.17 (±0.69), with a change in mean of 0.57. The Z-score of 3.65 is quite high, and the p-value is 0.000, indicating a statistically significant increase in Interest Epistemic Curiosity as a result of the intervention (*p*< 0.050). For the Deprivation Epistemic Curiosity, the change was minimal, from a pre-test mean of 2.46 (±0.73) to a post-test mean of 2.57 (±0.73), resulting in a change of only 0.12. The Z-score of 0.86 and a p-value of 0.389 indicate that this change is not statistically significant (*p*> 0.050).

This study compared the classes where ECP was implemented with the same class where ECP wasn't implemented and looked at the difference in the overall students' class grades. Figure 8 shows the final grade distribution for ECP and non-ECP students in CHEM 110. The students who enrolled in the chemistry classes where ECP was implemented, outperformed the non-ECP students in the higher-grade categories.

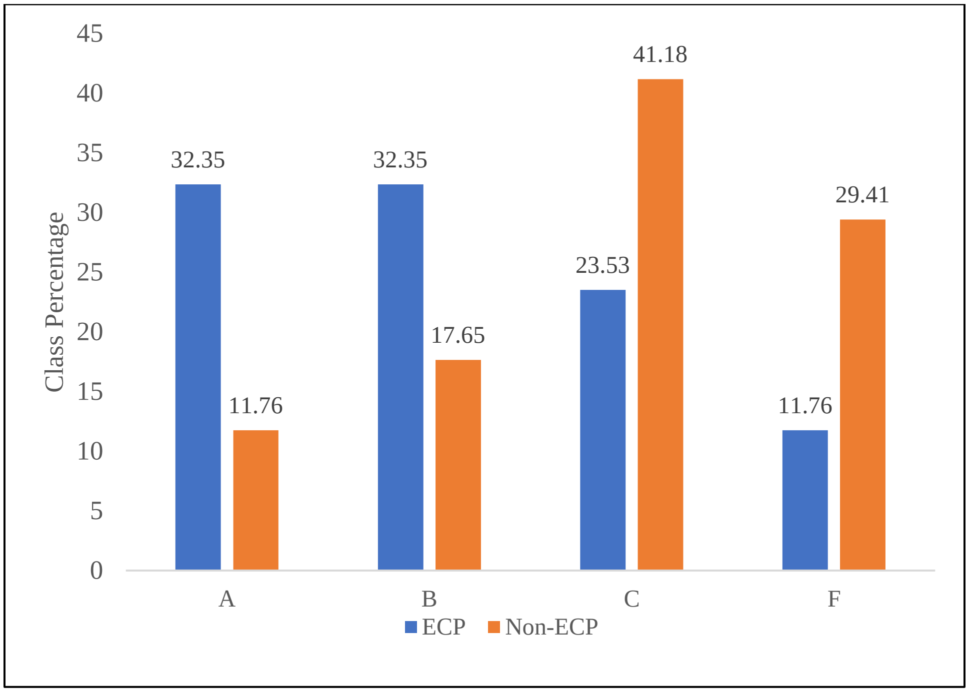

Figure 8: Final Grade Distribution for CHEM 110 ECP vs. Non-ECP Class

Figure 8 illustrates that ECP students exhibit a significantly greater proportion of A and B grades (approximately 35%) compared to non-ECP students (approximately 15%). This suggests that ECP students possess a more comprehensive understanding of the course concepts and skills, resulting in superior performance on examinations. The graph illustrates a significant disparity in the distribution of C and F grades between non-ECP students, who account for approximately 75%, and ECP students, who represent around 65%. This shows that non-ECP students face greater difficulties in meeting the course requirements and expectations, resulting in a struggle to attain higher grades.

Also, Figure 9 shows the final grade distribution for ECP and non-ECP students in CHEM 203. Also, for this course, the students who enrolled in the chemistry classes where ECP was implemented, outperformed the non-ECP students in every grade category.

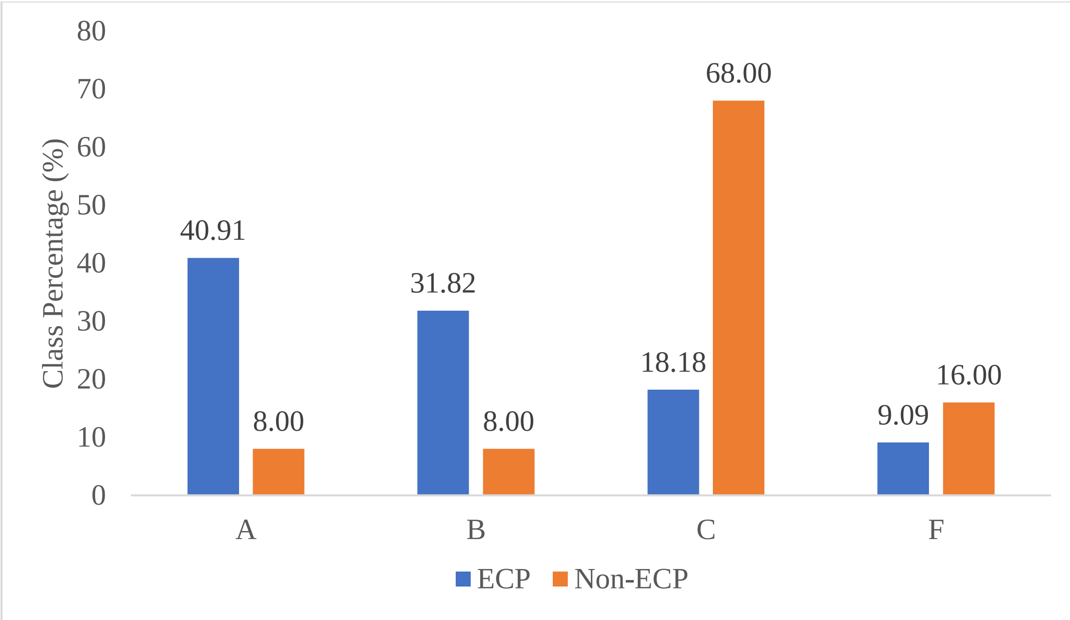

Figure 9: Final Grade Distribution for CHEM 203 ECP vs Non-ECP Class

Figure 9 illustrates that non-ECP students exhibit a significantly higher proportion of C grades, approximately 40%, compared to ECP students, who have a mere 10%. This implies that non-ECP students encounter greater challenges in comprehending the course material and face difficulties in attaining higher grades.

Discussion

The results of this study provide insight into the significant impact of hands-on pedagogy on enhancing peer learning, collaboration, and curiosity among undergraduate chemistry students. By integrating active learning techniques, laboratory experiments, and interactive teaching methodologies, students exhibited significant enhancements in their engagement, capacity for collaboration, and curiosity.

One of the key aspects illuminated by this study is the positive impact of active engagement in hands-on activities and the enhancement of peer learning and collaboration. As evidenced by the significant increase in scores related to peer learning and collaboration, students participating in hands-on pedagogy not only developed a deeper understanding of fundamental chemical principles, but also exhibited a greater tendency to work together, explain concepts to one another, and engage in group problem-solving. This aligns with previous research by Litman [33] which highlights the benefits of collaborative learning in fostering academic achievement and motivation among students.

Furthermore, the study's findings emphasize the role of hands-on pedagogy in nurturing students' curiosity. The increase in scores related to interest epistemic curiosity indicates that students became more eager to explore new ideas, learn about unfamiliar subjects, and engage in discussions about abstract concepts. This is particularly noteworthy given the importance of curiosity in driving scientific inquiry and innovation [34]. By providing students with interactive learning experiences that stimulate their curiosity, educators can cultivate a lifelong passion for learning and discovery among chemistry undergraduates.

Lastly, the comparison of academic performance between classes where experiment-centric pedagogy was implemented and those where it was not, underscores the positive impact of hands-on pedagogy on students' overall achievement. The higher proportion of A and B grades achieved by ECP students compared to non-ECP students reflects a more comprehensive understanding of course concepts and skills among the former. This not only highlights the effectiveness of hands-on pedagogy in enhancing learning outcomes but also suggests its potential to address disparities in academic achievement among students.

Conclusion

The experiment-centric pedagogy project, which ran in the chemistry department from fall 2021 to fall 2022, was evaluated to determine its impact on undergraduate students' curiosity, peer learning, and collaboration. This study used the Motivated Strategies for Learning Questionnaire (MSLQ) to assess students both before and after the course. The results show a positive shift in students' attitudes and behaviors in the target areas. The Interest Epistemic Curiosity scale demonstrated a notable increase, this suggests a significant boost in students' intrinsic drive and eagerness to delve into new concepts and learn about unknown topics. This finding is critical because it demonstrates the efficacy of experiment-centric pedagogy in creating an intellectually stimulating environment that fosters curiosity.

The Peer Learning and Collaboration scale exhibited a statistically significant, albeit modest, enhancement. This demonstrates the efficacy of the experiment-centric pedagogy in fostering student collaboration, an essential skill for academic and professional achievement. However, the scores on the deprivation epistemic curiosity scale did not exhibit a significant improvement. This implies that although the experiment-centric pedagogy is successful in fostering curiosity that arises from interest, it may not have a substantial impact on students' inclination to persevere in solving challenging questions.

The significant improvements in the Interest Epistemic Curiosity, Peer Learning, and Collaboration constructs indicate that experiment-centric pedagogy is an effective pedagogical approach for improving these important educational factors. However, the absence of a significant change in the Deprivation Epistemic Curiosity Scale suggests that additional refinements or strategies may be required to address all aspects of curiosity. Future research could delve deeper into these areas, potentially leading to a better understanding and application of experiment-centric teaching methods.

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References

[1] R. L. Stowe, L. J. Scharlott, V. R. Ralph, N. M. Becker, and M. M. Cooper, "You Are What You Assess: The Case for Emphasizing Chemistry on Chemistry Assessments," *J. Chem. Educ.*, vol. 98, no. 8, pp. 2490–2495, Aug. 2021, doi: 10.1021/acs.jchemed.1c00532.

[2] D. Lombardi *et al.*, "The Curious Construct of Active Learning," *Psychol Sci Public Interest*, vol. 22, no. 1, pp. 8–43, Apr. 2021, doi: 10.1177/1529100620973974.

[3] J. W. Reid *et al.*, "Investigating patterns of student engagement during collaborative activities in undergraduate chemistry courses," *Chem. Educ. Res. Pract.*, vol. 23, no. 1, pp. 173–188, 2022, doi: 10.1039/D1RP00227A.

[4] E. Khasawneh, A. Hodge-Zickerman, C. S. York, T. J. Smith, and H. Mayall, "Examining the effect of inquiry-based learning versus traditional lecture-based learning on students'

achievement in college algebra," *INT ELECT J MATH ED*, vol. 18, no. 1, p. em0724, Jan. 2023, doi: 10.29333/iejme/12715.

[5] D. Boud and A. Lee, "'Peer learning' as pedagogic discourse for research education [1]," *Studies in Higher Education*, vol. 30, no. 5, pp. 501–516, Oct. 2005, doi: 10.1080/03075070500249138.

[6] N. Falchikov, *Learning together: peer tutoring in higher education*. London ; New York: RoutledgeFalmer, 2001.

[7] D. W. Johnson, R. T. Johnson, and K. Smith, "The State of Cooperative Learning in Postsecondary and Professional Settings," *Educ Psychol Rev*, vol. 19, no. 1, pp. 15–29, Feb. 2007, doi: 10.1007/s10648-006-9038-8.

[8] B. Barron, "Achieving Coordination in Collaborative Problem-Solving Groups," *Journal of the Learning Sciences*, vol. 9, no. 4, pp. 403–436, Oct. 2000, doi: 10.1207/S15327809JLS0904_2.

[9] E. Bonawitz, I. Bass, and E. Lapidow, "Choosing to Learn: Evidence Evaluation for Active Learning and Teaching in Early Childhood," in *Active Learning from Infancy to Childhood*, M. M. Saylor and P. A. Ganea, Eds., Cham: Springer International Publishing, 2018, pp. 213–231. doi: 10.1007/978-3-319-77182-3_12.

[10] G. Pluck and H. L. Johnson, "Stimulating curiosity to enhance learning," 2011.

[11] A. Y. Kolb and D. A. Kolb, "Learning Styles and Learning Spaces: Enhancing Experiential Learning in Higher Education," *AMLE*, vol. 4, no. 2, pp. 193–212, Jun. 2005, doi: 10.5465/amle.2005.17268566.

[12] P. Sendall, C. S. Stuetzle, Z. A. Kissel, and T. Hameed, "Experiential Learning in the Technology Disciplines," 2019.

[13] D. H. J. M. Dolmans, S. M. M. Loyens, H. Marcq, and D. Gijbels, "Deep and surface learning in problem-based learning: a review of the literature," *Adv in Health Sci Educ*, vol. 21, no. 5, pp. 1087–1112, Dec. 2016, doi: 10.1007/s10459-015-9645-6.

[14] D. L. Linton, J. K. Farmer, and E. Peterson, "Is Peer Interaction Necessary for Optimal Active Learning?," *LSE*, vol. 13, no. 2, pp. 243–252, Jun. 2014, doi: 10.1187/cbe.13-10-0201.

[15] S. Clark, A. G. Harbaugh, and S. Seider, "Fostering adolescent curiosity through a question brainstorming intervention," *Journal of Adolescence*, vol. 75, no. 1, pp. 98–112, Aug. 2019, doi: 10.1016/j.adolescence.2019.07.007.

[16] R. Golman and G. F. Loewenstein, "Curiosity, Information Gaps, and the Utility of Knowledge," *SSRN Journal*, 2012, doi: 10.2139/ssrn.2149362.

[17] F. Koca, "Motivation to Learn and Teacher–Student Relationship".

[18] J. R. Hartman and E. A. Nelson, "'Do we need to memorize that?' or cognitive science for chemists," *Found Chem*, vol. 17, no. 3, pp. 263–274, Oct. 2015, doi: 10.1007/s10698-015-9226-z.

[19] J. Sweller, "Cognitive Load Theory," in *Psychology of Learning and Motivation*, vol. 55, Elsevier, 2011, pp. 37–76. doi: 10.1016/B978-0-12-387691-1.00002-8.

[20] M. Bannert, "Managing cognitive load—recent trends in cognitive load theory," *Learning and Instruction*, vol. 12, no. 1, pp. 139–146, Feb. 2002, doi: 10.1016/S0959-4752(01)00021-4.

[21] N. Vermeulen, O. Corneille, and P. M. Niedenthal, "Sensory load incurs conceptual processing costs," *Cognition*, vol. 109, no. 2, pp. 287–294, Nov. 2008, doi: 10.1016/j.cognition.2008.09.004.

[22] Ø. Anmarkrud, A. Andresen, and I. Bråten, “Cognitive Load and Working Memory in Multimedia Learning: Conceptual and Measurement Issues,” *Educational Psychologist*, vol. 54, no. 2, pp. 61–83, Apr. 2019, doi: 10.1080/00461520.2018.1554484.
[23] F. Paas and P. Ayres, “Cognitive Load Theory: A Broader View on the Role of Memory in Learning and Education,” *Educ Psychol Rev*, vol. 26, no. 2, pp. 191–195, Jun. 2014, doi: 10.1007/s10648-014-9263-5.
[24] L. Guo and C. Wang, “Enabling automatic retrieval of schemas from long-term memory in English grammar practice,” *Asia Pacific Educ. Rev.*, vol. 23, no. 2, pp. 361–373, Jun. 2022, doi: 10.1007/s12564-022-09762-9.
[25] S. Kalyuga, “Cognitive Load Theory: How Many Types of Load Does It Really Need?,” *Educ Psychol Rev*, vol. 23, no. 1, pp. 1–19, Mar. 2011, doi: 10.1007/s10648-010-9150-7.
[26] H. Tümay, “Emergence, Learning Difficulties, and Misconceptions in Chemistry Undergraduate Students’ Conceptualizations of Acid Strength,” *Sci & Educ*, vol. 25, no. 1–2, pp. 21–46, Mar. 2016, doi: 10.1007/s11191-015-9799-x.
[27] J. Sweller, “Element Interactivity and Intrinsic, Extraneous, and Germane Cognitive Load,” *Educ Psychol Rev*, vol. 22, no. 2, pp. 123–138, Jun. 2010, doi: 10.1007/s10648-010-9128-5.
[28] J. Jordan, J. Wagner, D. E. Manthey, M. Wolff, S. Santen, and S. J. Cico, “Optimizing Lectures From a Cognitive Load Perspective,” *AEM Education and Training*, vol. 4, no. 3, pp. 306–312, Jul. 2020, doi: 10.1002/aet2.10389.
[29] P. A. Kirschner, J. Sweller, F. Kirschner, and J. Zambrano R., “From Cognitive Load Theory to Collaborative Cognitive Load Theory,” *Intern. J. Comput.-Support. Collab. Learn*, vol. 13, no. 2, pp. 213–233, Jun. 2018, doi: 10.1007/s11412-018-9277-y.
[30] N. Debue and C. Van De Leemput, “What does germane load mean? An empirical contribution to the cognitive load theory,” *Front. Psychol.*, vol. 5, Oct. 2014, doi: 10.3389/fpsyg.2014.01099.
[31] P. R. Pintrich, D. A. F. Smith, T. Garcia, and W. J. Mckeachie, “Reliability and Predictive Validity of the Motivated Strategies for Learning Questionnaire (Mslq),” *Educational and Psychological Measurement*, vol. 53, no. 3, pp. 801–813, Sep. 1993, doi: 10.1177/0013164493053003024.
[32] J. A. Litman and C. D. Spielberger, “Measuring Epistemic Curiosity and Its Diversive and Specific Components,” *Journal of Personality Assessment*, vol. 80, no. 1, pp. 75–86, Feb. 2003, doi: 10.1207/S15327752JPA8001_16.
[33] J. A. Litman, “Interest and deprivation factors of epistemic curiosity,” *Personality and Individual Differences*, vol. 44, no. 7, pp. 1585–1595, May 2008, doi: 10.1016/j.paid.2008.01.014.
[34] C. N. Loes, “The Effect of Collaborative Learning on Academic Motivation,” *TLI*, vol. 10, Jan. 2022, doi: 10.20343/teachlearninqu.10.4.