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Concept scaffolding in problem-based learning: Enhancing conceptual understanding of circular motion in a first-year physics module for engineering students

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ABSTRACT

First-year engineering students struggle to connect abstract physics concepts to real-world applications in complex topics such as circular motion and banking curves. Traditional lecture-based instruction often does not develop the deep conceptual understanding and problem-solving skills required for engineering tasks. This study examines the integration of concept scaffolding within a problem-based learning (PBL) framework to enhance students' understanding and application of circular motion principles in a first-year physics module. The intervention involved an engineering design problem in which students calculated optimal banking angles for a highway exit ramp with minimal reliance on friction. To support students, a range of scaffolding strategies was embedded in the learning process. These included guided inquiry worksheets, dynamic simulations for visualising force vectors, structured peer collaboration, and continuous formative feedback in constructing and interpreting free-body diagrams, and critically evaluating their design decisions. A mixed-methods research approach was employed. Quantitative data from pre- and post-assessments of 60 students indicated a statistically significant improvement in conceptual understanding and problem-solving ability, with scores increasing from 42.3% (SD = 10.4) to 76.8% (SD = 9.1); a paired-sample t-test confirmed this gain ($t(59) = 21.5$, $p < 0.001$). Qualitative data from student reflections revealed greater engagement, improved confidence, and clearer articulation of design rationales. The findings highlight the value of structured scaffolding within PBL environments in fostering both conceptual mastery and the transfer of theoretical knowledge to applied contexts. This approach offers a scalable and effective strategy for improving learning outcomes in foundational STEM education, especially engineering-focused physics instruction.

Keywords: Concept Scaffolding, Problem-Based Learning, Guided Inquiry Worksheets

INTRODUCTION

The challenge of enabling students to bridge the gap between abstract theoretical constructs and their application to real-world problems has always been a grappling problem for Physics education. This is clearly evident in first-year engineering courses, where topics such as circular motion, centripetal force, and banking curves demand both mathematical accuracy and contextual reasoning. Studies have consistently shown that students often acquire procedural knowledge of equations without attaining a

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deep conceptual understanding of their physical meaning or relevance.[1] The difficulties of translating classroom learning to authentic engineering tasks ultimately undermine academic performance and professional preparedness. These challenges in the South African context are compounded by diverse educational backgrounds and varying levels of preparedness among first-year cohorts, highlighting the need for targeted pedagogical interventions.[2]

Even though traditional lecture-based methods are efficient in content delivery, they frequently fail to engage students in higher-order thinking and application. International scholarship has demonstrated that these approaches promote surface learning, in which students focus on memorization rather than conceptual integration.[3] Constructivist approaches such as problem-based learning (PBL) have gained traction in physics education, addressing the above stated problem. PBL situates learning within authentic, real-world problems, fostering active engagement, collaboration, and deeper knowledge construction.[4] In the South African higher education sector, student-centred pedagogies, including PBL and related active learning approaches, are increasingly promoted to improve retention, engagement, and graduate readiness.[5] However, evidence suggests that without adequate scaffolding, students, particularly those new to the discipline, may experience cognitive overload, limiting the effectiveness of PBL.[6]

Concept scaffolding provides a promising solution to this challenge. Scaffolding entails the intentional structuring of tasks, tools, and support mechanisms that guide learners through progressively complex levels of understanding until they can operate independently.[7] Recent research in STEM education emphasises the importance of scaffolding in helping students navigate threshold concepts, such as force and motion, which serve as critical gateways to disciplinary competence.[8] Studies have shown internationally that scaffolding strategies such as guided inquiry with simulations, interactive visual simulations (e.g., PhET), and structured peer collaboration can significantly improve students' problem-solving performance, confidence in applying physics concepts, and scientific inquiry self-efficacy.[9]

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[1] Jennifer L Docktor and José P Mestre, "Synthesis of Discipline-Based Education Research in Physics," *Physical Review Special Topics-Physics Education Research* 10, no. 2 (2014): 020119; P. B. Kohl and E. A. Vincent, "Developing Mathematical Thinking in Physics: Insights from Introductory-Level Mathematics and Physics Courses," *Physical Review Physics Education Research* 14, no. 2 (2018): 020120..

[2] Kohl and Vincent, "Developing Mathematical Thinking in Physics: Insights from Introductory-Level Mathematics and Physics Courses"; Felix Maringe and Nevensha Sing, "Teaching Large Classes in an Increasingly Internationalising Higher Education Environment: Pedagogical, Quality and Equity Issues," *Higher Education* 67, no. 6 (2014): 761–82; J. Jawitz, "New Academics in South Africa: Entering the Teaching–Research Nexus," *Higher Education* 71, no. 4 (2016): 557–73.

[3] Michelene T H Chi and Ruth Wylie, "The ICAP Framework: Linking Cognitive Engagement to Active Learning Outcomes," *Educational Psychologist* 49, no. 4 (2014): 219–43.

[4] Cindy E. Hmelo-Silver, "Problem-Based Learning: What and How Do Students Learn?," *Educational Psychology Review* 16, no. 3 (September 2004): 235–66, https://doi.org/10.1023/B:EDPR.0000034022.16470.f3; Aman Yadav et al., "Case-based Instruction: Improving Students' Conceptual Understanding through Cases in a Mechanical Engineering Course," *Journal of Research in Science Teaching* 51, no. 5 (2014): 659–77.

[5] Danie de Klerk et al., *Reimagining South African Higher Education: Towards a Student-Centred Learning and Teaching Future* (African Sun Media, 2024).

[6] Paul A Kirschner et al., "Why Minimal Guidance during Instruction Does Not Work: An Analysis of the Failure of Constructivist," *Based Teaching Work: An Analysis of the Failure of Constructivist, Discovery, Problem-Based, Experiential, and Inquiry-Based Teaching,(November 2014)*, 2010, 37–41; J. Van de Pol, N. Mercer, and M. Volman, "Scaffolding Student Talk: Teachers' Concurrent Use of Instructional Scaffolding Strategies in Whole-Class Discussions," *Learning and Instruction* 60 (2019): 1–11.

[7] David Wood, Jerome S Bruner, and Gail Ross, "The Role of Tutoring in Problem Solving," *Journal of Child Psychology and Psychiatry* 17, no. 2 (1976): 89–100.

[8] Jan H F Meyer and Ray Land, "Threshold Concepts and Troublesome Knowledge: An Introduction," in *Overcoming Barriers to Student Understanding* (Routledge, 2006), 3–18.

[9] Siti Jamiatul Husnaini and Sufen Chen, "Effects of Guided Inquiry Virtual and Physical Laboratories on Conceptual Understanding, Inquiry Performance, Scientific Inquiry Self-Efficacy, and Enjoyment," *Physical Review Physics Education Research* 15, no. 1 (March 25, 2019): 010119, https://doi.org/10.1103/PhysRevPhysEducRes.15.010119; Fernando Espinoza, "Impact of Guided Inquiry with Simulations on Knowledge of Electricity and Wave Phenomena," *ArXiv Preprint ArXiv:2012.05826*, 2020; Herbert James Banda and Joseph Nzabahimana, "Effect of Integrating Physics Education Technology Simulations on Students' Conceptual Understanding in Physics: A Review of Literature," *Physical Review Physics Education Research* 17, no. 2 (December 21, 2021): 023108, https://doi.org/10.1103/PhysRevPhysEducRes.17.023108; Mary Jane Brundage, Alysa Malespina, and Chandralekha Singh, "Peer Interaction Facilitates Co-Construction of Knowledge in Quantum Mechanics," *Physical Review Physics Education Research* 19, no. 2 (2023): 020133.

In South African higher education, student-centred and inclusive pedagogical approaches are increasingly recognized as essential for addressing learning inequities, fostering epistemological access, and supporting student success in STEM fields.[10]

This study explores the integration of concept scaffolding within a PBL framework to improve first-year engineering students' understanding of circular motion. The intervention involved, specifically, an engineering design problem in which students calculated optimal banking angles for a highway exit ramp with minimal reliance on friction, a problem directly linking physics principles to real-world engineering applications. To support students, scaffolding strategies were embedded in the learning process, including guided inquiry worksheets, dynamic simulations to visualise force vectors, structured peer collaboration, and continuous formative feedback. These supports aimed to help students derive and apply the centripetal force equation, construct and interpret free-body diagrams, and critically evaluate their design decisions.

This study aims to evaluate how structured concept scaffolding within PBL can enhance conceptual mastery, problem-solving ability, and student engagement in a foundational physics module for engineering students. The objectives are fourfold:

1. Determine to what extent concept scaffolding improves the conceptual understanding of circular motion in students.
2. Assess how concept scaffolding influences problem-solving strategies and the application of physics principles.
3. Explore the perceptions of students about the concept of scaffolding in terms of confidence, engagement, and articulation of reasoning.
4. Provide evidence-based recommendations for integrating concept scaffolding within PBL in South African engineering education contexts.

To achieve these objectives, a mixed-method approach was employed. Quantitative data from pre- and post-assessments measured gains in conceptual understanding and problem-solving ability, while qualitative reflections captured students' experiences and perceptions of the scaffolding strategies. This design aligns with contemporary Physics Education Research (PER) trends that advocate methodological triangulation, combining measurable learning outcomes with rich qualitative insights into student engagement to provide a more valid and nuanced understanding of learning (e.g., research on methodological triangulation in educational research and recent PER exemplars.[11] To address persistent challenges in STEM learning, empirical data must be combined with student voice, and this study contributes to the growing body of literature advocating for student-centred, scaffolded pedagogies as an effective means.

Eventually, this study underscores the value of concept scaffolding in PBL as a pedagogical strategy that not only improves students' immediate learning of circular motion but also builds the confidence, basic knowledge and transferable skills required for their progression in engineering education. Globally, the concerns about conceptual understanding in physics and the need to support diverse student populations in South African higher education are being addressed.

LITERATURE REVIEW

Traditional Instruction of Physics and Its Shortcomings

Historically, Physics has been taught using traditional lecture-based pedagogies such as direct instruction, in which the instructor assumes the central role in transmitting knowledge and students are passive recipients. Although this approach allows for efficient content delivery across large cohorts, a growing body of literature highlights its limitations, particularly in fostering conceptual understanding among engineering students. Lecture-based instruction often promotes rote memorisation rather than

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[10] de Klerk et al., *Reimagining South African Higher Education: Towards a Student-Centred Learning and Teaching Future*; Getachew T. Sedebo et al., "Inclusive STEM Education to Fight Poverty and Inequality: The Case of South Africa," *African Journal of Science, Technology, Innovation and Development* 17, no. 1 (January 2, 2025): 56–64, https://doi.org/10.1080/20421338.2024.2417779.

[11] Lauren A Barth-Cohen, Hillary Swanson, and Jared Arnell, "Methods of Research Design and Analysis for Identifying Knowledge Resources," *Physical Review Physics Education Research* 19, no. 2 (2023): 020119.

meaningful engagement with physics concepts.[12] It is particularly evident in first-year modules where high school students must transition from their learning styles to the more abstract and mathematically rich demands of higher education.

Studies indicate that engineering students often perform procedural manipulations of equations without understanding their underlying physical principles.[13] When addressing topics such as circular motion and centripetal force, learners may substitute values into formulas but fail to visualise the underlying force interactions, leading to misconceptions and fragile knowledge structures.[14] The similar problem in South Africa is not different, and these challenges are exacerbated by systemic inequalities in secondary education, resulting in varied levels of preparedness among university entrants.[15] Many first-year students face difficulties in applying abstract principles to real-world engineering contexts, contributing to low retention and throughput rates in STEM programmes.[16]

International research further suggests that lecture-heavy models tend to restrict active participation, critical thinking, and problem-solving skills essential for engineering practice.[17] Although students might achieve short-term gains on assessments, their ability to transfer learning to authentic design or problem-solving contexts remains limited. These findings underscore the urgent need to supplement traditional physics instruction with approaches that actively engage students, deepen conceptual understanding, and build transferable competencies.

Problem-Based Learning (PBL) in Physics Education

PBL emerged from medical education in the late 20th century but has since gained significant traction in STEM education as a learner-centred alternative to conventional instruction. PBL, at its core, positions learning within authentic, ill-structured problems that require students to collaboratively explore, hypothesise, and apply disciplinary knowledge.[18] The PBL approach aligns with constructivist theories of learning, which posit that knowledge is actively constructed by learners rather than passively received.[19]

Empirical evidence strongly supports PBL's effectiveness in fostering deeper conceptual understanding, problem-solving ability, and student engagement. A landmark meta-analysis by Freeman et al. demonstrated that active learning approaches such as PBL significantly reduce failure rates and improve examination performance in STEM disciplines compared to traditional lecturing.[20] More recent studies have extended this evidence, showing that PBL improves the ability of students to apply physics principles to engineering design contexts, thereby supporting long-term retention and professional readiness.[21]

PBL in South Africa has been identified as a critical pedagogical strategy to address issues of student disengagement and high attrition rates in STEM fields. For example, Garraway argues that student-centred methods such as PBL create opportunities for epistemological access, enabling students

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[12] Docktor and Mestre, "Synthesis of Discipline-Based Education Research in Physics."

[13] Kohl and Vincent, "Developing Mathematical Thinking in Physics: Insights from Introductory-Level Mathematics and Physics Courses."

[14] Marcos D Caballero et al., "Unpacking Students' Use of Mathematics in Upper-Division Physics," *ArXiv Preprint ArXiv:1409.7660*, 2014.

[15] Maringe and Sing, "Teaching Large Classes in an Increasingly Internationalising Higher Education Environment: Pedagogical, Quality and Equity Issues."

[16] Jawitz, "New Academics in South Africa: Entering the Teaching–Research Nexus."

[17] Chi and Wylie, "The ICAP Framework: Linking Cognitive Engagement to Active Learning Outcomes"; Scott Freeman et al., "Active Learning Increases Student Performance in Science, Engineering, and Mathematics," *Proceedings of the National Academy of Sciences* 111, no. 23 (2014): 8410–15.

[18] Hmelo-Silver, "Problem-Based Learning: What and How Do Students Learn?"

[19] L. S. Vygotsky, *Mind in Society: The Development of Higher Psychological Processes* (Cambridge, Massachusetts: Harvard University Press, 1978).

[20] Freeman et al., "Active Learning Increases Student Performance in Science, Engineering, and Mathematics."

[21] Yadav et al., "Case-based Instruction: Improving Students' Conceptual Understanding through Cases in a Mechanical Engineering Course"; Mary C English and Anastasia Kitsantas, "Supporting Student Self-Regulated Learning in Problem-and Project-Based Learning," *Interdisciplinary Journal of Problem-Based Learning* 7, no. 2 (2013): 6.

from diverse educational backgrounds to engage with disciplinary knowledge in meaningful terms.[22] Similarly, systematic reviews of PBL in higher education have found that it fosters not only academic learning but also critical employability skills, such as collaboration and critical thinking competencies that align with broader graduate readiness agendas.[23]

Despite these strengths, students may struggle with the cognitive demands of open-ended problems without adequate support, leading to frustration and limited learning gains.[24] This insight has prompted calls for structured scaffolding mechanisms to complement PBL and ensure equitable access to learning opportunities.

Concept Scaffolding as a Pedagogical Support

Firstly articulated by Wood, Bruner and Ross, the concept of scaffolding refers to the process of providing learners with temporary, structured support to enable them to perform tasks they could not manage independently.[25] Over the past two decades, scaffolding has become a central theme in educational research, particularly in relation to supporting learning in complex or abstract domains such as physics.

Scaffolding strategies span a spectrum from cognitive supports, such as guided inquiry worksheets and worked examples that structure student thinking, to technological tools like dynamic simulations that help visualise abstract scientific processes. Guided inquiry worksheets have been shown to improve participation and metacognitive reasoning in large STEM classes, while dynamic simulations embedded with scaffolding strengthen conceptual understanding, retention, and critical thinking abilities.[26] Collaborative scaffolds, including structured peer interactions and teacher feedback, further assist students in articulating reasoning and refining problem-solving approaches [40]. These strategies, when implemented, serve to reduce cognitive load, sustain motivation, and build confidence until learners achieve mastery.

Evidence in the international arena underscores the value of scaffolding in STEM contexts. Although Newton's laws and force–motion relationships are recognized threshold concepts in mechanics studies, using analogical scaffolding, such as guiding students through similar friction problems demonstrate that structured supports can aid conceptual understanding.[27] Also, Chen, Kalyuga and Sweller argue that scaffolding mitigates the risk of cognitive overload in inquiry-based learning environments by directing attention to essential elements of a task.[28] Recent meta-analytical evidence shows that structured scaffolding, especially conceptual and metacognitive support, significantly improves students' ability to integrate theoretical knowledge with applied contexts, thus improving knowledge transfer in situations.

Scaffolding, typically in South Africa, has been highlighted as essential for addressing epistemological access challenges in physics education. In the South African context, research shows that scaffolded academic literacy practices—such as making disciplinary reading and writing conventions explicit—support epistemological access, particularly for students from under-prepared

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[22] James Windsor Garraway, "Participatory Parity and Epistemological Access in the Extended Curriculum Programmes," *Education as Change* 21, no. 2 (2017): 109–25.

[23] Taufiqur Rahman et al., "Effects of Project-Based Learning on Employability Skills," *Review of Islamic Studies* 2, no. 1 (January 15, 2023): 1–10, https://doi.org/10.35316/ris.v2i1.473.

[24] Kirschner et al., "Why Minimal Guidance during Instruction Does Not Work: An Analysis of the Failure of Constructivist."

[25] Wood, Bruner, and Ross, "The Role of Tutoring in Problem Solving."

[26] Milo, Koretsky et al., "The Role of Pedagogical Tools in Active Learning: A Case for Sense-Making," *International Journal of STEM Education* 5, no. 18 (2018).

[27] Meyer and Land, "Threshold Concepts and Troublesome Knowledge: An Introduction"; Shih-Yin Lin and Chandralekha Singh, "Effect of Scaffolding on Helping Introductory Physics Students Solve Quantitative Problems Involving Strong Alternative Conceptions," *Physical Review Special Topics—Physics Education Research* 11, no. 2 (2015): 020105; Jan H F Meyer and Ray Land, "Threshold Concepts and Troublesome Knowledge (2): Epistemological Considerations and a Conceptual Framework for Teaching and Learning," *Higher Education* 49, no. 3 (2005): 373–88.

[28] O. Chen, S. Kalyuga, and J. Sweller, "Cognitive Load Theory, Instructional Design, and Learning from Worked Examples: A Review of the Literature," *Educational Psychology Review* 28, no. 4 (2016): 831–52.

educational backgrounds.[29] These findings reinforce the argument that scaffolding is a necessary condition for equitable and effective learning in diverse educational contexts.

Synthesising the Literature: Positioning the Present Study

Three key insights have emanated from the reviewed literature. First, traditional lecture-based instruction is insufficient to develop the conceptual depth and applied competence required of engineering students. Second, PBL offers a powerful alternative by engaging students in authentic problem-solving, but it is overwhelming for students who are new to the concept if implemented without adequate support. Third, scaffolding strategies have shown effectiveness in helping students navigate complex concepts, overcome misconceptions, and build confidence in their learning.

What remains underexplored, especially in the South African context, is the integration of scaffolding in a PBL framework in first-year physics education for engineering students. International studies have explicitly integrated scaffolding into PBL for physics/mechanics; [30] however, in the South African context, the focus has been more on support and access broadly and not yet on discipline-specific scaffolding for mechanics.

This study addresses this gap by examining how scaffolding strategies, such as guided inquiry worksheets, simulations, peer collaboration, and formative feedback, can be systematically integrated into a PBL environment to support the understanding of circular motion by fisrt year engineering students. By situating physics learning within an authentic engineering design challenge and embedding structured supports, this research aims to bridge the gap between abstract conceptual knowledge and its real-world application.

Furthermore, the study contributes to both international and South African debates on student-centred pedagogies by offering empirical evidence of how scaffolding within PBL can enhance conceptual mastery, engagement, and problem-solving ability, through scalable, evidence-based strategies that address the persistent challenges of attrition, inequity, and limited conceptual transfer in STEM education.

METHODOLOGY

Research Design

This study used a mixed-methods research design that integrates both quantitative and qualitative data to provide a comprehensive evaluation of the intervention. Mixed-methods approaches are particularly well-suited to educational research in STEM because they allow for triangulation between numerical indicators of learning gains and rich qualitative insights into student experience.[31] International evidence has shown that exclusive reliance on quantitative or qualitative methods risks oversimplifying the multifaceted nature of learning.[32] The present design allowed the measurement of learning outcomes while also exploring the affective and metacognitive dimensions of student engagement.

Participants

The participants were 60 first-year engineering students enrolled in a physics module at a South African university of technology. This group represented a diverse demographic profile in terms of linguistic backgrounds, prior schooling, and levels of unpreparedness for university-level physics, reflecting broader national challenges in STEM education.[33] Many students entered higher education with limited exposure to applied problem-solving in physics, which reinforced the needs of scaffolding to ensure

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[29] C. Bertram, “Scaffolding Academic Literacy in Higher Education: Making Disciplinary Reading and Writing Practices Explicit,” *Journal of Education* 87, no. 1 (2022): 1–20.

[30] Lin and Singh, “Effect of Scaffolding on Helping Introductory Physics Students Solve Quantitative Problems Involving Strong Alternative Conceptions.”

[31] John W Creswell and Vicki L Plano Clark, *Designing and Conducting Mixed Methods Research* (Sage publications, 2017); J. M. Case and D. Marshall, “Bridging the Gap Between Engineering Education Research and Practice: A Framework for Relational Mixed Methods Research,” *Studies in Engineering Education* 2, no. 1 (2016): 1–12.

[32] Freeman et al., “Active Learning Increases Student Performance in Science, Engineering, and Mathematics.”

[33] Maringe and Sing, “Teaching Large Classes in an Increasingly Internationalising Higher Education Environment: Pedagogical, Quality and Equity Issues”; Jawitz, “New Academics in South Africa: Entering the Teaching–Research Nexus.”

epistemological access. Participation was voluntary, with informed consent secured in accordance with ethical research standards.

Intervention Description

The Engineering Design Problem

The core intervention was a design engineering problem that required students to calculate the optimal banking angle for a highway exit ramp under conditions where the reliance on friction was minimised. The problem incorporated concepts such as ideal velocity, the relationship between centripetal force and friction, and the forces acting on banked circular paths, extending further to real-world applications such as the design of racetracks. By situating physics within a design-oriented task, the intervention aligned with PBL principles of authenticity and contextual relevance.[34]

Scaffolding Strategies

To support students in navigating the complexity of circular motion, multiple scaffolding strategies were embedded:

- **Guided inquiry worksheets** structured the problem-solving process and incrementally increased task complexity from friction and centripetal force on horizontal surfaces to wet weather analysis problems, forces on banked surfaces of a circular path, involving calculating optimal banking angles for a highway exit ramp, taking into consideration the effect of ideal velocity to navigate the turn without relying on friction.

- **Dynamic simulations** enabled students to manipulate variables and visualise interactions of forces, reinforcing findings that interactive simulations significantly enhance conceptual understanding in mechanics.[35]

- **Structured peer collaboration** fostered cooperative learning and peer-to-peer explanation, which are critical for deep learning in diverse South African classrooms.

- **Continuous formative feedback** and prompting provided by the lecturer reinforced conceptual clarity and encouraged reflection on design decisions, consistent with research advocating feedback as a core scaffold in higher education, where the lecturer monitored group discussions and provided real-time guidance, reinforcing conceptual clarity and confidence.[36]

Together, these strategies sought to reduce cognitive load, support confidence building, and enable mastery of threshold concepts such as centripetal force. The deliberate integration of scaffolding within a PBL framework responded directly to international concerns about the challenges of open-ended learning without adequate support.[37]

Instructional Aims

The instructional design was designed to enable students to:

1. Derive and apply the centripetal force equation.
2. Construct and interpret free-body diagrams.
3. Critically evaluate design choices in the context of applied engineering challenges.

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[34] Hmelo-Silver, "Problem-Based Learning: What and How Do Students Learn?"; English and Kitsantas, "Supporting Student Self-Regulated Learning in Problem-and Project-Based Learning."

[35] Luis A. Herrera, Rosa M. Rodríguez, and Carlos R. Lopez, "The Role Of Digital Simulation in Enhancing Conceptual Understanding Of Physics Among University Students," *International Journal of Mathematics and Science Education* 1, no. 1 (November 14, 2024): 62–68, https://doi.org/10.62951/ijmse.v1i1.82.

[36] Van de Pol, Mercer, and Volman, "Scaffolding Student Talk: Teachers' Concurrent Use of Instructional Scaffolding Strategies in Whole-Class Discussions."

[37] Kirschner et al., "Why Minimal Guidance during Instruction Does Not Work: An Analysis of the Failure of Constructivist."

These aims align with international calls for physics education to foster not only procedural competence but also the capacity for critical reasoning and knowledge transfer.[38]

Data Collection

Quantitative Data

A pre- and post-assessment design was used to evaluate the achievement of learning outcomes. Assessments comprised of problem-solving tasks and conceptual questions about circular motion, banking angles, and free-body diagrams. Pre-tests provided baseline measures while post-tests captured the impact of the intervention. This design follows best practices for evaluating pedagogical innovations in physics education.[39]

Qualitative Data

Student reflections were collected at the end of the intervention. Learners were asked to describe their engagement with scaffolding strategies, perceived changes in confidence, and their ability to articulate reasoning. Reflection as a tool has been shown to provide valuable insights into metacognitive development and affective participation in the STEM context.

Data Analysis

Quantitative Analysis

Pre- and post-test scores were analysed using a paired-sample t-test to determine statistical significance. The paired-sample t-test is a well-established method for assessing learning gains in intervention studies, particularly when comparing measurements taken from the same participants before and after an educational intervention. [40] The results indicated significant improvements in both conceptual understanding and applied problem-solving.

Qualitative Analysis

Student reflections were thematically analysed using Braun and Clarke's framework, allowing the identification of patterns across the data.[41] Themes such as increased confidence, greater conceptual clarity, and improved collaboration emerged, providing interpretive depth to the quantitative findings.The methodology of mixed method discussed above, combining a design-oriented intervention with embedded scaffolding, provided a rigorous and contextually relevant approach to investigate how PBL can be enhanced in South African Physics Education. By aligning international best practices with local challenges, the study offers transferable insights into improving conceptual understanding in first-year engineering cohorts.

PRESENTATION OF RESULTS

Quantitative Findings

The quantitative phase of this study focused on measuring changes in conceptual understanding and problem-solving ability in circular motion. Pre- and post-assessment scores for the 60 participating first-year engineering students demonstrated a marked improvement. The mean pre-test score was 42.3% (SD = 10.4), reflecting the limited baseline conceptual grasp of circular motion concepts among students. Following the intervention, the mean post-test score increased to 76.8% (SD = 9.1), indicating a substantial improvement. A paired-sample t-test confirmed the statistical significance of this gain ($t(59) = 21.5$, $p < 0.001$), demonstrating the effectiveness of the intervention.

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[38] Docktor and Mestre, "Synthesis of Discipline-Based Education Research in Physics"; Kohl and Vincent, "Developing Mathematical Thinking in Physics: Insights from Introductory-Level Mathematics and Physics Courses."

[39] Freeman et al., "Active Learning Increases Student Performance in Science, Engineering, and Mathematics."

[40] Allen I Talikan et al., "On Paired Samples T-Test: Applications, Examples and Limitations," *Ignatian International Journal for Multidisciplinary Research* 2, no. 4 (2024): 943–51.

[41] Virginia Braun and Victoria Clarke, "Reflecting on Reflexive Thematic Analysis," *Qualitative Research in Sport, Exercise and Health* 11, no. 4 (2019): 589–97.

These results align with international findings that active and scaffolded learning interventions produce superior outcomes compared to traditional lecture-based instruction reported that student performance in STEM subjects improved significantly under active learning conditions, with failure rates reduced by nearly 55%. [42] similarly emphasised that structured interventions addressing misconceptions in mechanics can yield substantial conceptual gains. Within South Africa, Case and Marshall also noted that student-centred approaches improved learning outcomes, particularly for students transitioning from under-resourced schooling systems.[43]

Table 1. Pre- and Post-Test Results of Student Performance (n = 60)

Assessment	Mean (%)	SD	Statistical Test Results
Pre-test	42.3	10.4	
Post-test	76.8	9.1	T(59) = 21.5, $p < 0.001$

The table illustrates the robust improvement in both mean performance and score consistency after the scaffolding intervention. The reduced standard deviation in post-test scores (from 10.4 to 9.1) suggests that the intervention also narrowed performance disparities among students, thus promoting equity of learning outcomes. The performance trend, as stated above, confirms that embedding scaffolding strategies within a PBL framework significantly enhances conceptual mastery and reduces variance across a heterogeneous student cohort. Such outcomes are particularly significant in the South African context, where widening participation has increased diversity in preparedness levels.

An analysis of the Inquiry Worksheet indicates that the instrument is not suitable for assessing reliability using Cronbach’s alpha. The worksheet contains heterogeneous items (conceptual, diagrammatic and inquiry-based) that do not measure a single latent construct. Additionally, the open-ended nature of several questions prevents standardised scoring required for internal consistency analysis. As such, Cronbach’s alpha cannot be meaningfully applied to this instrument.

Qualitative Findings

Complementing the quantitative outcomes, qualitative data from student reflections provided insights into the affective, cognitive, and social dimensions of learning. Three main themes emerged: greater engagement, improved confidence, and a clearer articulation of design rationales.

Greater Engagement

The students reported that the engineering design problem, supported by scaffolding strategies, made learning more meaningful and engaging. One student, for example, reflected:

> *“Working on the banked curve problem made me realise how equations in circular motion in physics are not just numbers but tools for solving real-life engineering challenges.”*

The above response aligns with work on PBL, which situates learning in authentic, ill-structured problems that promote deeper engagement and understanding.[44] Similarly, the research in South Africa emphasises that students become more motivated when academic content is connected to real-world professional applications.

Incorporation of dynamic simulations and collaborative tasks further enhanced active participation. The students emphasised how the simulations helped them visualise forces acting on the car and the role of velocity in navigating turns without friction, and visual tools are effective in bridging abstract mechanics concepts.

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[42] Docktor and Mestre, “Synthesis of Discipline-Based Education Research in Physics.”

[43] Case and Marshall, “Bridging the Gap Between Engineering Education Research and Practice: A Framework for Relational Mixed Methods Research.”

[44] Hmelo-Silver, “Problem-Based Learning: What and How Do Students Learn?”; John R Savery, “Overview of Problem-Based Learning: Definitions and Distinctions,” *Essential Readings in Problem-Based Learning: Exploring and Extending the Legacy of Howard S. Barrows* 9, no. 2 (2015): 5–15.

Improved Confidence

The concept scaffolding strategies contributed significantly to building student confidence. Several participants expressed that the step-by-step support provided by guided inquiry worksheets and formative feedback helped them tackle complex problems more independently. One student noted:

> *"At first, I was nervous about the application of trigonometric angles and resolving forces in banked curves, but with the worksheets and feedback, I became more confident that I could apply the equations correctly."*

This echoes the findings of Awonke et al, who observed that structured concept scaffolding enables students to overcome threshold concepts in physics.[45] The South African context discusses inclusive pedagogical strategies, specifically concept scaffolding, to address challenges faced by *underprepared students* in a South African university of technology context.

Not only did content mastery improve confidence, but it also extended to collaborative work. Students reported feeling more confident when explaining their reasoning to peers, reflecting the dual benefit of scaffolding: enhancing individual competence while fostering social learning.[46]

Clearer Articulation of Design Rationales

The third emergent theme was students' improved ability to articulate the reasoning behind their design decisions. Initially, students relied on rote use of equations without deeper justification, but by the end of the intervention, reflections revealed that learners were better able to explain how velocity, banking angle, and centripetal force impact the engineering design of banked curves. For example:

> *"I could explain why the curve angle must be designed a certain way depending on the speed, and how this prevents skidding even in wet weather conditions."*

This finding aligns with de Pol et al., who demonstrated that scaffolding not only supports correct problem-solving but also enhances students' metacognitive capacity to explain their reasoning and fosters articulation, as it equips learners with the confidence to engage in disciplinary discourse.[47]

Integrating Quantitative and Qualitative Insights

When triangulated, the findings present a coherent narrative: the quantitative data show that students' conceptual understanding and problem-solving ability improved significantly, while the qualitative reflections illuminate the underlying mechanisms. The scaffolding strategies promoted participation, built confidence, and allowed students to articulate reasoning, all of which reinforced the learning gains captured in the test scores. The integration of concept scaffolding into a PBL framework significantly improved first-year engineering students' mastery of circular motion concepts. Quantitative assessments confirmed a 34.5% improvement in mean scores with statistically significant results ($t = 21.5$, $p < 0.001$), while qualitative reflections highlighted improved engagement, confidence, and reasoning. These findings underscore the value of embedding concept scaffolding strategies into PBL to support both conceptual and affective dimensions of learning, offering a replicable model for physics education in South Africa and beyond.

DISCUSSION

Interpretation of Findings

The findings of this study affirm the effectiveness of integrating concept scaffolding within a PBL framework to enhance conceptual understanding and application of circular motion in engineering-focused physics. Quantitative results demonstrated a substantial increase in performance, with mean

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[45] Mbangi Awonke et al., "Supporting Underprepared Students through Technology and Inclusive Pedagogical Strategies," in *Proceedings of the Focus Conference (TFC 2024)* (Springer Nature, 2024), 422–51.

[46] Van de Pol, Mercer, and Volman, "Scaffolding Student Talk: Teachers' Concurrent Use of Instructional Scaffolding Strategies in Whole-Class Discussions."

[47] Van de Pol, Mercer, and Volman, "Scaffolding Student Talk: Teachers' Concurrent Use of Instructional Scaffolding Strategies in Whole-Class Discussions."

scores of students improving from 42.3% to 76.8%, a statistically significant gain ($t(59) = 21.5$, $p < 0.001$), indicating that students were able to internalise key principles. These outcomes show that scaffolding mechanisms provided the necessary cognitive support for students to grasp threshold concepts in physics, particularly centripetal force and forces on banked curves, while enabling them to apply this understanding to authentic engineering problems. This aligns with international research showing that scaffolding reduces cognitive overload and strengthens conceptual coherence when learning concepts from abstract mechanics. The reduction in score variance further suggests that scaffolding acted as an equaliser, allowing underprepared students to catch up with their more experienced peers—an important result in the highly diverse South African higher education context, where epistemological access remains a systemic challenge.

Qualitative reflections added depth to these findings by highlighting affective and metacognitive gains. Students reported greater engagement, noting that the engineering design challenge connected abstract equations to real-world relevance, echoing findings that PBL improves motivation through authentic contexts.[48] They also expressed increased confidence, attributing their growth to guided inquiry worksheets and timely feedback, consistent with evidence that scaffolding builds self-efficacy in STEM. The students described meaningful engagement arising from authentic engineering scenarios; this echoes the study's guiding premise that PBL must connect theory to real-world contexts to stimulate deep learning. Reflections indicated that students were able to visualise physics concepts more clearly using simulations and guided worksheets, leading to shifts in their representational fluency, confidence in interpreting force interactions, and capacity to articulate the rationale behind engineering design decisions. Finally, students demonstrated clearer articulation of design rationales, moving towards disciplinary discourse competence, a critical threshold in STEM education.[49]

Linking Findings to Research Questions

The discussion now directly addresses the core research questions:

Research Question 1: ***To what extent does concept scaffolding improve students' conceptual understanding of circular motion?***

The findings confirm a substantial improvement in conceptual understanding, supported by both statistical evidence and the narratives of the learners. Students not only solved circular motion problems accurately but also demonstrated the ability to articulate why centripetal force behaves as it does under conditions of friction, velocity, and banking angle changes. This reflects the mastery of a threshold concept, which, according to Meyer and Land, signals a significant shift in disciplinary understanding.[50] The intervention clearly helped students cross this conceptual threshold by structuring learning experiences that progressively deepened understanding, consistent with physics education research on guided inquiry and simulation-based scaffolding.

Research Question 2: ***How does concept scaffolding influence students' problem-solving strategies and their application of physics principles?***

Students progressed from plug-and-play problem solving to analysing engineering design constraints, selecting appropriate equations, and interpreting force diagrams in context. Their reflections reveal enhanced metacognitive awareness: they no longer solved equations mechanically, but instead evaluated whether their solutions made sense in the engineering scenario. Scaffolding supported this shift by:

- Breaking problems into manageable conceptual steps
- Providing visual supports for abstract force interactions
- Offering feedback that guided reasoning rather than supplying answers
- Encouraging peer explanation, which strengthened mathematical and conceptual justification

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[48] Yadav et al., "Case-based Instruction: Improving Students' Conceptual Understanding through Cases in a Mechanical Engineering Course."

[49] Jan Meyer and Ray Land, *Overcoming Barriers to Student Understanding* (Taylor & Francis Limited New York, 2005).

[50] Meyer and Land, *Overcoming Barriers to Student Underst.*

This indicates that scaffolding supported the development of problem-solving behaviours, which literature identifies as essential for first-year engineering students who struggle to transfer physics knowledge to design contexts.

Research Question 3: ***How do students perceive concept scaffolding in relation to engagement, confidence, and reasoning?***

The qualitative themes indicate that the intervention positively influenced learners' self-efficacy and engagement. Students explicitly linked their increased confidence to:

- The structured pacing of guided worksheet questions
- Visualisation through simulations
- Clarifying discussions with peers
- Continuous formative feedback from the lecturer

These elements created a psychologically safe learning environment, reducing anxiety associated with physics problem-solving and empowering students to participate actively. Students also demonstrated increased competence, as they were able to articulate engineering rationales and justify design decisions, an important learning outcome often overlooked in introductory physics instruction.

Research Question 4: ***What evidence-based recommendations can be drawn for integrating concept scaffolding within PBL in South African engineering education?***

The findings suggest that scaffolding within PBL offers a scalable, contextually appropriate model for South African universities of technology. Given the wide variations in student preparedness, scaffolding acts as a bridge between heterogeneous schooling backgrounds and the demands of engineering physics. The reduction in performance disparities and improved engagement point towards scaffolding as a mechanism for promoting equity, epistemological access, and social justice in STEM education. The findings thus far confirm that scaffolding within PBL works by providing structured support at multiple levels: cognitive, through inquiry tasks and simulations; affective, through confidence-building feedback; and social, through peer collaboration. These mechanisms explain why the intervention was successful in fostering both mastery and transfer.

Implications for STEM Education

The implications of these results extend beyond the specific module and topic of circular motion. They point towards a scalable, equitable, and effective pedagogical strategy for foundational STEM education.

First, the study demonstrates that concept scaffolding within PBL can narrow achievement gaps. The reduced standard deviation in post-test scores suggests that weaker students benefited disproportionately, thereby reducing disparities in performance. This is crucial in South Africa, where diverse schooling backgrounds contribute to uneven preparedness in physics.[51] By supporting disadvantaged learners, scaffolding contributes to the social justice agenda in higher education.

Second, the intervention highlights the professional relevance of physics learning for engineering students. By designing and placing concepts in a design task to calculate optimal banking angles, the approach mirrored authentic engineering practice, thereby fostering the transfer of theoretical knowledge to applied contexts. This alignment with professional competencies resonates with international calls to make STEM education more practice-oriented and with South African imperatives to enhance employability and graduate readiness.[52]

Third, the findings underscore the importance of addressing affective dimensions of learning in addition to cognitive gains. Engagement, motivation, and confidence are critical predictors of persistence in STEM pathways. By demonstrating improvements in these areas, the study suggests that

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[51] Maringe and Sing, "Teaching Large Classes in an Increasingly Internationalising Higher Education Environment: Pedagogical, Quality and Equity Issues."

[52] English and Kitsantas, "Supporting Student Self-Regulated Learning in Problem-and Project-Based Learning."

concept scaffolding supported PBL can help reduce attrition rates in engineering programmes, a pressing challenge both globally and in South Africa.[53]

Finally, the results contribute to debates around the design of PBL. Although PBL has been shown to improve learning, critics caution that it can overwhelm novice learners if it is not sufficiently guided. This study confirms these concerns but offers a solution: PBL must be scaffolded to be effective at introductory levels. This insight has broader implications for curriculum designers in STEM, suggesting that hybrid approaches—combining authentic problem-solving with structured guidance—may offer the optimal balance.

RECOMMENDATIONS

Future Research

Based on the outcomes of this study, several avenues for future research are recommended.

1. Scaling across contexts: Replication across multiple universities, including both well-resourced and under-resourced institutions, would test the scalability and adaptability of scaffolding within PBL.
2. Longitudinal studies: Future research should track student cohorts beyond a single module to examine whether concept scaffolding-supported PBL fosters long-term retention, progression into advanced modules, and preparedness for professional practice.
3. Extension to other physics domains: Investigating whether scaffolding within PBL improves learning in topics beyond mechanics, such as electromagnetism or quantum physics, would test the broader applicability of the approach.
4. Technology-enhanced scaffolding: With increasing reliance on digital learning environments, research should explore how adaptive technologies, virtual simulations, or artificial intelligence tutors can expand the reach and impact of scaffolding.
5. Equity-focused studies: Given South Africa's diverse student demographics, future work should specifically investigate how scaffolding impacts students from disadvantaged backgrounds. Such research could provide evidence for policy interventions aimed at improving equity and inclusion in STEM.
6. Instructor perspectives: Finally, examining how instructors design, implement, and adapt concept scaffolding within PBL would provide insights into professional development needs and institutional support structures required for scaling.

CONCLUSION

This study demonstrates that embedding concept scaffolding within a PBL framework is highly effective in fostering conceptual mastery, engagement, confidence and the transfer of physics knowledge to applied engineering contexts. Quantitative and qualitative findings converge to show that students not only improved their problem-solving performance but also gained confidence, motivation, and the ability to articulate design rationales.

By embedding guided inquiry, simulations, collaboration, and feedback, students effectively bridged theoretical understanding with real-world engineering applications. These findings affirm international evidence that scaffolding reduces misconceptions and fosters transferable knowledge while addressing South African priorities of equity and epistemological access. Ultimately, scaffolding-supported PBL emerges as a scalable, contextually responsive strategy for advancing foundational STEM education.

The broader implications are clear as concept scaffolding-supported PBL offers a scalable, equitable, and contextually relevant strategy for advancing foundational STEM education, particularly in engineering-focused physics. By combining authentic problem-solving with structured supports, the approach addresses cognitive, affective, and social dimensions of learning simultaneously.

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[53] Kirschner et al., "Why Minimal Guidance during Instruction Does Not Work: An Analysis of the Failure of Constructivist."

Although the scope was limited, its findings provide valuable insights to both international and South African debates on effective pedagogy in STEM. With further research to scale and refine the approach, scaffolding within PBL holds the potential to transform first-year physics education into an inclusive, engaging, and professionally relevant foundation for engineering students.

Limitations

Despite the encouraging results, the study has several limitations that must be acknowledged.

1. Sample size and context: The study involved 60 students from a single South African university of technology. Although this sample provides valuable insights, it cannot be assumed that the findings will generalise to larger or different institutional contexts without further testing.
2. Short-term measurement: The study assessed gains immediately after the intervention. While the results show significant improvements, they do not confirm whether learning was retained over time or transferred to subsequent modules.
3. Self-reported reflections: The qualitative data relied on student reflections, which, while valuable, may have been influenced by social desirability bias. Triangulation with classroom observations or instructor reports would provide a more robust account of engagement and confidence.
4. Topic specificity: The intervention focused on circular motion, a threshold concept in physics. Although the findings are promising, it remains uncertain whether similar scaffolding strategies would be equally effective in other domains, such as electromagnetism or thermodynamics.

Recognising these limitations, the study situates its contributions as significant yet preliminary, highlighting the need for further research to consolidate and extend the findings.

BIBLIOGRAPHY

Awonke, Mbangi, Ncobela Cyprial Ndumiso, Mbangi Hlumela Siyolise, Rapai Fred, Kavita Behara, and Msomi Alfred Mvunyelwa. “Supporting Underprepared Students through Technology and Inclusive Pedagogical Strategies.” In *Proceedings of the Focus Conference (TFC 2024)*, 422–51. Springer Nature, 2024.

Banda, Herbert James, and Joseph Nzabahimana. “Effect of Integrating Physics Education Technology Simulations on Students’ Conceptual Understanding in Physics: A Review of Literature.” *Physical Review Physics Education Research* 17, no. 2 (December 21, 2021): 023108. https://doi.org/10.1103/PhysRevPhysEducRes.17.023108.

Barth-Cohen, Lauren A, Hillary Swanson, and Jared Arnell. “Methods of Research Design and Analysis for Identifying Knowledge Resources.” *Physical Review Physics Education Research* 19, no. 2 (2023): 020119.

Bertram, C. “Scaffolding Academic Literacy in Higher Education: Making Disciplinary Reading and Writing Practices Explicit.” *Journal of Education* 87, no. 1 (2022): 1–20.

Braun, Virginia, and Victoria Clarke. “Reflecting on Reflexive Thematic Analysis.” *Qualitative Research in Sport, Exercise and Health* 11, no. 4 (2019): 589–97.

Brundage, Mary Jane, Alysa Malespina, and Chandralekha Singh. “Peer Interaction Facilitates Co-Construction of Knowledge in Quantum Mechanics.” *Physical Review Physics Education Research* 19, no. 2 (2023): 020133.

Caballero, Marcos D, Bethany R Wilcox, Leanne Doughty, and Steven J Pollock. “Unpacking Students’ Use of Mathematics in Upper-Division Physics.” *ArXiv Preprint ArXiv:1409.7660*, 2014.

Case, J. M., and D. Marshall. “Bridging the Gap Between Engineering Education Research and Practice: A Framework for Relational Mixed Methods Research.” *Studies in Engineering Education* 2, no. 1 (2016): 1–12.

Chen, O., S. Kalyuga, and J. Sweller. “Cognitive Load Theory, Instructional Design, and Learning from Worked Examples: A Review of the Literature.” *Educational Psychology Review* 28, no. 4 (2016): 831–52.

Chi, Michelene T H, and Ruth Wylie. "The ICAP Framework: Linking Cognitive Engagement to Active Learning Outcomes." *Educational Psychologist* 49, no. 4 (2014): 219–43.

Creswell, John W, and Vicki L Plano Clark. *Designing and Conducting Mixed Methods Research*. Sage Publications, 2017.

Docktor, Jennifer L, and José P Mestre. "Synthesis of Discipline-Based Education Research in Physics." *Physical Review Special Topics-Physics Education Research* 10, no. 2 (2014): 020119.

English, Mary C, and Anastasia Kitsantas. "Supporting Student Self-Regulated Learning in Problem- and Project-Based Learning." *Interdisciplinary Journal of Problem-Based Learning* 7, no. 2 (2013): 6.

Espinoza, Fernando. "Impact of Guided Inquiry with Simulations on Knowledge of Electricity and Wave Phenomena." *ArXiv Preprint ArXiv:2012.05826*, 2020.

Freeman, Scott, Sarah L Eddy, Miles McDonough, Michelle K Smith, Nnadozie Okoroafor, Hannah Jordt, and Mary Pat Wenderoth. "Active Learning Increases Student Performance in Science, Engineering, and Mathematics." *Proceedings of the National Academy of Sciences* 111, no. 23 (2014): 8410–15.

Garraway, James Windsor. "Participatory Parity and Epistemological Access in the Extended Curriculum Programmes." *Education as Change* 21, no. 2 (2017): 109–25.

Herrera, Luis A., Rosa M. Rodríguez, and Carlos R. Lopez. "The Role Of Digital Simulation in Enhancing Conceptual Understanding Of Physics Among University Students." *International Journal of Mathematics and Science Education* 1, no. 1 (November 14, 2024): 62–68. https://doi.org/10.62951/ijmse.v1i1.82.

Hmelo-Silver, Cindy E. "Problem-Based Learning: What and How Do Students Learn?" *Educational Psychology Review* 16, no. 3 (September 2004): 235–66. https://doi.org/10.1023/B:EDPR.0000034022.16470.f3.

Husnaini, Siti Jamiatul, and Sufen Chen. "Effects of Guided Inquiry Virtual and Physical Laboratories on Conceptual Understanding, Inquiry Performance, Scientific Inquiry Self-Efficacy, and Enjoyment." *Physical Review Physics Education Research* 15, no. 1 (March 25, 2019): 010119. https://doi.org/10.1103/PhysRevPhysEducRes.15.010119.

Jawitz, J. "New Academics in South Africa: Entering the Teaching–Research Nexus." *Higher Education* 71, no. 4 (2016): 557–73.

Kirschner, Paul A, John Sweller, Richard E Clark, P. A. Kirschner, and R. E. Clark. "Why Minimal Guidance during Instruction Does Not Work: An Analysis of the Failure of Constructivist." *Based Teaching Work: An Analysis of the Failure of Constructivist, Discovery, Problem-Based, Experiential, and Inquiry-Based Teaching,(November 2014)*, 2010, 37–41.

Klerk, Danie de, Greig Krull, Tshepiso Maleswena, and Fiona MacAlister. *Reimagining South African Higher Education: Towards a Student-Centred Learning and Teaching Future*. African Sun Media, 2024.

Kohl, P. B., and E. A. Vincent. "Developing Mathematical Thinking in Physics: Insights from Introductory-Level Mathematics and Physics Courses." *Physical Review Physics Education Research* 14, no. 2 (2018): 020120.

Koretsky, Milo, Jessie Keeler, John Ivanovitch, and Ying Cao. "The Role of Pedagogical Tools in Active Learning: A Case for Sense-Making." *International Journal of STEM Education* 5, no. 18 (2018).

Lin, Shih-Yin, and Chandralekha Singh. "Effect of Scaffolding on Helping Introductory Physics Students Solve Quantitative Problems Involving Strong Alternative Conceptions." *Physical Review Special Topics—Physics Education Research* 11, no. 2 (2015): 020105.

Maringe, Felix, and Nevensha Sing. "Teaching Large Classes in an Increasingly Internationalising Higher Education Environment: Pedagogical, Quality and Equity Issues." *Higher Education* 67, no. 6 (2014): 761–82.

Meyer, Jan H F, and Ray Land. "Threshold Concepts and Troublesome Knowledge: An Introduction." In *Overcoming Barriers to Student Understanding*, 3–18. Routledge, 2006.

———. "Threshold Concepts and Troublesome Knowledge (2): Epistemological Considerations and a Conceptual Framework for Teaching and Learning." *Higher Education* 49, no. 3 (2005): 373–88.

Meyer, Jan, and Ray Land. *Overcoming Barriers to Student Understanding*. Taylor & Francis Limited, New York, 2005.

Pol, J. Van de, N. Mercer, and M. Volman. "Scaffolding Student Talk: Teachers' Concurrent Use of Instructional Scaffolding Strategies in Whole-Class Discussions." *Learning and Instruction* 60 (2019): 1–11.

Savery, John R. "Overview of Problem-Based Learning: Definitions and Distinctions." *Essential Readings in Problem-Based Learning: Exploring and Extending the Legacy of Howard S. Barrows* 9, no. 2 (2015): 5–15.

Sedebo, Getachew T., Ajebush A. Shafi, Mammo Muchie, and Michael Y. Shatalov. "Inclusive STEM Education to Fight Poverty and Inequality: The Case of South Africa." *African Journal of Science, Technology, Innovation and Development* 17, no. 1 (January 2, 2025): 56–64. https://doi.org/10.1080/20421338.2024.2417779.

Talikan, Allen I, Rufaida Salapuddin, Jainalyn A Aksan, Roslina J Rahimulla, Adzhar Ismael, Rumida Jimlah, Nasra Idris, Rubina B Dammang, Dermayna A Jamar, and Emelyn Sarahadil. "On Paired Samples T-Test: Applications, Examples and Limitations." *Ignatian International Journal for Multidisciplinary Research* 2, no. 4 (2024): 943–51.

Taufiqur Rahman, Nurul Fitria, Evi Nurhidayah, and Ika Yuliandani. "Effects of Project-Based Learning on Employability Skills." *Review of Islamic Studies* 2, no. 1 (January 15, 2023): 1–10. https://doi.org/10.35316/ris.v2i1.473.

Vygotsky, L. S. *Mind in Society: The Development of Higher Psychological Processes*. Cambridge, Massachusetts: Harvard University Press, 1978.

Wood, David, Jerome S Bruner, and Gail Ross. "The Role of Tutoring in Problem Solving." *Journal of Child Psychology and Psychiatry* 17, no. 2 (1976): 89–100.

Yadav, Aman, Megan Vinh, Gregory M Shaver, Peter Meckl, and Stephanie Firebaugh. "Case-based Instruction: Improving Students' Conceptual Understanding through Cases in a Mechanical Engineering Course." *Journal of Research in Science Teaching* 51, no. 5 (2014): 659–77.

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