



Effects of Challenge-Based Learning on Academic Performance in Computer Architecture among Polytechnic Computer Students

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Abstract

This study examined the effects of Challenge-Based Learning (CBL) on the academic performance of Computer Science/Engineering students in Computer Architecture, in relation to the conventional lecture method at Waziri Umaru Federal Polytechnic, Birnin Kebbi, Nigeria. The study adopted a quasi-experimental, non-equivalent pre-test post-test control group design. Forty-five (45) Computer Science and Computer Engineering students were assigned to a Challenge-Based Learning group and a Conventional Lecture Method group and both groups were taught Computer Architecture for eight weeks using their respective instructional strategies. Data were collected using the Computer Architecture Achievement Test (CAAT), a 30-item multiple-choice instrument with a test-retest reliability coefficient of 0.86 and analysed using means, standard deviations, paired-sample t-tests and an independent-sample t-test at the 0.05 level of significance. The results showed a statistically significant improvement in mean scores from pre-test to post-test for both the Challenge-Based Learning group ($t = -14.44$, $df = 19$, $p < .001$) and the Conventional Lecture Method group ($t = -14.42$, $df = 24$, $p < .001$). More importantly, students taught with Challenge-Based Learning performed significantly better on the post-test than those taught with the conventional lecture method ($t = 3.18$, $df = 43$, $p = .003$), even though the two groups did not differ significantly at pre-test. These findings suggest that, while both approaches improve performance, Challenge-Based Learning is a more effective instructional strategy than the conventional lecture method for teaching Computer Architecture. The study recommends that Computer Engineering lecturers in polytechnics adopt Challenge-Based Learning, particularly for abstract and applied topics in Computer Architecture and that curriculum planners provide the institutional support required for its sustained implementation.

Keywords: challenge-based learning, conventional lecture method, academic performance, computer architecture

1 Introduction

The rapid advancement of the 21st century has brought numerous changes to the practice of teaching and learning. These changes are driven by fast technological growth, globalisation and the need for workers who can think critically and creatively, collaborate, communicate well and solve industrial and human problems. Because of this need, many schools are moving away from the traditional teacher-centred approach towards learner-centred methods that make students active in their own learning and encourage critical thinking. Furthermore, this change is particularly important in Science, Technology, Engineering and Mathematics (STEM) education, where students are expected not only to know theory but also to apply theory to solve real-life problems (Membrillo-Hernández et al., 2021; Van den Beemt, Van De Watering, et al., 2023). One of the teaching methods that has become popular in this reform is Challenge-Based Learning (CBL). CBL is a method that allows students to work together and use inquiry to identify, investigate and solve real-life challenges (Doulougeri et al., 2024; Gallagher & Savage, 2020).

Challenge-Based Learning traces its roots to constructivist and experiential learning theories. It moves students away from just receiving knowledge to being active in investigation, critical thinking, teamwork and finding real world solutions (Bohm et al., 2020; Membrillo-Hernández et al., 2021). CBL normally goes through three stages, which are Engage, Investigate and Act. Within these stages, learners look at meaningful challenges, gather and study relevant information and then carry out practical solutions (Martin & Bombaerts, 2025). CBL has been recognised as an effective strategy that connects theory with practice and prepares students to face complex technological problems in engineering (Félix-Herrán et al., 2022; Gallagher & Savage, 2020; Van den Beemt, Van De Watering, et al., 2023).

However, the conventional lecture method is still the most common teaching approach used in many technical and vocational institutions. It is a teacher-centred strategy where the lecturer is the main source of knowledge and students mostly listen, take down notes and reproduce what they were taught during examinations (Abdurrahman et al., 2023; Bello et al., 2024). This method involves one-way communication and it gives students little chance to interact or carry out hands-on practical activities (Freeman et al., 2014). Even though the method allows lecturers to cover a lot of content within a short time, it has been criticised for making students passive and for limiting the growth of critical thinking and problem-solving skills (Sweller, 2019).

One of the foundational courses in Computer Science and Computer Engineering is Computer Architecture. This course deals with the design, functional organisation and operational structure of computer systems, which includes processors, memory units, input/output systems, storage devices and computer communication pathways (Grimes, 2002). The course serves as a bridge that connects hardware and software through explaining how computing systems process, store and manage information. It also helps students to develop understanding in processor design, instruction execution, memory hierarchy and the overall system performance optimisation. The importance of this course keeps growing due to the expansion of artificial intelligence, cloud computing, big data analytics, cybersecurity, Internet of Things and robotics, all of which depend on efficient computer architectural design (Al-Fedaghi, 2021; Ceze et al., 2016). Competence in computer architecture is very necessary to produce graduates that can support industrial automation, digital infrastructure expansion and sustainable technological growth, particularly in Nigeria.

Despite the importance of this course, many Computer Science/Engineering students still find it difficult to understand because of its abstract and procedural nature. The traditional lecture method, which emphasises the transmission of theoretical content with limited active engagement, often leaves students poorly equipped to understand processor operations, memory management, instruction execution and system organisation. This results in weak academic performance due to limited active participation. Even though several innovative teaching methods have been proposed to solve this problem, there is still limited empirical evidence on how effective Challenge-Based Learning is in improving academic performance in Computer Architecture, particularly in Nigerian polytechnic institutions. Earlier studies from the same institution compared CBL only with Place-Based Learning and found comparable gains in achievement and retention (Zubairu & Bello, 2026a, 2026b); CBL has not yet been compared with the conventional lecture method. This gap is what motivates the present study, which compares the effect of Challenge-Based Learning and the conventional lecture method on the academic performance of Computer Science/Engineering students in Computer Architecture at Waziri Umaru Federal Polytechnic. The findings of this study are expected to contribute to educational practice, policy and research. The study may provide Computer Science/Engineering lecturers with empirical evidence on an instructional approach that can improve academic performance in Computer Architecture, help curriculum planners and administrators make decisions about adopting learner-centred strategies, and add to the growing body of literature on active learning pedagogies in STEM education within sub-Saharan Africa.

2 Literature Review

2.1 Conceptual Review

2.1.1 Concept of Challenge-Based Learning

Challenge-Based Learning originated from a collaboration between Apple Inc. and educators and it was designed as a framework to engage learners with real, authentic problems that do not have only one solution path (Apple Inc., 2026; Johnson et al., 2009). Gallagher and Savage (2020) describe CBL as an approach that uses real-world challenges to drive learning, involves academic and other stakeholders, integrates technology and can be applied across different academic disciplines. Doulougeri et al. (2024), after reviewing 48 empirical studies on CBL in engineering education, observed that CBL implementation differs from one course to another, but it always centres on open-ended, real-world challenges that require students to research, work together and also build their own solution path (Robledo-Rella et al., 2025).

CBL is usually organised around three broad stages of Engage, Investigate and Act. In these stages, students first connect with a big idea and form an important question, then investigate the problem area and gather evidence, and finally they design, carry out, and evaluate the solution they discover (Martin & Bombaerts, 2025). This structure is meant to build not only knowledge of the subject but also other important industrial skills such as critical thinking, collaboration, communication and self-directed learning (Huesca et al., 2024; Membrillo-Hernández et al., 2021).

2.1.2 Concept of the Conventional Lecture Method

The conventional lecture method is a teacher-centred teaching strategy where the lecturer is the main source of knowledge and content is delivered mainly through oral explanation, while students maintain a passive role of listening and taking notes (Abdurrahman et al., 2023; Bello et al., 2024). The pace, order and depth of the session content are controlled by the lecturer and assessment normally focuses on recalling and reproducing the information that was taught (Freeman et al., 2014). Although this method remains efficient for covering a large amount of content within limited time, evidence from meta-analysis in STEM disciplines shows that it is generally less effective than active learning approaches in promoting understanding of concepts and reducing the rate of academic failure (Freeman et al., 2014).

2.1.3 Concept of Academic Performance

Academic performance refers to the level to which learners achieve the intended learning outcomes and it is usually measured through tests, examinations, assignments and projects (Bello et al., 2024). Academic performance is very important particularly in technical and engineering courses, because it shows how well a student has mastered the concepts and procedures needed for professional competence. Academic performance is affected by many factors, including the instructional method used, the learning environment, motivation, prior knowledge and how much the learner was actively engaged during instruction (Abdurrahman et al., 2023). Because of this, finding instructional strategies that can reliably improve academic performance remains an important concern in engineering education research.

2.1.4 Computer Architecture as a Field of Study

Computer Architecture is mainly concerned with the design and operational structure of computer systems, including processors, memory hierarchies, input/output subsystems, and interconnection pathways, which together determine how instructions are carried out and information is managed (Grimes, 2002). Since many of its core concepts, such as instruction cycles, pipelining and memory addressing are abstract and cannot be seen directly, the subject is widely considered to be cognitively demanding for undergraduate and polytechnic learners. This makes a strong case for teaching strategies that can make such abstract ideas concrete through simulation, hands-on tasks and applied problem-solving (Al-Fedaghi, 2021; Ceze et al., 2016).

2.2 Theoretical Framework

Constructivist learning theory, which is associated with Piaget (1970) and Vygotsky (1978), states that learners actively build knowledge and understanding through interaction with their environment instead of passively absorbing information given directly by the teacher. Piaget focused on the individual cognitive side of this process, whereby learners build mental structures by acting on and reflecting on experience, while Vygotsky focused on its social and cultural side, arguing that higher thinking develops through guided interaction with more capable peers or instructors within the learner's zone of proximal development. Challenge-Based Learning brings out both of these ideas: it makes students reason through a real problem on their own while also working with peers and receiving guidance from the instructor, so that learning becomes something that is socially guided and actively built, rather than something transmitted to the student.

Experiential learning theory, which was developed by Kolb (1984), builds on this constructivist foundation by describing learning as a cyclical process made up of concrete experience, reflective observation, abstract conceptualisation and active experimentation. Kolb's model suggests that learners who move through direct experience with a problem, reflect on it, form abstract principles, and then test the principles in a new situation, will develop deeper and more lasting understanding than learners who only meet the content in an abstract and decontextualised way. Challenge-Based Learning fits closely with this cycle as students meet a concrete, real-world challenge, discuss and analyse it with their peers, use Computer Architecture concepts to explain and model the problem and then design, test and improve a solution.

The conventional lecture method is better explained through cognitive load theory (Sweller, 1988, 2019), which states that working memory has limited capacity and learning is affected when instruction puts extra and unnecessary load on learners that is not related to the building of knowledge structures. Because the lecture method usually presents abstract Computer Architecture content, such as instruction cycles or memory hierarchies, without giving learners a concrete reference point, students must hold and process unfamiliar abstract material in working memory with very little support.

This can increase unnecessary cognitive load and reduce the depth of knowledge building, compared with approaches such as CBL that ground abstract content in a real challenge. Taken together, these three theories provide a good reason to expect that Challenge-Based Learning will produce stronger post-test performance than the conventional lecture method in a conceptually abstract subject such as Computer Architecture, while also explaining why the conventional method can still produce some meaningful learning gains when compared with a pre-test baseline.

2.3 Research Questions

The following research questions guided the study:

1. What is the mean score difference between the pre-test and post-test academic performance of students taught Computer Architecture using Challenge-Based Learning?
2. What is the mean score difference between the pre-test and post-test academic performance of students taught Computer Architecture using the conventional lecture method?
3. What is the mean score difference between the post-test academic performance of students taught using Challenge-Based Learning and those taught using the conventional lecture method?

2.4 Research Hypotheses

The following null hypotheses were formulated and tested at the 0.05 level of significance:

- HO1: There is no significant difference between the mean pre-test and post-test academic performance of students taught Computer Architecture using Challenge-Based Learning.
- HO2: There is no significant difference between the mean pre-test and post-test academic performance of students taught Computer Architecture using the conventional lecture method.
- HO3: There is no significant difference between the mean post-test academic performance of students taught Computer Architecture using Challenge-Based Learning and those taught using the conventional lecture method.

3 Methodology

3.1 Research Design

The study adopted a quasi-experimental, non-equivalent pre-test post-test control group design. This design was considered appropriate because random assignment of individual students to groups was not administratively feasible within intact polytechnic classes (Tang & Chow, 2020). The design involved two instructional groups: Group A (Challenge-Based Learning) and Group B (Conventional Lecture Method) both of which received instruction in Computer Architecture using their respective strategies over the same eight-week period.

3.2 Population and Sample

The population of the study comprised Computer Science and Computer Engineering students enrolled in Waziri Umaru Federal Polytechnic, Birnin Kebbi, Nigeria. A total of 45 students formed the study sample, drawn from two intact classes and assigned to the Challenge-Based Learning group (Group A) and the Conventional Lecture Method group (Group B), as shown in Table 1. The CBL group (Group A) is the same cohort of 20 Computer Engineering students whose results were reported in Zubairu and Bello (2026a, 2026b), where CBL was compared with Place-Based Learning; the present study reports a different comparison, between this CBL group and a conventional-lecture group.

Table 1

Sample Distribution for the Study

SN	Experimental Groups	Sample Size
1.	Group A-Challenge-Based Learning Group	20
2.	Group B-Conventional Lecture Method Group	25
	Total	45

3.3 Assignment of Groups and Ethical Considerations

The two intact classes were assigned to the instructional conditions by department. Computer Engineering students received Challenge-Based Learning (Group A), while Computer Science students received the conventional lecture method (Group B). Computer Engineering was assigned to CBL because its programme is hardware- and project-oriented, with regular laboratory and practical work, which made the team-based, applied challenges easier to organise for that class. Because individual students could not be randomly assigned, the pre-test was used to check the baseline equivalence of the two groups (see Table 7). The institution has no research ethics committee; permission to conduct the study was therefore obtained administratively, through a formal written request signed by the Registrar, who directed the Head of Department to provide the necessary support. Participation was voluntary. The purpose of the study was explained verbally to the students, who gave verbal informed consent before the pre-test, and they were assured that their scores would be treated confidentially and used for research purposes only.

3.4 Instrumentation

The instrument used for data collection was the Computer Architecture Achievement Test (CAAT) designed to measure students' academic performance in Computer Architecture. The instrument consisted of 30 multiple-choice items, each with four options (A–D) and a single correct answer. Test items were developed from the course curriculum and validated by subject-matter experts for content relevance, clarity and alignment with instructional objectives. The instrument was piloted to determine its reliability, which was established using Pearson's Product-Moment Correlation Coefficient (test–retest method) and yielded a test–retest reliability coefficient (coefficient of stability) of 0.86, which indicates high stability of scores over time. The same instrument was used in earlier studies with the CBL cohort (Zubairu & Bello, 2026a, 2026b).

3.5 Experimental Procedure

A pre-test was administered to both groups in the first week of the study to establish baseline knowledge of Computer Architecture. Thereafter, the experimental treatment was implemented over eight weeks: Group A received instruction structured around the Engage, Investigate and Act phases of Challenge-Based Learning, in which students worked in small teams to investigate and solve authentic, applied Computer Architecture problems (for example, tracing instruction execution through a simplified processor pipeline or diagnosing a memory-addressing scenario) together with the lecturer acting as facilitator, while Group B received instruction on the same syllabus content through the conventional lecture method, in which the lecturer delivered content through exposition, explanation and demonstration with limited student-led activity. At the end of the eight-week treatment period, a post-test was administered to both groups using the same instrument, with items reshuffled to minimise recall bias and preserve measurement validity. Both groups were taught by the same lecturer, which controlled for differences between instructors. In addition, both groups followed the same syllabus, scheme of work, contact hours, learning materials and achievement test, so that the instructional method was the main planned difference between them.

3.6 Method of Data Analysis

Data collected were analysed using both descriptive and inferential statistics. Mean and standard deviation were used to answer the research questions. A paired-sample t-test was used to determine the significance of the difference between

pre-test and post-test scores within each group (testing HO1 and HO2), while an independent-sample t-test was used to determine the difference between the post-test scores of the two groups (testing HO3). All hypotheses were tested at the 0.05 level of significance.

4 Results

4.1 Descriptive and Inferential Results for Group A (Challenge-Based Learning)

Table 2

Mean Scores of Pre-test and Post-test for Group A

SN	TEST	N	MEAN SCORE	SD	MEAN DIFFERENCE
1.	Pre-test	20	4.70	2.79	-32.55
2.	Post-test	20	37.25	9.80	

Table 2 shows that the mean score for Group A rose from 4.70 (SD = 2.79) at pre-test to 37.25 (SD = 9.80) at post-test, a mean gain of 32.55 points, indicating a substantial improvement in performance following exposure to Challenge-Based Learning.

Table 3

Paired-Sample t-Test of Pre-test and Post-test Scores for Group A

TEST	N	MEAN	SD	MEAN DIFFERENCE	95%CI	t	df	P
Pre-test	20	4.70	2.79	-32.55	-37.27 to -	-14.44	19	<.001*
Post-test	20	37.25	9.80		27.83			

**Significant at $p < .05$*

Table 3 shows a mean difference of -32.55 between pre-test and post-test scores for Group A, with a 95% confidence interval of -37.27 to -27.83. The calculated t-value of -14.44 (df = 19) yielded a p-value of less than .001, which is statistically significant at $p < .05$. HO1 is therefore rejected: there is a significant difference between the pre-test and post-test academic performance of students taught Computer Architecture using Challenge-Based Learning.

4.2 Descriptive and Inferential Results for Group B (Conventional Lecture Method)

Table 4

Mean Scores of Pre-test and Post-test for Group B

SN	TEST	N	MEAN SCORE	SD	MEAN DIFFERENCE
1.	Pre-test	25	4.12	2.93	-24.44
2.	Post-test	25	28.56	8.52	

Table 4 shows that the mean score for Group B rose from 4.12 (SD = 2.93) at pre-test to 28.56 (SD = 8.52) at post-test, a mean gain of 24.44 points, indicating a notable improvement in performance following exposure to the conventional lecture method.

Table 5

Paired-Sample t-Test of Pre-test and Post-test Scores for Group B

TEST	N	MEAN	SD	MEAN DIFFERENCE	95%CI	t	df	P
Pre-test	25	4.12	2.93	-24.44	-27.94 to -	-14.42	24	<.001*
Post-test								

Post-test	25	28.56	8.52	20.94
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*Significant at $p < .05$

Table 5 shows a mean difference of -24.44 between pre-test and post-test scores for Group B, with a 95% confidence interval of -27.94 to -20.94. The calculated t-value of -14.42 ($df = 24$) yielded a p-value of less than .001, which is statistically significant at $p < .05$. H_0 is therefore rejected: there is a significant difference between the pre-test and post-test academic performance of students taught Computer Architecture using the conventional lecture method.

4.3 Comparison of Post-test Performance between Group A and Group B

Table 6

Mean Difference of Post-test Scores of Group A and Group B

SN	TEST	N	MEAN SCORE	SD	MEAN DIFFERENCE
1.	Post-test (Group A)	20	37.25	9.80	8.69
2.	Post-test (Group B)	25	28.56	8.52	

Table 6 shows that Group A recorded a higher mean post-test score ($M = 37.25$, $SD = 9.80$) than Group B ($M = 28.56$, $SD = 8.52$), a mean difference of 8.69 points in favour of the Challenge-Based Learning group.

Table 7

Independent-Sample t-Test of Pre-test and Post-test Scores of Group A and Group B

TEST	Group	N	MEAN	SD	MEAN DIFFERENCE	95%CI	t	df	P
Pre-test	CBL	20	4.70	2.79	0.58	-1.16 to 2.32	0.67	43	.505
	Lecture	25	4.12	2.93					
Post-test	CBL	20	37.25	9.80	8.69	3.18 to 14.20	3.18	43	.003*
	Lecture	25	28.56	8.52					

*Significant at $p < .05$

Table 7 shows that, at pre-test, the mean difference between Group A ($M = 4.70$, $SD = 2.79$) and Group B ($M = 4.12$, $SD = 2.93$) was 0.58, with a 95% confidence interval of -1.16 to 2.32. The t-value of 0.67 ($df = 43$) yielded a p-value of .505, which is not statistically significant, suggesting that the two groups were comparable in baseline academic performance before treatment. At post-test, the mean difference between Group A ($M = 37.25$, $SD = 9.80$) and Group B ($M = 28.56$, $SD = 8.52$) was 8.69, with a 95% confidence interval of 3.18 to 14.20. The t-value of 3.18 ($df = 43$) yielded a p-value of .003, which is statistically significant at $p < .05$. H_0 is therefore rejected: there is a significant difference between the post-test academic performance of students taught Computer Architecture using Challenge-Based Learning and those taught using the conventional lecture method, in favour of the Challenge-Based Learning group.

5 Discussion of Findings

The findings of this study provide clear answers to the three research questions and support the rejection of all three null hypotheses. For Research Question 1 and H_{01} , students taught Computer Architecture using Challenge-Based Learning showed a large and statistically significant improvement from pre-test ($M = 4.70$) to post-test ($M = 37.25$). This finding aligns with the theoretical expectation, drawn from constructivist and experiential learning theory (Kolb, 1984; Vygotsky, 1978), that engaging students with authentic, real-world challenges promotes active construction of knowledge and deeper conceptual understanding than passive reception. It also corroborates prior empirical evidence that CBL produces substantial gains in engineering-related learning outcomes, including the large-scale comparison reported by Robledo-Rella et al. (2025) and the competency gains documented by Huesca et al. (2024) and Membrillo-Hernández et al. (2021).

Similarly, for Research Question 2 and HO2, students taught using the conventional lecture method also showed a statistically significant improvement from pre-test ($M = 4.12$) to post-test ($M = 28.56$). This result is unsurprising and is consistent with the well-established finding that direct instruction, when delivered systematically over a sustained period, does produce measurable learning gains relative to a low baseline (Freeman et al., 2014; Sweller, 2019). It confirms that the conventional lecture method is not without instructional value. Rather, both strategies were effective at moving students beyond their pre-treatment level of understanding, an outcome consistent with the pattern reported by Tang and Chow (2020), in which both the CBL and comparison groups improved significantly over time even though CBL produced the larger gain.

The most theoretically and practically important finding relates to Research Question 3 and HO3. Although the two groups were statistically equivalent at pre-test ($p = .505$), suggesting that the observed post-test difference is unlikely to be due to pre-existing differences in ability, Group A significantly outperformed Group B at post-test ($p = .003$), with a mean advantage of 8.69 points. This pattern indicates no significant difference at baseline, followed by a significant CBL advantage after treatment (Robledo-Rella et al., 2025; Tang & Chow, 2020). This provides supportive evidence that the observed advantage is related to the instructional strategy rather than to prior differences in achievement, although, as noted in the limitations, other differences between the intact groups cannot be excluded. This finding can be explained through the lens of cognitive load theory (Sweller, 1988, 2019): because Computer Architecture concepts such as instruction cycles, pipelining and memory addressing are highly abstract, the conventional lecture method may impose comparatively high extraneous cognitive load on learners who must process unfamiliar concepts with little concrete reference, whereas the CBL approach embeds the same content within a tangible challenge, which is likely to reduce extraneous load and free cognitive resources for schema construction. The finding is also consistent with the CBL literature's broader claim that the strategy's real advantage over conventional instruction becomes most visible on outcomes requiring integrated, applied understanding rather than isolated recall (Doulougeri et al., 2024; Membrillo-Hernández et al., 2019). This is precisely the kind of understanding a well-designed Computer Architecture achievement test would be expected to capture. The result also complements the earlier finding that this CBL group performed at the same level as a group taught with Place-Based Learning (Zubairu & Bello, 2026a); taken together, the two comparisons suggest that CBL is at least as effective as another learner-centred approach and more effective than lecture-based instruction.

Taken together, these findings suggest that Challenge-Based Learning is not simply an alternative to the conventional lecture method but a more effective one for teaching a conceptually abstract course such as Computer Architecture in tertiary institutions. This extends the existing CBL literature, which has been dominated by studies from Latin American, European and Asian institutions (Doulougeri et al., 2024; Huesca et al., 2024; Robledo-Rella et al., 2025). It also extends the active-learning literature in Nigerian higher institutions, which has concentrated on the flipped classroom in programming and mathematics related courses (Abdurrahman et al., 2023; Bello et al., 2024).

The findings should nonetheless be interpreted in light of the study's limitations. The sample was drawn from two intact classes at a single institution, and true random assignment of individual students to groups was not undertaken; this constraint is inherent to the quasi-experimental design and is shared with much of the similar literature (Robledo-Rella et al., 2025; Tang & Chow, 2020). The sample was also small ($N = 45$, unevenly split between 20 and 25 students) and no a priori power analysis was conducted. A sensitivity calculation indicates that groups of this size give 80% power ($\alpha = .05$, two-tailed) only for large standardised differences (Cohen's d of about 0.82 or more), so smaller true effects could have gone undetected and the size of the observed effect ($d \approx 0.95$) is likely to be imprecisely estimated. Because the groups were formed by department (Computer Engineering for CBL and Computer Science for the lecture method), the study cannot fully separate the effect of the teaching method from differences between the two programmes, such as students' interest in or prior exposure to hardware-related content, even though the pre-test scores were similar. In addition, although a single lecturer taught both groups, which removed between-instructor differences, the lecturer was aware of the two conditions, so possible expectancy effects cannot be ruled out. Future studies should use more institutions, randomly assign classes to conditions, and use different lecturers or blinded assessment. Taken together, these limitations restrict how far the findings can be generalised. In addition, the eight-week treatment period is relatively short, and the sustainability of the observed CBL advantage over a longer curriculum, as examined by Huesca et al. (2024), was not assessed in this study. Although a retention test given three weeks after the post-test showed no significant decline in the CBL group's scores (Zubairu & Bello, 2026b), no comparable data were collected for the lecture group, so the relative durability of the two approaches remains untested. Finally, the study measured academic performance using a single achievement test and did not assess the broader transversal competencies (such as collaboration, communication or self-directed learning) that the CBL literature suggests are also meaningfully affected by the approach.

6 Conclusion

This study set out to determine the effect of Challenge-Based Learning on the academic performance of Computer Science/Engineering students in the Computer Architecture course, relative to the conventional lecture method at a Nigerian polytechnic. The results showed that both instructional strategies produced statistically significant improvement in students' performance from pre-test to post-test, confirming that both approaches have instructional value. However, students taught using Challenge-Based Learning achieved significantly higher post-test scores than those taught using the conventional lecture method, despite the two groups being statistically equivalent at the outset of the study. This provides credible quasi-experimental evidence that Challenge-Based Learning is a more effective strategy than the conventional lecture method for teaching Computer Architecture and it lends empirical support to the view that authentic and hands-on engagement with real-world challenges promotes stronger learning of abstract technical content than transmission-based instruction alone. The study demonstrates that the approach can be feasibly implemented within the resource constraints typical of Nigerian polytechnic education.

7 Recommendations

Based on the findings and conclusion of this study, the following recommendations are made:

1. Computer Science/Engineering lecturers in polytechnics should adopt Challenge-Based Learning, particularly for topics in Computer Architecture that are abstract or procedural in nature, such as instruction execution, pipelining and memory hierarchy.
2. Where full replacement of lecture-based instruction is not immediately feasible, lecturers may adopt a blended approach that retains brief conventional exposition for foundational concepts while using Challenge-Based Learning for applied and integrative aspects of the course.
3. Polytechnic curriculum planners and academic boards should review Computer Engineering course delivery guidelines to explicitly accommodate learner-centred strategies such as Challenge-Based Learning, including the time, space, and small-group teaching support such strategies require.

References

- Abdurrahman, M. S., Abdullahi, F., & Bello, S. B. (2023). Effect of flipped classroom strategy among polytechnic students' academic performance in functions and geometry. *Bayero Journal of Education in Africa*, 9(1), 124–131.
- Al-Fedaghi, S. (2021). Conceptual modeling for computer organization and architecture. *Journal of Computer Science*, 17(2), 123–134. <https://doi.org/10.3844/jcssp.2021.123.134>
- Apple Inc. (2026). CBL: Framework overview – Apple Education Community. <https://education.apple.com/learning-center/>
- Bello, S. B., Zubairu, S. A., Nwoji, J. O., Samaila, K., & Attah, A. O. (2024). Effects of flipped classroom on students' academic achievement in computer programming in tertiary institutions, Kebbi State, Nigeria. *African Journal of Science, Technology and Mathematics Education (AJSTME)*, 10(6), 990–996.
- Bohm, N. L., Klaassen, R., Den Brok, P. J., & Van Bueren, E. M. (2020). Choosing challenges in challenge-based courses. *Proceedings SEFI 48th Annual Conference: Engaging Engineering Education*, 93–103.
- Ceze, L., Hill, M. D., & Wenisch, T. F. (2016). Arch2030: A vision of computer architecture research over the next 15 years. *Computing Community Consortium Catalyst*.
- Doulougeri, K., Vermunt, J. D., Bombaerts, G., & Bots, M. (2024). Challenge-based learning implementation in engineering education: A systematic literature review. *Journal of Engineering Education*, 113(3), 1076–1106. <https://doi.org/10.1002/jee.20588>
- Félix-Herrán, L. C., Izaguirre-Espinosa, C., Parra-Vega, V., & Sánchez-Orta, A. (2022). A challenge-based learning intensive course for competency development in undergraduate engineering students: Case study on UAVs. *Electronics*, 11, 1–25.

- Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences*, 111(23), 8410–8415. <https://doi.org/10.1073/pnas.1319030111>
- Gallagher, S. E., & Savage, T. (2020). Challenge-based learning in higher education: An exploratory literature review. *Teaching in Higher Education*, 1–23. <https://doi.org/10.1080/13562517.2020.1863354>
- Grimes, J. (2002). Computer architecture. In *Encyclopedia of physical science and technology* (3rd ed., Vol. 3). Academic Press.
- Huesca, G., Rodríguez-Rosales, A., Lara-Prieto, V., Ruiz-Cantisani, M. I., & Acevedo, J. (2024). Effectiveness of challenge-based learning in undergraduate engineering programs from competencies and gender perspectives. *Education Sciences*, 14(3), 255. <https://doi.org/10.3390/educsci14030255>
- Johnson, L. F., Smith, R. S., Smythe, J. T., & Varon, R. K. (2009). Challenge-based learning: An approach for our time. The New Media Consortium.
- Kolb, D. A. (1984). *Experiential learning: Experience as the source of learning and development*. Prentice-Hall.
- Martin, D. A., & Bombaerts, G. (2025). What is the structure of a challenge-based learning project? A shortitudinal trajectory analysis of student process behaviours in an interdisciplinary engineering course. *European Journal of Engineering Education*, 50(1), 51–81. <https://doi.org/10.1080/03043797.2024.2376222>
- Membrillo-Hernández, J., Ramírez-Cadena, M. J., Martínez-Acosta, M., Cruz-Gómez, E., & Elizalde, H. (2019). Challenge-based learning: The importance of world-leading companies as training partners. *International Journal on Interactive Design and Manufacturing (IJIDeM)*, 13, 1103–1113. <https://doi.org/10.1007/s12008-019-00569-4>
- Membrillo-Hernández, J., Ramírez-Cadena, M. de J., Ramírez-Medrano, A., García-Castelán, R. M. G., & García-García, R. (2021). Implementation of the challenge-based learning approach in academic engineering programs. *International Journal on Interactive Design and Manufacturing (IJIDeM)*, 15, 287–298. <https://doi.org/10.1007/s12008-021-00755-3>
- Piaget, J. (1970). *Genetic epistemology*. Columbia University Press.
- Robledo-Rella, V., Neri, L., García-Castelán, R. M. G., Gonzalez-Nucamendi, A., Valverde-Rebaza, J., & Noguez, J. (2025). A comparative study of a new challenge-based learning model for engineering majors. *Frontiers in Education*, 10, Article 1545071. <https://doi.org/10.3389/feduc.2025.1545071>
- Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science*, 12(2), 257–285. https://doi.org/10.1207/s15516709cog1202_4
- Sweller, J. (2019). Cognitive load theory and educational technology. *Educational Technology Research and Development*, 68, 1–16. <https://doi.org/10.1007/s11423-019-09701-3>
- Tang, A. C. Y., & Chow, M. C. M. (2020). To evaluate the effect of challenge-based learning on the approaches to learning of Chinese nursing students: A quasi-experimental study. *Nurse Education Today*, 85, Article 104293. <https://doi.org/10.1016/j.nedt.2019.104293>
- Van den Beemt, A., Van De Watering, G., & Bots, M. (2023). Conceptualising variety in challenge-based learning in higher education: The CBL-compass. *European Journal of Engineering Education*, 48(1), 24–41. <https://doi.org/10.1080/03043797.2022.2078181>
- Van den Beemt, A., Van De Watering, G., Sonia, G., O'Riordan, F., Gormley, C., Chiang, F., Caratozzolo, P., Zavala, G., & Membrillo-Hernández, J. (2023). Taking the challenge: An exploratory study of the challenge-based learning context in higher education institutions across three different continents. *Education Sciences*, 13, Article 1054.
- Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Harvard University Press.
- Zubairu, S. A., & Bello, S. B. (2026a). Comparative effects of challenge-based learning and place-based learning on academic performance in computer architecture among computer engineering students. *Journal of Education, Communication, and Digital Humanities*, 4(2), 243–256. <https://doi.org/10.5281/zenodo.21613084>

Zubairu, S. A., & Bello, S. B. (2026b). Effects of challenge-based learning and place-based learning on polytechnic computer engineering students' retention in computer architecture. *International Journal of Applied Research and Sustainable Sciences*, 4(6), 631–642. <https://doi.org/10.59890/ijarss.v4i6.36>.

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