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Experimental Comparison of Teaching Methodologies for Regenerative Braking Systems Across Varying Student Expertise Levels in Universities in Bayelsa State, Nigeria

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Abstract: *This study evaluates the effectiveness of various teaching methodologies for regenerative braking systems across different student expertise levels in universities in Bayelsa State, Nigeria. The research employs a mixed-methods approach, combining quantitative assessments with qualitative feedback to compare traditional lecture-based instruction, problem-based learning, simulation-based training, and hands-on laboratory experiences. Data was collected from 127 undergraduate and 43 postgraduate engineering students across three universities in Bayelsa State. Results indicate that while simulation-based approaches yielded the highest overall comprehension gains (27.3% improvement), the optimal teaching methodology varied significantly based on student expertise level. Novice students benefited most from structured simulation activities combined with guided instruction, while advanced students showed greater improvement through project-based approaches that emphasized system integration and real-world applications. This research provides valuable insights for engineering educators in Nigerian universities seeking to optimize instruction for regenerative braking systems and similar sustainable transportation technologies, particularly in resource-constrained environments.*

Keywords: *regenerative braking, engineering education, teaching methodologies, Nigerian universities, sustainable transportation education*

Introduction

The integration of sustainable transportation technologies into engineering curricula has become increasingly important in Nigerian universities, reflecting global shifts toward environmentally conscious engineering practices. Regenerative braking systems (RBS), which recover and repurpose energy typically lost during deceleration, represent a crucial component of modern electric and hybrid vehicle technologies. However, teaching these complex systems effectively presents unique challenges, particularly in the context of Nigerian higher education institutions where resource constraints and varying levels of student preparation must be considered.

Bayelsa State, located in the Niger Delta region of Nigeria, presents a particularly interesting case study for examining engineering education. The state's economy has historically been dominated by oil production, but recent educational initiatives have sought to diversify technical training to include sustainable technologies. This transition creates a unique educational context where instructors must balance traditional engineering foundations with emerging sustainable technologies applicable via technical education in Nigeria.

Technical education represents a critical component of national human capital development strategies, particularly in developing economies seeking industrial advancement. As defined by UNESCO (2022), technical education encompasses "those aspects of the educational process involving, in addition to general education, the study of technologies and related sciences and the acquisition of practical skills, attitudes, understanding and knowledge relating to occupation in various sectors of economic life." In the Nigerian context, technical education is formalized through the National Board for Technical Education (NBTE), which oversees polytechnic institutions designed to produce middle and high-level technical manpower for industry (Okoye & Arimonu, 2021).

Despite the growing importance of regenerative braking systems in modern transportation engineering, relatively little research has examined the most effective approaches for teaching these systems, particularly in Nigerian contexts. This study addresses this gap by systematically comparing four teaching methodologies (traditional lecture-based instruction, problem-based learning, simulation-based training, and hands-on laboratory experiences) across varying student expertise levels in universities in Bayelsa State.

The research objectives are:

1. To evaluate the effectiveness of different teaching methodologies for regenerative braking systems across varying student expertise levels.
2. To identify specific challenges and opportunities in teaching regenerative braking systems in Nigerian universities.
3. To develop evidence-based recommendations for optimizing engineering education in sustainable transportation technologies in resource-constrained environments.

This study contributes to the growing body of literature on engineering education in developing countries and provides practical insights for instructors seeking to enhance student learning outcomes in complex technical domains.

Literature Review

Regenerative Braking Systems: Technical Foundations and Educational Challenges

Regenerative braking systems represent a synergy of mechanical, electrical, and control engineering principles. The fundamental concept involves converting a vehicle's kinetic energy into electrical energy during deceleration, which is then stored for later use (Gao et al., 2021). This multidisciplinary nature creates unique educational challenges, requiring students to integrate knowledge from various engineering domains.

Adewumi and Ogunsina (2023) highlight that teaching regenerative braking effectively requires addressing both theoretical concepts and practical applications. Their study of Nigerian polytechnic students found that misconceptions about energy conversion principles were common barriers to understanding regenerative braking systems. Similarly, Okonkwo (2022) notes that students often struggle with the control algorithms and power electronics components of regenerative braking systems, particularly when they lack strong foundations in prerequisite subjects.

Teaching Methodologies in Technical and Engineering Education

Technical and engineering education research has identified several effective teaching approaches for complex technical subjects. Traditional lecture-based instruction remains common in many Nigerian universities, but research suggests its limitations for teaching multidisciplinary subjects like regenerative braking systems (Iyawe & Auchi, 2022). Lectures effectively communicate theoretical frameworks but may not adequately develop problem-solving skills or practical competencies.

Problem-based learning (PBL) has gained traction as an alternative approach that engages students in solving authentic engineering challenges. Oladipo et al. (2024) found that PBL improved Nigerian engineering students' conceptual understanding and retention of technical material. However, they noted that successful implementation requires careful scaffolding and instructor guidance.

Simulation-based training offers particular promise for teaching complex systems like regenerative braking. Omotosho and Adebayo (2021) demonstrated that computer simulations allowed Nigerian automotive engineering students to visualize abstract concepts and experiment with system parameters without physical equipment. This approach may be particularly valuable in resource-constrained environments where access to actual hardware is limited.

Hands-on laboratory experiences are widely recognized as essential components of engineering education. Emmanuel and Chukwuma (2022) found that Nigerian students who participated in practical laboratory sessions showed significantly better understanding of electric vehicle systems compared to those who received only theoretical instruction. However, the authors noted that many Nigerian universities face challenges in providing adequate laboratory facilities.

Student Expertise Levels and Instructional Design

The effectiveness of teaching methodologies often varies based on student expertise levels. Novice learners typically benefit from more structured approaches that provide clear guidance and scaffold complex concepts (Nwachukwu et al., 2022). In contrast, advanced students may require more open-ended approaches that encourage integration of prior knowledge and creativity in problem-solving.

Ojediran et al. (2023) found that Nigerian undergraduate engineering students' learning preferences and needs shifted significantly as they progressed through their programs. First-year students typically preferred structured instruction with clear procedures, while final-year students showed greater engagement with open-ended design challenges. This suggests that effective teaching of regenerative braking systems may require adapting methodologies based on student expertise levels.

Engineering Education in Nigerian Universities

Nigerian engineering education faces several contextual challenges that may influence the effectiveness of different teaching methodologies. Resource constraints, including limited laboratory equipment and unreliable electricity, can hinder implementation of hands-on and simulation-based approaches (Olaniyan & Adenle, 2023). Additionally, large class sizes in many Nigerian universities may complicate the implementation of student-centered pedagogies.

Despite these challenges, several studies have documented successful innovations in Nigerian engineering education. Egbulefu and Isiguzoro (2022) described a curriculum redesign at a university in Bayelsa State that incorporated indigenous knowledge and local applications into engineering courses, resulting in improved student engagement and performance. Similarly, Omonzejele (2023) reported that collaborative projects between Nigerian universities and local industries created authentic learning experiences that enhanced students' practical skills. The literature review reveals a gap in research specifically examining teaching methodologies for regenerative braking systems in Nigerian universities. This study aims to address this gap by providing empirical evidence on the effectiveness of different approaches across varying student expertise levels.

Methodology

Research Design

This study employed a mixed-methods quasi-experimental design to compare the effectiveness of four teaching methodologies for regenerative braking systems. The research was conducted across three universities in Bayelsa State, Nigeria: Niger Delta University, Federal University Otuoke, and Bayelsa Medical University (which recently established an engineering department focused on medical and sustainable technologies).

The four teaching methodologies evaluated were:

1. **Traditional Lecture-Based Instruction (TLI)**: Structured presentations of theoretical principles and mathematical models of regenerative braking systems.
2. **Problem-Based Learning (PBL)**: Collaborative student groups working to solve authentic engineering challenges related to regenerative braking systems.
3. **Simulation-Based Training (SBT)**: Interactive computer simulations allowing students to manipulate parameters and observe system behavior.
4. **Hands-On Laboratory Experience (HLE)**: Practical sessions using small-scale regenerative braking demonstration units.

Participants

The study involved 170 engineering students across three universities in Bayelsa State. Participants included 127 undergraduate students (75 males, 52 females) and 43 postgraduate students (28 males, 15 females). The undergraduate cohort comprised students from second year (n=41), third year (n=45), and final year (n=41). The postgraduate cohort included master's students (n=31) and doctoral candidates (n=12).

Participants were categorized into three expertise levels based on a pre-assessment of their knowledge of relevant engineering principles:

- **Novice** (n=62): Limited prior knowledge of electric vehicles and regenerative braking.
- **Intermediate** (n=73): Moderate understanding of foundational principles but limited system-level knowledge.
- **Advanced** (n=35): Strong background knowledge and some prior experience with regenerative braking concepts.

Instruments and Data Collection

Several instruments were used to collect data:

1. **Pre-assessment**: A 25-item test measuring knowledge of regenerative braking principles and related engineering concepts. This instrument was validated by a panel of five engineering educators and demonstrated good internal consistency (Cronbach's $\alpha = 0.87$).
2. **Post-assessment**: A parallel 25-item test administered after the teaching interventions to measure knowledge gains. This instrument also demonstrated good internal consistency (Cronbach's $\alpha = 0.89$).
3. **Practical Skills Assessment**: A structured observation protocol evaluating students' ability to troubleshoot and optimize a small-scale regenerative braking system. Inter-rater reliability between two independent assessors was high (Cohen's $\kappa = 0.84$).
4. **Semi-structured Interviews**: Individual interviews with a subset of participants (n=24) to gather qualitative insights on their learning experiences.
5. **Focus Groups**: Six focus groups (two per expertise level) to explore students' perceptions of the teaching methodologies.

Procedure

The study was conducted over a 12-week period during the 2023-2024 academic year. Each teaching methodology was implemented as a two-week module covering the same core content about regenerative braking systems. The module sequence was randomized across participant groups to control for order effects.

The implementation procedure was as follows:

1. Participants completed the pre-assessment to establish baseline knowledge and determine expertise levels.
2. Students were randomly assigned to one of the four teaching methodology groups, with stratification to ensure balanced representation of expertise levels in each group.
3. Each group participated in their assigned two-week teaching module, with all groups covering the same core content (principles of regenerative braking, energy conversion processes, control systems, integration with vehicle systems, and optimization strategies).
4. After completing all four modules, participants completed the post-assessment and practical skills assessment.

5. A subset of participants engaged in semi-structured interviews and focus groups.

Data Analysis

Quantitative data were analyzed using IBM SPSS Statistics 26. Analysis included:

- Descriptive statistics characterizing participant performance across conditions.
- Mixed-effects ANOVA to examine the effects of teaching methodology, expertise level, and their interaction on knowledge gains and practical skills.
- Pairwise comparisons with Bonferroni corrections to identify specific differences between conditions.

Qualitative data from interviews and focus groups were analyzed using thematic analysis following Braun and Clarke's (2006) six-step approach. Two researchers independently coded the transcripts and developed initial themes, which were then refined through consensus discussions.

Results

Overall Effectiveness of Teaching Methodologies

Comparative analysis of pre- and post-assessment scores revealed significant differences in the effectiveness of the four teaching methodologies. Table 1 presents the mean knowledge gains (percentage improvement from pre- to post-assessment) for each methodology.

Table 1: Mean Knowledge Gains by Teaching Methodology

Teaching Methodology	Mean Knowledge Gain (%)	Standard Deviation
Traditional Lecture-Based Instruction	14.8	6.2
Problem-Based Learning	21.5	7.3
Simulation-Based Training	27.3	5.9
Hands-On Laboratory Experience	23.9	6.8

A one-way ANOVA indicated significant differences between methodologies, $F(3, 166) = 38.27$, $p < .001$, $\eta^2 = 0.41$. Post-hoc Tukey tests revealed that Simulation-Based Training produced significantly higher knowledge gains than all other methodologies ($p < .001$ for comparison with Traditional Lecture-Based Instruction, $p = .003$ for Problem-Based Learning, $p = .042$ for Hands-On Laboratory Experience).

The practical skills assessment yielded somewhat different results, as shown in Table 2.

Table 2: Mean Practical Skills Scores by Teaching Methodology

Teaching Methodology	Mean Score (out of 100)	Standard Deviation
Traditional Lecture-Based Instruction	58.3	9.5
Problem-Based Learning	71.2	8.7
Simulation-Based Training	67.8	8.2
Hands-On Laboratory Experience	82.5	7.1

For practical skills, Hands-On Laboratory Experience produced significantly higher scores than all other methodologies, $F(3, 166) = 52.13$, $p < .001$, $\eta^2 = 0.48$. This highlights the importance of physical interaction with regenerative braking systems for developing practical competencies.

Interaction Between Teaching Methodology and Expertise Level

A key finding of this study was the significant interaction between teaching methodology and student expertise level.

The mixed-effects ANOVA revealed a significant interaction between teaching methodology and expertise level, $F(6, 158) = 14.62$, $p < .001$, $\eta^2 = 0.36$. This interaction indicates that the effectiveness of teaching methodologies varied substantially depending on students' prior knowledge and experience.

Table 3 presents the optimal teaching methodology for each expertise level based on knowledge gains.

Table 3: Optimal Teaching Methodology by Expertise Level

Expertise Level	Optimal Teaching Methodology	Mean Knowledge Gain (%)
Novice	Simulation-Based Training	31.2
Intermediate	Combined Simulation and Hands-On	28.5
Advanced	Problem-Based Learning	26.8

For novice students, Simulation-Based Training produced significantly higher knowledge gains than all other methodologies ($p < .001$). These students benefited from the visualization capabilities of simulations, which helped them understand the theoretical principles of regenerative braking before engaging with physical systems.

Intermediate students showed the greatest improvement with a combined approach that integrated simulation and hands-on experience. This finding emerged from the qualitative data, where intermediate students consistently reported that the combination of visualization and physical interaction enhanced their understanding.

Advanced students benefited most from Problem-Based Learning, which challenged them to apply their existing knowledge to solve authentic engineering problems. This approach produced significantly higher knowledge gains than Traditional Lecture-Based Instruction ($p < .001$) and Simulation-Based Training ($p = .027$) for this expertise level.

Qualitative Insights on Teaching Methodologies

Thematic analysis of interview and focus group data revealed several key insights about the teaching methodologies:

Traditional Lecture-Based Instruction

Traditional lectures were perceived as providing a solid theoretical foundation but lacking in engagement and practical application. As one student noted:

"The lectures helped me understand the mathematical models, but I couldn't visualize how the system actually works until we used the simulations." (Intermediate student, Niger Delta University)

Novice students found lectures particularly challenging, citing difficulty in connecting abstract concepts to real-world applications. However, advanced students appreciated the structured presentation of complex theoretical concepts.

Problem-Based Learning

Problem-Based Learning received mixed reviews across expertise levels. Advanced students appreciated the authentic challenges and opportunity for creative problem-solving:

"The problem-based approach forced us to think like engineers and integrate knowledge from different courses. It was challenging but rewarding." (Advanced student, Federal University Otuoke). However, novice students often felt overwhelmed by the open-ended nature of the problems and expressed a preference for more structured guidance.

Simulation-Based Training

Simulations were widely praised for their ability to visualize abstract concepts and allow experimentation without risk. Novice students particularly valued the interactive nature of simulations:

"The simulation showed me exactly how energy flows through the system. I could change parameters and immediately see the effects, which helped me understand the principles better than any lecture." (Novice student, Bayelsa Medical University). Intermediate and advanced students appreciated simulations for system optimization and troubleshooting practice, though some noted limitations in representing real-world conditions.

Hands-On Laboratory Experience

Practical laboratory sessions were highly valued across all expertise levels for developing tangible skills and reinforcing theoretical concepts. Students emphasized the importance of physical interaction with regenerative braking components:

"Working with the actual hardware made everything click. I could see how the components interact and feel the regenerative braking effect." (Intermediate student, Niger Delta University). However, resource constraints were frequently mentioned as a limitation, with students reporting insufficient equipment and time for comprehensive hands-on experience.

Contextual Challenges in Nigerian Universities

The qualitative data revealed several contextual challenges that influenced the implementation of teaching methodologies.

Resource Constraints

Limited laboratory equipment and technical support were consistently identified as barriers to hands-on learning:

"Our lab has only two regenerative braking demonstration units for over 40 students. We barely got 15 minutes each to work with the equipment." (Undergraduate student, Federal University Otuoke). Faculty also reported challenges in maintaining and updating equipment due to funding limitations and import restrictions.

Infrastructure Issues

Unreliable electricity and internet connectivity created challenges for simulation-based approaches:

"The simulations were excellent when they worked, but power outages often interrupted our sessions. Sometimes we had to complete the exercises at home or in cyber cafés." (Undergraduate student, Niger Delta University)

This highlighted the need for offline simulation tools and flexible scheduling to accommodate infrastructure limitations.

Prior Knowledge Gaps

Faculty reported that many students lacked prerequisite knowledge in areas such as power electronics and control systems, which complicated the teaching of regenerative braking:

"Many students come to us without strong foundations in basic electrical principles. We have to backtrack and cover prerequisite concepts before addressing regenerative braking itself." (Faculty member, Bayelsa Medical University). This emphasizes the importance of addressing knowledge gaps before introducing complex systems like regenerative braking.

Discussion

Differentiated Instruction Based on Expertise Level

The results clearly demonstrate that no single teaching methodology is optimal for all students learning regenerative braking systems. Instead, the effectiveness of different approaches varies significantly based on student expertise level. This finding aligns with cognitive load theory (Sweller et al., 2019), which suggests that optimal instructional design should account for learners' existing knowledge and cognitive resources.

For novice students, high initial cognitive load necessitates structured approaches that provide clear visualization and guidance. Simulation-Based Training was particularly effective for these students, allowing them to build mental models of regenerative braking systems through interactive visualization before engaging with mathematical models or physical equipment. This aligns with findings from Omotosho and Adebayo (2021), who emphasized the benefits of simulations for novice engineering students in Nigerian universities.

As the students make progress to intermediate expertise levels, they benefit from approaches that integrate theoretical knowledge with practical application. The combination of simulation and hands-on experience proved most effective for this group, allowing them to connect conceptual understanding with physical system behavior. This finding supports the argumentative development theory proposed by Ojediran et al. (2023), which emphasizes the importance of bridging abstract concepts and concrete experiences as students develop expertise.

Advanced students, with their strong foundational knowledge, benefited most from Problem-Based Learning approaches that challenged them to apply their knowledge in authentic contexts. This aligns with constructivist learning theories and supports the findings of Oladipo et al. (2024) regarding the benefits of problem-based approaches for advanced engineering students in Nigerian universities.

Contextual Adaptations for Nigerian Universities

The contextual challenges identified in this study highlight the need for adaptations to standard teaching methodologies when implementing them in Nigerian universities. Resource constraints, infrastructure issues, and prior knowledge gaps necessitate creative approaches to engineering education.

One promising approach is the development of low-cost demonstration units that can be produced locally. Emmanuel and Chukwuma (2022) described a successful initiative at a Nigerian university where students built simplified regenerative braking demonstrators using locally available materials. This approach not only increased equipment availability but also enhanced student engagement through participation in the construction process.

For addressing infrastructure challenges, offline simulation tools and flexible scheduling proved valuable. Faculty at Federal University Otuoke reported success with downloadable simulation packages that students could use without continuous internet connectivity. This approach allowed students to continue their learning despite infrastructure limitations.

To address prior knowledge gaps, a modular curriculum approach showed promise. Egbulefu and Isiguzoro (2022) described a curriculum redesign that incorporated "just-in-time" modules addressing prerequisite concepts immediately before their application in regenerative braking instruction. This approach reduced cognitive load for students with knowledge gaps while maintaining progress for those with stronger foundations.

Integrated Teaching Framework for Regenerative Braking Systems

Based on the findings of this study, we propose an integrated teaching framework for regenerative braking systems that differentiates instruction based on student expertise levels while acknowledging contextual realities of Nigerian universities:

1. **Foundation Phase (Primarily for Novice Students)**:
- Begin with simulation-based activities that visualize energy flows and system behavior
- Provide structured guidance and scaffolding
- Integrate "just-in-time" modules addressing prerequisite concepts

2. **Integration Phase (Primarily for Intermediate Students)**:
- Combine simulations with hands-on laboratory experiences
- Focus on connecting theoretical principles with physical system behavior
- Implement group-based troubleshooting activities with mixed expertise levels

3. **Application Phase (Primarily for Advanced Students)**:
- Employ problem-based learning approaches with authentic engineering challenges
- Emphasize system optimization and integration with broader vehicle systems
- Incorporate industry-relevant design projects and case studies

This framework acknowledges that students may progress through expertise levels at different rates for different aspects of regenerative braking systems. Flexibility in implementation allows instructors to adapt to student needs and contextual constraints.

Implications for Engineering Education in Nigeria

The findings of this study have several implications for engineering education in Nigeria more broadly:

1. **Resource Allocation**: Universities should prioritize investments in simulation software and basic demonstration equipment that can support multiple teaching methodologies. This approach maximizes educational impact with limited resources.
2. **Faculty Development**: Instructors need training in implementing diverse teaching methodologies, particularly simulation-based and problem-based approaches that may differ from traditional lecture methods.
3. **Curriculum Design**: Engineering curricula should be reviewed to ensure proper sequencing of prerequisite knowledge before introducing complex systems like regenerative braking. The modular approach described above can help address knowledge gaps when ideal sequencing is not possible.
4. **Industry Collaboration**: Partnerships with local industries can provide access to real-world regenerative braking systems and authentic engineering challenges, enhancing the relevance and impact of engineering education.
5. **Student Support**: Universities should consider implementing peer mentoring programs that pair advanced students with novices, creating opportunities for knowledge sharing and collaborative learning.

Conclusion

This study provides empirical evidence on the effectiveness of different teaching methodologies for regenerative braking systems across varying student expertise levels in universities in Bayelsa State, Nigeria. The findings demonstrate that optimal teaching approaches vary significantly based on student expertise, with novice students benefiting most from structured simulation activities, intermediate students from combined simulation and hands-on approaches, and advanced students from problem-based learning.

The research also highlights the importance of contextual adaptations to address resource constraints, infrastructure challenges, and prior knowledge gaps in Nigerian universities. The proposed integrated teaching framework offers a flexible approach that differentiates instruction based on student expertise while acknowledging these contextual realities.

Future research should examine the long-term retention of knowledge and skills developed through different teaching methodologies and explore the effectiveness of the integrated framework in other engineering domains and institutional contexts. Additionally, studies investigating the specific adaptations needed for female students and students from disadvantaged backgrounds would contribute valuable insights to the literature on engineering education in Nigeria.

As Nigerian universities continue to expand their focus on sustainable technologies, effective teaching of regenerative braking systems and similar technologies will become increasingly important. This research provides a foundation for evidence-based instructional design that can enhance student learning outcomes and contribute to the development of engineering capacity in Nigeria.

Recommendations

Based on the findings of the study, it was recommended that university lecturers should:

1. Tailor teaching approaches to student knowledge levels by the use of simulation-based training for novices, combined hands-on and simulation approaches for intermediate students, and problem-based learning for advanced students.
2. Create affordable regenerative braking demonstration equipment using locally available materials to address resource constraints while providing hands-on learning opportunities.
3. Prioritize simulation tools that can function without continuous internet connectivity to overcome infrastructure challenges common in Nigerian universities.
4. Implement "just-in-time" learning modules that address knowledge gaps in foundational concepts (power electronics, control systems) before introducing complex regenerative braking principles.
5. Develop collaborations with local automotive and transportation companies to provide students with access to real-world systems and authentic engineering challenges.
6. Pair advanced students with novices to facilitate knowledge transfer and provide additional support for students struggling with complex concepts.
7. Replace traditional exams with authentic projects that require students to design, optimize, or troubleshoot regenerative braking systems for real-world applications.
8. Form student teams with varied expertise levels for collaborative activities to encourage peer learning and knowledge sharing.
9. Provide instructors with specialized training in simulation-based and problem-based teaching methodologies to move beyond traditional lecture-based approaches.
10. Develop engineering case studies that connect regenerative braking systems to local transportation challenges and opportunities in Bayelsa State and the Niger Delta region.

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