The Future of Engineering Education
2024 Annual Conference & Exposition
Oregon Convention Center
Portland, OR . June 23 - 26, 2024
ASEE
Paper ID #44060

Impact of Experimental Centric Pedagogy on Learning Outcomes: A Comparative Trend Analysis in Industrial Engineering and Biology

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Abstract

Experimental Centric Pedagogy (ECP) is a teaching strategy that emphasizes experiential learning through hands-on activities. It can be considered a teaching concept that encourages students to learn by doing. There is a lack of evidence of the sustained impact of active learning pedagogy. Hence, this study seeks to investigate the influence of ECP in Biology in a Historically Black College and University (HBCU) since the project began in 2019. The study compares the students who participated in ECP, using various measures of engagement, motivation, cognitive processes, and collaborative learning experiences between spring 2022 and fall 2023. A well-developed and validated instrument, the Motivated Strategies for Learning Questionnaire (MSLQ), was adopted for this study, as well as a self-developed questionnaire to measure students' engagement during the implementation of pedagogy. The study contributes to the current understanding of the efficacy of ECP in enhancing learning outcomes. The study found a sustained level of cognitive development and motivation among the students, but there was a decline in peer learning and collaboration. It provides valuable insights for educators and curriculum designers seeking to implement effective pedagogical strategies in STEM education. The implications of this study extend beyond Biology, giving a head start for the widespread adoption of ECP in STEM education and the need to innovate by understanding the environment and student factor while implementing this student-focused pedagogy.

Introduction

In the post-COVID-19 era, contemporary education has experienced a paradigm shift. Moving away from traditional lecture-based pedagogies toward more dynamic and interactive approaches. One such transformative method gaining prominence is Experimental-Centric Pedagogy (ECP), an instructional strategy emphasizing hands-on experiences, real-world applications, and collaborative learning. Owolabi et al [1] described experimental-centric pedagogy as an instructional approach emphasizing hands-on, experiential learning to enhance student engagement and understanding. It involves active participation in experiments, problem-solving, and real-world applications, aiming to foster critical thinking, creativity, and practical skills. This is one of the emerging active learning strategies that have received national and international recognition for its impact on learner's motivation, self-efficacy, and cognitive development [2], [3], [4].

Science, technology, engineering, and mathematics education requires a deep understanding of the physical and natural aspects of existence, living organisms, and intricate biological processes. This field of study serves as a unique arena for investigating the efficacy of ECP. Traditional lecture-based approaches have been the cornerstone of education, but there is an increasing interest in exploring alternative methods that engage students actively in the learning process.

As the education landscape continues to evolve, assessing the impact of active learning pedagogies, especially the ECP, on learning, particularly within distinct academic disciplines, is imperative. Therefore, this study focuses on the comparative trend analysis of the impact of Experimental Centric Pedagogy on learning outcomes in Biology using various measures such as engagement, motivation, cognitive processes, and collaborative learning experiences.

Research Objectives

1. To carry out comparative trend analysis to discern the trajectory of students' engagement over time in the biology department under the influence of experimental-centric pedagogy;
2. To carry out comparative trend analysis to identify trends in students' motivation over time in the biology department when exposed to experimental-centric pedagogy;
3. To carry out a comparative trend analysis to track changes in collaborative learning experiences over time in biology courses under experimental-centric pedagogy and
4. To examine the evolving trends in cognitive processes in the biology department under experimental-centric pedagogy.

Research Questions

1. What trends can be identified in students' motivation in the biology department when exposed to experimental-centric pedagogy?

2. How do collaborative learning experiences in biology courses change over time under experimental-centric pedagogy?
3. What are the evolving trends in cognitive processes in the biology department under experimental-centric pedagogy?
4. How does the trajectory of students' engagement in the biology department change over time under the influence of experimental-centric pedagogy?

Literature Review

Partin [5] investigated the interplay between learning environments, motivation, attitudes, and course performance in post-secondary science education. The research employed a path model to examine the mediating effects of motivation and attitudes on the relationship between perceived learning environments and course performance. The study revealed that the classroom learning environment has a moderate total effect on self-efficacy and intrinsic goal orientation and a moderate indirect effect on attitudes toward biology. Furthermore, attitudes and self-efficacy moderately and directly affect course performance. The model tested in the study explained a significant portion of the variance in course performance, self-efficacy, attitudes toward biology, and intrinsic goal orientation. It concluded that to enhance course performance, instructors should focus on building self-efficacy among their students and ensuring the course's personal relevance.

In their study, Connor et al. [6] explored the potential impacts of an Experimental Centric Pedagogy (ECP) approach in an introductory digital electronics course. The study conducted a comprehensive analysis of final exams over eight years, identifying nine expected learning outcomes and seven corresponding question types to measure these outcomes. The outcomes were categorized into three levels of proficiency: less than 50%, between 50% and 75%, and greater than 75%. The study found that, on average, one outcome (the application of sequential circuits) fell below the basic understanding level (less than 50%). Additionally, three outcomes (the application of Boolean algebra, the sum of products and Karnaugh mapping, and the application of combinational circuits) were within the basic understanding level (between 50% and 75%) for electrical engineering students. The study findings concluded that the ECP approach can improve student learning outcomes, particularly for topics that require hands-on experimentation and circuit design.

O'Sullivan *et al.* [7] explored the implementation of active learning strategies in a hybrid medical biochemistry course. They identify the challenges of traditional biochemistry courses, which often necessitate extensive memorization and can lead to a disconnect between classroom teaching and clinical application. The authors propose active learning strategies that engage students cognitively and deviate from the conventional didactic teaching approach to address these issues. These strategies, including project-based learning and a flipped classroom approach, were implemented in an American-style MD program in the UAE. This active learning approach transformed students into teachers, who presented and assessed high-stakes topics to their peers through review sessions. These sessions provided a platform for presenting and contextualizing theory with medical cases, bridging the gap between theoretical knowledge and clinical application. The study suggests that such strategies can enhance learning outcomes and boost student motivation, satisfaction, and engagement in the classroom, leading to improved performance. This research significantly contributes to the field of medical education by demonstrating the effectiveness of active learning strategies in a hybrid medical biochemistry course.

The study by Wilton *et al.* [8] aimed to assess the impact of course design on student academic performance and retention in an introductory biology course. Comparing a traditional lecture-based course with an intervention course incorporating active-learning strategies, the research found that students in the intervention course showed significantly improved academic achievement and retention rates. Additionally, participants in the intervention course reported a greater sense of classroom belonging, attributed to increased student interactions and peer-led discussions. These findings underscore the importance of integrating active learning approaches to enhance student outcomes in STEM education. Educators can create supportive learning environments that improve academic performance and retention in STEM majors by structuring courses to promote engagement and belonging.

Consequently, an investigation of the impact of active learning strategies on students' conceptual understanding and affective changes in introductory biology compared two active-learning environments, focusing on graphic organizer/worksheet activities and clicker-based case studies facilitated by instructors with different educational backgrounds. The study's findings revealed that students in both environments exhibited significant learning gains, with differences observed in certain attitudinal measures related to enjoyment of biology and real-world connections. While most attitudinal and motivational data did not significantly differ between the two groups, the study reinforced the positive association between active learning and student outcomes in biology education. By emphasizing the benefits of active learning in promoting conceptual understanding and shaping positive attitudes, the research underscores the importance of diverse instructional approaches to enhance student engagement and learning in STEM disciplines [9].

Literature and studies indicate that employing ECP and other active learning strategies can improve learning outcomes, increase student motivation, satisfaction, and engagement, cultivate a stronger sense of classroom community, and encourage better conceptual understanding and positive attitudes toward the subject. While ample evidence supports the benefits of active learning strategies, there is a lack of longitudinal evidence regarding the long-term effectiveness of hands-on teaching methods across several semesters. Past research has primarily focused on analyzing the effects of these strategies within a single semester or academic year. We are interested in studying the long-term effects of experimental-centric pedagogy (ECP) on Biology learning outcomes by analyzing data over multiple semesters.

Methodology

This study was conducted among first and sophomore undergraduates enrolled in different biology courses at one of the nation's historically black colleges and universities. This quantitative descriptive study was conducted from Spring 2022 to Fall 2023 to evaluate the longitudinal impact of the experimental-centric pedagogy among the learners. Three (3) instructors participated in implementing the experiment-centric pedagogy, and a uniform module design was adopted. A full discussion on this experiment-centric pedagogy has been published with preliminary findings during the spring and fall of 2021[10]. More so, students who took the courses where ECP was implemented were pre-informed, and participation in data collection was not coerced. The current study adopted a validated instrument, the Motivated Strategies for Learning Questionnaire (MSLQ), developed by Pintrich [11]. The MLSQ adopted for this study is a 24-item, 7-point Likert scale instrument that measures 3 key constructs: motivation, cognitive process, development, peer learning, and collaboration. Each item's minimum obtainable mean score was 1, and the maximum was 7. A self-developed questionnaire, which is a 5-point Likert scale, was also deployed among the students to investigate the students' level of engagement during the usage of this pedagogy. Each item's minimum obtainable mean score was 1, and the maximum was 5. The post-implementation responses of the students were collected using an electronic approach, and the data was cleaned and analyzed using Statistical Package for Social Scientists (IBM SPSS 25.0). To ensure that participants' data used in this study were uniform, students who took more than one of the courses where ECP was implemented were excluded from the data analysis. Each item's mean and standard deviation were determined, and a weighted mean average was also obtained and compared across the terms.

Results and Discussion

Motivation

The result presented in Table 1 revealed the semester-by-semester mean responses of the learners who have participated in learning using the experiment-centric pedagogy. The motivational items mean score from spring 2022 – to fall 2023 showed that there has been a progressive increase in the student's response to motivation across time. According to the results, although the effects slightly faded in the most recent term, adopting an experiment-centric pedagogy appears to have positively affected students' motivation levels over several terms. Motivation significantly increased from the Spring 2022 baseline to the following semesters, reaching its peak in Spring 2023 after two semesters of exposure to the new teaching method.

The observed increase was caused by increased interest, curiosity, desire for comprehension, and external motivations linked to grades and GPA. One outstanding item was the preference for challenging material, which remained consistent over time. This indicates that the teaching method specifically encouraged students' internal drive to thoroughly understand the course material and their external motivations linked to academic achievement. STEM students, in particular, are drawn to hands-on experimentation at the core of this teaching method because it aligns with their natural curiosity and enthusiasm for active scientific investigation. The consistent increase in motivation across several terms suggests that hands-on learning enabled students to interact with the course material in a stimulating manner that traditional passive lecturing may not achieve. This suggests an experiment-focused, active learning method can significantly boost STEM students' motivation.

Table 1: Term-by-term mean motivation scores of learners.

Items	Spring 2022		Fall 2022		Spring 2023		Fall 2023	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
In a class like this, I prefer course material that really challenges me so I can learn new things.	4.47	1.99	4.30	1.83	5.24	1.62	4.20	1.92
In a class like this, I prefer course material that arouses my curiosity, even if it is difficult to learn.	4.78	2.26	5.00	0.94	5.10	1.66	4.16	1.92
The most satisfying thing for me in this course is trying to understand the content as thoroughly as possible.	4.78	2.20	5.40	1.26	5.73	1.66	4.09	2.19
Getting a good grade in this class is the most satisfying thing for me right now	4.82	2.45	5.90	0.88	6.25	1.49	4.13	2.55
The most important thing for me right now is improving my overall grade point average	4.94	2.35	5.60	1.07	6.22	1.55	4.07	2.54
I want to do well in this class because it is important to show my ability to my friends, employer or others	4.79	2.33	5.70	1.16	6.08	1.51	4.09	2.48
Weighted Mean	**4.76**	**2.26**	**5.31**	**1.19**	**5.67**	**1.58**	**4.13**	**2.26**

This study's findings support previous research that highlights the motivational advantages of active, hands-on learning methods in STEM education. Freeman et al. [12] performed a meta-analysis showing that active learning enhances students' exam results compared to traditional lecturing. They discovered that failure rates decrease when using active learning models. Therefore, the findings in this current study corroborate the evidence that hands-on teaching methods can boost students' motivation and involvement, resulting in better academic performance in STEM classes. Prince [13] examined evidence indicating that active learning techniques enhance students' motivation to comprehend course material, leading to more profound learning than passive listening. The study's findings indicate that students benefited from the experiment-focused curriculum through heightened curiosity, increased desire for understanding, and improved grades. This aligns with Prince's findings regarding the beneficial motivational effects of active learning.

The slight decrease in Fall 2023, despite sustained high motivation compared to the initial level, necessitates a closer examination to determine if adjustments to the teaching method are needed to avoid stagnation. The decrease in motivation scores in Fall 2023 aligns with Cohen et al. [14] warning that the novelty and excitement of new teaching methods may fade over time. They stressed the importance of continuous iterations and enhancements to avoid stagnation. The present results reveal the significance of the need to consistently improve creative teaching approaches to sustain the motivational drive.

An experiment-centered curriculum emphasizing hands-on discovery can effectively enhance motivation and engagement in STEM learners. However, motivation necessitates continuous assistance. Maintaining prolonged motivation requires intentional structures, fair resources, and ongoing enhancement of interactive learning techniques. By providing thorough preparation and support for educators, implementing well-thought-out curriculum design, and creating policies that cater to student needs, active pedagogies can effectively inspire students in a lasting manner.
Motivation must be cultivated through continuous efforts to improve the learning environment. Relying solely on new methods can lead to decreased motivation without well-developed systems promoting involvement.

The initial longitudinal results show significant motivational advantages of using a hands-on, experiment-centered teaching approach for STEM students. More data from additional semesters would provide further evidence of the long-term effects. The current findings indicate that this approach may effectively enhance the involvement and continuity of STEM students by tapping into their natural curiosity for exploration via scientific trials.

Peer Learning and Collaboration

The longitudinal result (Table 2 and Figure 1) shows decreased collaborative learning behaviors among students after introducing an experiment-focused teaching method. The mean collaboration scores of the last two items in Table 2 showed a slight increase from Spring 2022 to Fall 2022, followed by a decrease over the next two semesters, reaching the lowest score in Fall 2023. Clearly, using personalized instruments does not strengthen the development of peer learning and collaboration among the learners.

Decreasing trends were observed in all three survey items related to peer explanation, group work, and discussion of course content. This suggests that the initial increase in student collaboration decreased gradually over time, eventually reaching levels like the starting point. Cohen et al. (2021) highlight that new teaching methods can lead to a temporary boost in involvement and interaction, but maintaining these changes in behavior necessitates continuous support.

The decrease in collaboration in STEM classrooms is worrisome due to research emphasizing peer-to-peer interaction's motivational and learning advantages in active learning settings. Research indicates that collaborating in small groups and engaging in discussions with peers can boost the motivation, understanding, and academic achievement of STEM students [15], [16], [17]. Transitioning to an experiment-focused teaching method may not be enough to sustain high levels of collaboration without formally incorporating cooperative structures. Cooper [18] highlights that incorporating hands-on activities alone cannot change student behaviors unless collaborative experiences and expectations are intentionally structured. Creating a collaborative community is essential for maximizing the motivational benefits of active learning in STEM.

Additional research should investigate changes to the experiment-focused curriculum that may help to increase engagement, which has been decreasing over time. This could include mandatory group experiments, jigsaw activities, or organized project teams. Sawyer & Obeid [19] explain that supporting interdependence in STEM tasks facilitates students in embracing collaborative learning orientations. Formal cooperative structures may help mitigate the decreased collaboration noted in this context. Continual revisions and enhancements are necessary to ensure this educational change enhances cooperative behaviors crucial for profound STEM learning.

Table 2: Term-by-Term Mean Score of Peer Learning and Collaboration

Items	Spring 2022		Fall 2022		Spring 2023		Fall 2023	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
When studying for this course, I often try to explain the material to a classmate or a friend.	4.57	1.99	4.00	1.15	4.08	2.10	4.02	2.00
I try to work with other students from this class to complete the course assignments.	4.35	2.12	4.40	1.51	4.33	2.14	4.09	2.04
When studying for this course, I often set aside time to discuss the course material with a group of students from the class.	4.61	2.08	4.70	1.49	4.27	2.13	4.11	1.98

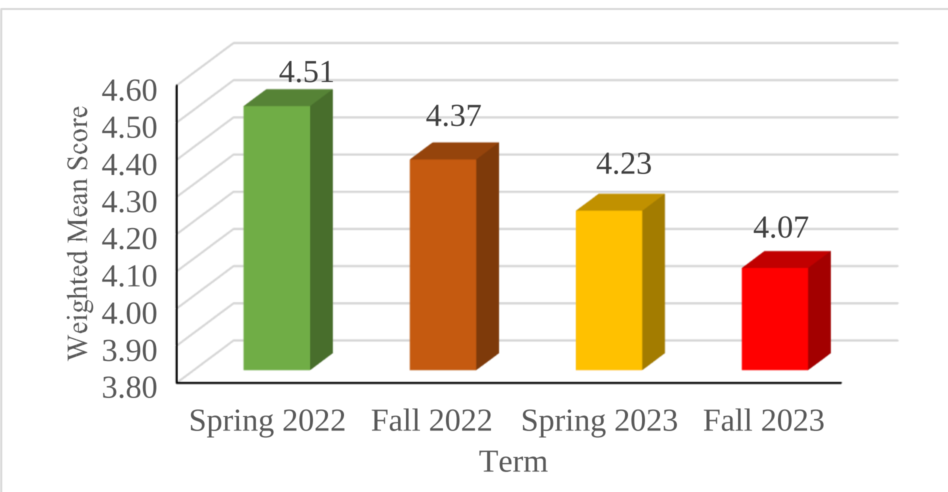

Figure 1: Summary of Peer Learning and Collaboration among the Learners

Cognitive process and development

The study's findings indicate that the experiment-focused teaching method resulted in significant immediate enhancements in behaviors associated with advanced cognitive abilities and metacognitive strategies in students. Nevertheless, the cognitive advantages diminished gradually following an initial surge. The weighted mean cognitive development scores showed a significant increase from Spring 2022 to Fall 2022, followed by a slight increase in Spring 2023 (Table 3). This suggests an initial phase of strong cognitive development under the new teaching approach. Malik and Zhu [20] suggest that hands-on learning can enhance the development of scientific reasoning skills compared to lecture-based instruction. The initial progress is consistent with research highlighting the cognitive advantages of active participation for students studying STEM subjects [12].

The decrease by Fall 2023 aligns with Dinsmore et al. [21] research indicating that sustained cognitive development necessitates continuous support and application of new cognitive frameworks rather than just an initial introduction to ideas. The decline in questioning, metacognition, and critical analysis suggests that hands-on activities may not be enough to sustain cognitive improvements without consistently reinforcing mental habits over time. Marusic and Slisko [22] highlighted the importance of regularly engaging STEM students in applying inquiry skills to develop their scientific thinking dispositions in specific contexts. The latest findings indicate that an experiment-centered curriculum can stimulate cognitive development, but maintaining these habits may require ongoing explicit training that is integrated over time. Decreasing scores despite ongoing experiential learning emphasizes that cognitive advancement necessitates more than just engaging in activities.

The result presented in Table 4 shows that using an experiment-centric pedagogy resulted in gradual improvements over several semesters, but these gains decreased by the last term. Engagement scores increased slightly from Spring 2022 to Fall 2022 and showed more significant growth from Fall 2022 to Spring 2023 with the new teaching method. Yet, the increase in activity halted, and involvement decreased once more by Fall 2023 despite the continuous interactive curriculum. Initial favorable patterns correspond with studies indicating that active learning frequently enhances student involvement in STEM classrooms compared to traditional lecturing [23], [24].

Table 3: Term-by-term mean scores of cognitive processes and development.

Items	Spring 2022		Fall 2022		Spring 2023		Fall 2023	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
I often find myself questioning things I hear or read in this course to decide if I find them convincing.	4.47	2.01	5.30	1.49	5.22	1.57	4.04	2.03
I try to play around with ideas of my own related to what I am learning in this course.	4.33	2.06	4.80	1.48	5.00	1.66	4.08	1.88
Whenever I read or hear an assertion or conclusion in this class, I think about possible alternatives.	4.37	1.89	4.50	1.58	4.75	1.75	4.02	1.86
When I become confused about something I'm reading for this class; I go back and try to figure it out.	4.82	2.20	5.40	1.51	5.45	1.63	4.12	1.96
If course materials are difficult to understand, I change the way I read the material.	4.55	1.99	5.40	1.17	5.22	1.71	4.11	1.94
Before I study new course material thoroughly, I often skim it to see how it is organized.	4.37	2.16	5.20	1.14	5.27	1.70	4.04	2.05
I try to think through a topic and decide what I am supposed to learn from it rather than just reading it over when studying.	4.65	1.99	4.70	1.25	5.20	1.70	4.09	1.99
Weighted Mean	**4.50**	**2.04**	**5.00**	**1.37**	**5.16**	**1.67**	**4.07**	**1.96**

Table 4: Term by term mean scores of student engagement and growth.

Items	Spring 2022		Fall 2022		Spring 2023		Fall 2023	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Helped me to develop skills in problem solving in this subject area	2.43	1.02	2.20	0.92	2.76	0.95	2.59	1.03
Think about problems in graphical/pictorial or practical ways	2.51	0.94	2.30	0.67	2.73	0.96	2.62	1.00
Learn how electric circuits are used in practical applications	2.69	0.90	2.89	0.60	2.82	0.93	2.65	1.07
Recall course content	2.53	0.96	2.60	0.70	2.88	0.96	2.59	1.01
Using such devices help improve grades	2.63	1.01	2.60	0.52	2.80	1.06	2.70	1.04
Develop confidence in content area	2.35	0.93	2.56	0.53	2.73	0.98	2.59	1.01
Become motivated to learn course content	2.29	0.94	2.40	0.84	2.65	1.07	2.56	1.02
Develop interest in the subject area	2.31	0.92	2.30	0.67	2.72	0.97	2.57	1.02
Using such devices help complete lab assignments	2.33	0.88	2.20	0.92	2.65	1.07	2.51	0.99
Weighted Mean	2.45	0.94	2.49	0.71	2.75	1.00	2.55	1.01

Student engagement and growth

The experiment focused on problem-solving, motivation, confidence, and interest, which showed measurable growth. This indicates that the experiment targeted dimensions associated with active learning as identified in previous studies. This supports the idea that practical activities can enhance STEM education [13]. The decrease by Fall 2023 reflects warnings from Braxton et al. [3] that numerous reforms often lead to only a temporary increase in engagement. They stress that maintaining behavioral changes necessitates consistently cultivating a supportive culture for an extended period. The latest findings suggest that although lessons focused on experiments may increase engagement initially, it is important to sustain interest by consistently improving the engaging environment with various enhancements and student support [25]. In addition, these findings indicate that experiential learning is inadequate for sustaining long-term involvement in STEM subjects. Astleitner [26] explains that multidimensional engagement necessitates coordinated endeavors across different facets of the learning environment. The results emphasize the potential of interactive teaching methods and the necessity for thorough initiatives to encourage, assist, and sustainably motivate students.

Conclusion

Future research should investigate instructional aids, such as metacognitive reflection or two-stage exams, that may mitigate the decline in cognitive benefits over time. Early quantifiable improvements, as seen in motivation, peer learning, collaboration, and cognitive development, suggest that experiment-focused teaching methods can enhance these constructs when implemented carefully. The results highlight the effectiveness of active learning and emphasize the necessity of continuous reinforcement for a genuine shift in STEM cognition. The present longitudinal research aimed to evaluate the effects of an experiment-focused teaching approach on student performance in biology courses across several semesters. Comparative trend analysis shows that implementing a hands-on, experiential learning method resulted in initial enhancements in motivation, peer learning, cognitive development, and engagement.

Nevertheless, a significant portion of these improvements diminished by the end of the last semester, indicating the necessity for continuous adjustments to maintain advantages in the long term. The result of this study indicated significant growth in motivation during the initial two semesters of implementation, driven by increased curiosity, desire for comprehension, and academic performance objectives. This is consistent with prior studies showing that active learning enhances motivation among STEM students. Yet, motivation decreased slightly by the end of the term, highlighting the necessity of consistently improving and refining innovative teaching methods to sustain motivation.

Peer collaboration and cognitive growth initially increased significantly under the new model but later declined. Hands-on activities are insufficient to change behaviors and thinking without formal collaborative structures and explicit cognitive skill development integrated over time. Student engagement initially rose but declined by the final semester, indicating the necessity of consistently nurturing supportive environments that motivate students in the long run. Experiment-based strategies can potentially improve results, but continuous reinforcement is necessary to realize benefits. Early progress was probably due to the newness and diversity, but it did not last without intentional structures to support skill development, foster encouraging environments, and consistently enhance interactive learning techniques over time. Innovative teaching methods can lead to positive changes, but they must be carefully introduced and enhanced to effectively engage students in a long-lasting and comprehensive manner.

This study contributes to the needed longitudinal evidence regarding active learning in STEM disciplines. The identified trends offer valuable insights into the progression of outcomes over time and the necessary factors to maximize and maintain benefits. Future research should focus on monitoring long-term effects while investigating teaching methods, distribution of resources, and training techniques that can consistently enhance practical teaching methods to optimize learning, involvement, cooperation, and cognitive development.

Acknowledgment

This study is part of the work supported by the National Science Foundation Grant # 1915615, titled "Adapting an Experiment-centric Teaching Approach to Increase Student Achievement in Multiple STEM Disciplines." It should be noted that the opinions, results, conclusions, or recommendations expressed are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

References

[1] O. A. Owolabi, J. K. Ladeji-Osias, O. S. Alamu and K. A. Connor, "Global Impact Experiment-Centric Pedagogy and Home-Based Hands-on Learning Workshop at a Historically Black University", Paper presented at 2021 ASEE Annual Conference & Exposition, Virtual

[2] Meeting, Paper ID 34049

[3] P. Armbruster, M. Patel, E. Johnson, and M. Weiss, "Active Learning and Student-centered Pedagogy Improve Student Attitudes and Performance in Introductory Biology," *LSE*, vol. 8, no. 3, pp. 203–213, Sep. 2009, doi: 10.1187/cbe.09-03-0025.

[4] J. M. Braxton, W. A. Jones, A. S. Hirschy, and H. V. Hartley Iii, "The role of active learning in college student persistence," *New Drctns for Teach & Learn*, vol. 2008, no. 115, pp. 71–83, Sep. 2008, doi: 10.1002/tl.326.

[5] M. Devira, "Revisiting the implementation of active learning pedagogy in EFL classrooms," *Studies in English Language and Education*, vol. 7, no. 1, pp. 223–236, 2020.

[6] M. L. Partin, "The CLEM model: Path analysis of the mediating effects of attitudes and motivational beliefs on the relationship between perceived learning environment and course performance in an undergraduate nonmajor biology course," PhD Thesis, Bowling Green State University, 2008.

[7] K. Connor *et al.*, "Matched Assessment Data Set for Experiment-Centric Pedagogy Implementation in 13 HBCU ECE Programs," in *2017 ASEE Annual Conference & Exposition Proceedings*, Columbus, Ohio: ASEE Conferences, Jun. 2017, p. 28652. doi: 10.18260/1-2--28652.

[8] S. O'Sullivan, L. A. Campos, and O. C. Baltatu, "'Involve Me and I Learn': Active Learning in a Hybrid Medical Biochemistry First Year Course on an American-Style MD Program in the UAE," *Med.Sci.Educ.*, vol. 32, no. 3, pp. 703–709, Jun. 2022, doi: 10.1007/s40670-022-01545-6.

[9] M. Wilton, E. Gonzalez-Niño, P. McPartlan, Z. Terner, R. E. Christoffersen, and J. H. Rothman, "Improving Academic Performance, Belonging, and Retention through Increasing Structure of an Introductory Biology Course," *LSE*, vol. 18, no. 4, p. ar53, Dec. 2019, doi: 10.1187/cbe.18-08-0155.

[10] L. M. Cleveland, J. T. Olimpo, and S. E. DeChenne-Peters, "Investigating the Relationship between Instructors' Use of Active-Learning Strategies and Students' Conceptual Understanding and Affective Changes in Introductory Biology: A Comparison of Two Active-Learning Environments," *LSE*, vol. 16, no. 2, p. ar19, Jun. 2017, doi: 10.1187/cbe.16-06-0181.

[11] B. I.,Adeika, A., Ariyibi, A. Oni, O. A., Owolabi, A. I., Olude, S. K., Pramanik, and K. BistaIncreasing Student Motivation and Learning by Adopting the Experiment-Centric Pedagogy: A Case of Undergraduates in Biology. In *2023 ASEE Annual Conference & Exposition*. (2023, June).

[12] P. R. Pintrich, "A manual for the use of the Motivated Strategies for Learning Questionnaire (MSLQ).," 1980.

[13] J. Freeman *et al.*, "Engaging underrepresented groups in high school introductory computing through computational remixing with EarSketch," in *Proceedings of the 45th ACM technical symposium on Computer science education*, Atlanta Georgia USA: ACM, Mar. 2014, pp. 85–90. doi: 10.1145/2538862.2538906.

[14] M. Prince, "Does Active Learning Work? A Review of the Research," *J of Engineering Edu*, vol. 93, no. 3, pp. 223–231, Jul. 2004, doi: 10.1002/j.2168-9830.2004.tb00809.x.

[15] R. Cohen, I. Katz, N. Aelterman, and M. Vansteenkiste, "Understanding shifts in students' academic motivation across a school year: the role of teachers' motivating styles and needbased experiences," *Eur J Psychol Educ*, vol. 38, no. 3, pp. 963–988, Sep. 2023, doi: 10.1007/s10212-022-00635-8.

[16] M. T. H. Chi and R. Wylie, "The ICAP Framework: Linking Cognitive Engagement to Active Learning Outcomes," *Educational Psychologist*, vol. 49, no. 4, pp. 219–243, Oct. 2014, doi: 10.1080/00461520.2014.965823.

[17] C. Förtsch, S. Werner, T. Dorfner, L. Von Kotzebue, and B. J. Neuhaus, "Effects of Cognitive Activation in Biology Lessons on Students' Situational Interest and Achievement," *Res Sci Educ*, vol. 47, no. 3, pp. 559–578, Jun. 2017, doi: 10.1007/s11165016-9517-y.

[18] S. L. Eddy and K. A. Hogan, "Getting Under the Hood: How and for Whom Does Increasing Course Structure Work?," *LSE*, vol. 13, no. 3, pp. 453–468, Sep. 2014, doi: 10.1187/cbe.14-03-0050.

[19] K. S. Cooper, "Eliciting engagement in the high school classroom: A mixed-methods examination of teaching practices," *American educational research journal*, vol. 51, no. 2, pp. 363–402, 2014.

[20] J. Sawyer and R. Obeid, "Cooperative and collaborative learning: Getting the best of both words," *How we teach now: The GSTA guide to student-centered teaching*, pp. 163–177, 2017.

[21] K. M. Malik and M. Zhu, "Do project-based learning, hands-on activities, and flipped teaching enhance student's learning of introductory theoretical computing classes?," *Education and Information Technologies*, vol. 28, no. 3, pp. 3581–3604, 2023.

[22] D. L. Dinsmore, P. A. Alexander, and S. M. Loughlin, "Focusing the conceptual lens on metacognition, self-regulation, and self-regulated learning," *Educational psychology review*, vol. 20, pp. 391–409, 2008.

[23] M. Marušić and J. Sliško, "Influence of Three Different Methods of Teaching Physics on the Gain in Students' Development of Reasoning," *International Journal of Science Education*, vol. 34, no. 2, pp. 301–326, Jan. 2012, doi: 10.1080/09500693.2011.582522.

[24] S. J. Han, D. H. Lim, and E. Jung, "A collaborative active learning model as a vehicle for online team learning in higher education," in *Research Anthology on Developing Effective Online Learning Courses*, IGI Global, 2021, pp. 217–236.

[25] J. Watkins and E. Mazur, "Retaining students in science, technology, engineering, and mathematics (STEM) majors," *Journal of College Science Teaching*, vol. 42, no. 5, pp. 36–41, 2013.

[26] J. Handelsman, S. Miller, and C. Pfund, *Scientific teaching*. Macmillan, 2007.

[27] H. Astleitner, “Multidimensional Engagement in Learning–An Integrated Instructional Design Approach.,” *Journal of Instructional Research*, vol. 7, pp. 6–32, 2018.