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Implementation of Simulation-Focused, Problem-Based Learning in Engineering Apprenticeships

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Abstract
Simulation-focused Problem-Based Learning (SF-PBL) integrates immersive simulation tools with problem-based methodologies to support engineering apprentices in developing a deep understanding, real-world application, and reflective capacity. Rooted in cognitive, constructivist, and experiential learning theories, SFPBL provides realistic, safe environments where learners can explore complex scenarios, test hypotheses, and reflect on outcomes. This paper evaluates the implementation of Simulation-Focused Problem-Based Learning (SF-PBL) within a UK Engineering Degree Apprenticeship programme, using ANSYS as a core simulation tool. In that regard, a Computational Fluid Dynamics module has been picked and mixed sets of performance data and module evaluation feedback from two cohorts were analysed to explore the educational impact of embedding simulation-led problem tasks across the proposed module. Findings show notable improvements in learners' average marks (+8 marks out of 100) and first-attempt pass rates (increased by 20%), alongside substantial increases in perceived challenge, engagement, and workplace relevance which

leads to 95% in overall students' satisfaction in the module feedback (22% enhancement in compare with previous cohorts). Analysis of student feedback indicates that SF-PBL enhanced conceptual understanding, confidence, and the ability to integrate theory with practice. These outcomes strongly align with established pedagogical frameworks including experiential learning, constructivism, adult learning theory, and cognitive load theory, demonstrating that simulation-driven inquiry provides an effective bridge between academic learning and professional engineering practice. The study concludes that SF-PBL represents a robust and scalable approach for strengthening the capability, readiness, and applied problem-solving skills of engineering apprentices.

Keywords
Simulation-Based Learning, Problem-Based Learning, Simulation Focused – Problem-Based Learning, Engineering Apprenticeships, ANSYS, Vocational Pedagogy, Work-Based Learning, Dual Mentorship

Introduction

The engineering sector within the United Kingdom faces a persistently growing skills shortage, and the provision of apprenticeships is uniquely positioned to address this shortage. According to EngineeringUK (2024), there were 339,580 apprenticeship starts in England during the 2023/24 academic year, with around 29% (approximately 97,000) in engineering and technology-related subjects. Notably, degree-level apprenticeships (Levels 6 and 7) in engineering saw a 14% increase year-on-year and now comprise around 10% of all apprenticeship starts, reflecting increased employer confidence in higher-level vocational pathways (EngineeringUK, 2024).

Despite this encouraging trend, long-term analysis reveals fragility in apprenticeship provision. EngineeringUK's recent report, Fit for the Future notes that engineering and manufacturing technologies apprenticeships remain 9% below their 2014/15 peak, and the number of younger learners (under 25) entering these pathways has declined by 34% over the past decade (EngineeringUK, 2024). Industry bodies continue to raise concerns about the shortage of work-ready engineers, citing a disconnect between academic preparation and practical readiness (Royal Academy of Engineering, 2023; Richardson, 2022).

Degree apprenticeships are designed to bridge this gap by combining academic learning with structured on-the-job training. These programmes allow learners to earn and gain valuable industry experience while they learn and achieve a full undergraduate degree over three to five years (House of Commons Library, 2023). The apprenticeship levy and industry partnerships have enabled universities and employers to collaborate on designing the relevant curriculum and embedding industry-specific skills while ensuring alignment with national qualification frameworks (Department for Education, 2024).

However, one of the main pedagogical challenges remains: how can universities effectively support apprentices in acquiring not only theoretical knowledge but also the adaptability, critical thinking, and applied skills needed in dynamic workplace environments? Traditional approaches such as lectures, seminars, and laboratory sessions, often fall short in addressing the contextual, reflective, and integrative learning needs of apprentices (Raelin, 2008; Eraut, 2004). However, Simulation-Focused Problem-Based Learning (SF-PBL) offers an innovative model for bridging academic and professional development.

SF-PBL combines two well-established approaches: Problem-Based Learning (PBL), which engages learners in solving open-ended, real-world problems through inquiry and collaboration (Savery, 2006, 2015), and Simulation-Based Learning (SBL), which enables experimentation and modelling in virtual environments that replicate workplace conditions (Lateef, 2010). When applied to engineering apprenticeships, SF-PBL can immerse learners in authentic tasks that require the integration of domain knowledge, decision-making, and reflective evaluation. Thus, SF-PBL is highly suited to engineering apprenticeships. It helps in enhancing the conceptual understanding and at the same time, promotes reflection, confidence, and workplace transferability. As apprentices navigate the dual demands of university and employment, SF-PBL offers a strong framework to support their development.

For instance, simulation tools such as ANSYS a powerful engineering simulation tool-are already used within the University of Staffordshire's Manufacturing Engineer degree apprenticeship curriculum. In modules such as Professional Development and Practice (1st year), Mechanical Design and Structures (2nd year), Computational Fluid Dynamics (3rd year) and Structures and FEA (3rd year) apprentices simulate stress, deformation, fluid flow, and heat transfer in mechanisms and systems that closely resemble those used in their workplaces. These simulations allow learners to explore design decisions, validate assumptions, and iteratively refine models without incurring physical testing costs or safety risks. Examples of using ANSYS include the University of Bath where a project is underway to "transform the use of ANSYS software within the Faculty of Engineering to create a comprehensive suite of connected courses" that guide students from introductory through advanced simulation skills, emphasising real-world Multiphysics problem-solving (Pegg et al., 2024). Similarly, universities such as Cornell, Connecticut (UConn) and Massachusetts Amherst are partnering with ANSYS to embed simulation as a core component of curricula. Developed by faculty, simulation-focused courses provide authentic problem contexts, modelling assumptions, and results interpretation preparing learners for workplace expectations (ANSYS, 2021; ANSYS, 2022).

Although both SBL and PBL are supported by substantial empirical evidence in higher education, including meta-analytic syntheses demonstrating positive effects on complex skill acquisition and higher-order outcomes, most of this evidence treats SBL and PBL as separate literatures rather than as an integrated pedagogical approach. For example, Chernikova et al. (2020) reported a broad meta-analysis of SBL across higher education to indicate large positive effects and highlight how different scaffolds and technologies alter effectiveness. Similarly, recent meta-analytic work comparing problem-, project- and case-based approaches documents consistent benefits for motivation and higher-order learning outcomes in STEM contexts (Wijnia et al., 2024). However, despite these detailed syntheses, there is a clear gap: no systematic review or meta-analysis has, to our knowledge, examined the combined use of simulation and problem-based approaches specifically within degree apprenticeships or other dual-mentorship, work-integrated engineering programmes. Also, existing work typically explores PBL in higher education (Para-González et al., 2023) or simulation-based training in sector-specific contexts such as healthcare (Souza et al., 2025, Cant and Cooper, 2017), but not their integration within a dual-mentorship, work-integrated learning framework. Therefore, the present study is an attempt to address an important and under-synthesised area by operationalising SF-PBL within a dual-mentorship professional engineering course and illustrating how a commercial simulation platform (ANSYS) can function as a pedagogical scaffold across modules and workplace contexts.

This paper details how the academic team at the Department of Engineering, University of Staffordshire has embedded SF-PBL into its Manufacturing Engineer degree apprenticeship course, using ANSYS as a central tool. In this regard, a specific module (Computational Fluid Dynamics-CFD) has been selected and the pedagogical rationale and practical implementation of SF-PBL for the proposed module are discussed. In addition, the Academic Performance and Student feedback of two cohort of students in absence and presence of SF-PBL are compared to assess the impact of SF-PBL on learners' performance and feedback in an engineering module.

Pedagogical Rationale

SF-PBL is underpinned by a strong theoretical foundation. Active learning literature suggests that students in technology and engineering related disciplines taught using interactive methods perform significantly better than those taught via traditional lectures (Freeman et al., 2014; Aji and Khan, 2019). According to Sweller's (1988) Cognitive Load Theory, well-structured simulation environments can reduce extraneous burden while enhancing learners' ability to process and retain complex information. Similarly, Kolb's (1984) Experiential Learning Theory emphasises the cyclical process of doing, reflecting, thinking, and acting which is a natural fit for simulation-based problem-solving

Moreover, simulation-supported inquiry aligns with the needs of adult learners. Knowles et al. (2015) argue that adult learning is most effective when it is self-directed, relevant, and grounded in experience. Engineering apprentices, who often balance work responsibilities with academic requirements, benefit from learning that mirrors workplace realities and gives them agency in solving practical problems. SF-PBL also supports the principles of Work-Based Learning (WBL), a model in which learning is situated in real-life contexts, and formal education complements informal knowledge gained through practice (Fergusson, 2022; Roney et al., 2015). SFPBL draws on a multidisciplinary set of pedagogical theories that support both skill acquisition and conceptual understanding.

Constructivism

At its core, SFPBL is highly constructive in its approach to learning. Learners build knowledge through active engagement with problems, using simulations to explore the consequences of their decisions. Constructivism emphasises the importance of context, prior knowledge, and reflection-all of which are central to SFPBL (Vygotsky, 1978).

Kolb's Experiential Learning Cycle

David Kolb's experiential learning model (1984) provides a particularly relevant framework for SFPBL. The four stages-Concrete Experience, Reflective Observation, Abstract Conceptualisation, and Active Experimentation-map directly onto the SF-PBL. For example, running a thermal analysis in ANSYS provides the concrete experience, reflection occurs during review and discussion, conceptualisation through linkages to thermodynamics theory, and experimentation through modifying the model or applying it to new workplace contexts, such as optimising heat exchanger performance or evaluating thermal management in battery systems.

Information Processing and Cognitive Load

Simulation environments such as ANSYS are cognitively demanding. However, when designed well, they activate deeper processing by visualising abstract phenomena (e.g. stress concentration or fluid vortices), thereby promoting long-term retention. Sweller's Cognitive Load Theory (1988) reminds educators to structure tasks in ways that reduce extraneous load while promoting germane cognitive activity-highlighting the need for scaffolded simulation instruction.

Bloom's Taxonomy

Traditional teaching often operates at the lower levels of Bloom's taxonomy - remembering and understanding (Anderson & Krathwohl, 2001). SFPBL pushes learners to analyse, evaluate, and create. For instance, when an apprentice modifies the geometry of a mechanism or component and uses ANSYS to evaluate new stress distributions, they are engaging in higher order thinking like that required in professional design review processes. Such tasks mirror how engineers critically assess design alternatives, justify decisions, and ensure that proposed solutions meet performance and safety requirements.

Adult Learning and Situated Cognition

Apprentices are adult learners with clear expectations of relevance and application. According to Knowles et al. (2015), adult learners are most engaged when learning is problem-centred, self-directed, and applicable to their work. SFPBL delivers all three, especially when scenarios are co-designed with industry mentors and grounded in authentic workplace needs, such as the development of meta-skills including problem-solving, adaptability, collaboration, and reflective judgment that are critical for effective engineering practice.

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Methodology

At the University of Staffordshire, SF-PBL is integrated across several modules in the engineering curriculum. These include Computational Fluid Dynamic (CFD), Structures and FEA, and Individual Engineering Project. This study is performed using a mixed-methods evaluation design to examine the impact of SF-PBL within the Mechanical Engineering/Manufacturing Engineer Degree Apprenticeship programme at the University of Staffordshire. The effectiveness of introducing SF-PBL in a module titled CFD was selected for this study. The CFD module relies heavily on high-level mathematical assessment and provided an opportunity to improve the module outcomes by implementing SF-PBL using 100% portfolio-based assessment utilising ANSYS simulations. The 2022/23 cohort exhibited a 31% first-time failure rate, and only 45.5% of students felt the module developed skills for their future careers.

Implementation was assessed across two academic years, and a comparative cohort study was conducted to evaluate the impact. The performance and feedback of the 2022/23 cohort (pre-implementation, assessed via exam and portfolio) were compared with the 2023/24 cohort (post- implementation, assessed via a 100% portfolio). To compare the performance and outcomes, following data sources were used:

- **Academic Performance Data:** Aggregate final grade (anonymous) data for all enrolled students for both the cohorts was collected. The number of participants for this data were 64 and 50 respectively for the years 2022/23 and 2023/24.
- **Student Feedback Data:** At the end of each academic year, official module evaluation data was collected via the university's EvaSys system for both the cohorts. Participation was voluntary and anonymous with number of participants being 11 and 19 respectively for 2022/23 and 2023/24.

Results and Discussion

Across the two cohorts (2022/23 and 2023/24), academic performance data and student feedback survey responses were collected, and results are summarised in Figures 1 and 2 below. Results of students’ performance comparison across the two cohorts are indicated in Figure 1 whereas the students’ feedback data is shown in Figure 2. The results Responses included both quantitative ratings and open-ended qualitative comments on learning effectiveness, workload, engagement, and relevance to industry practice.

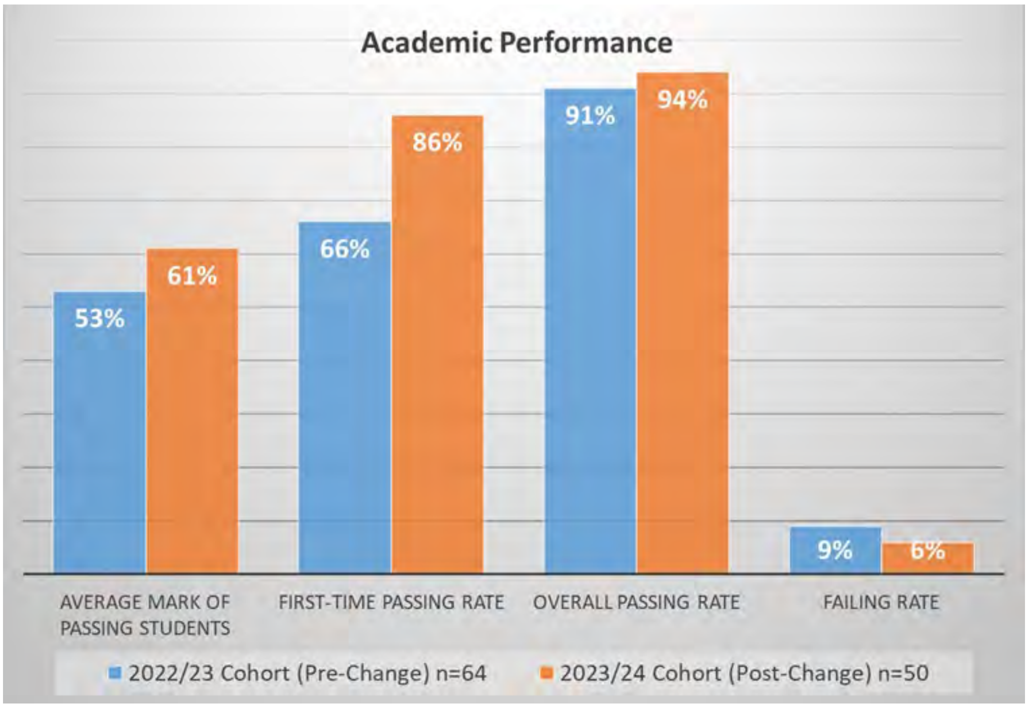

Figure 1. Academic performance data of cohorts before and after implementing change

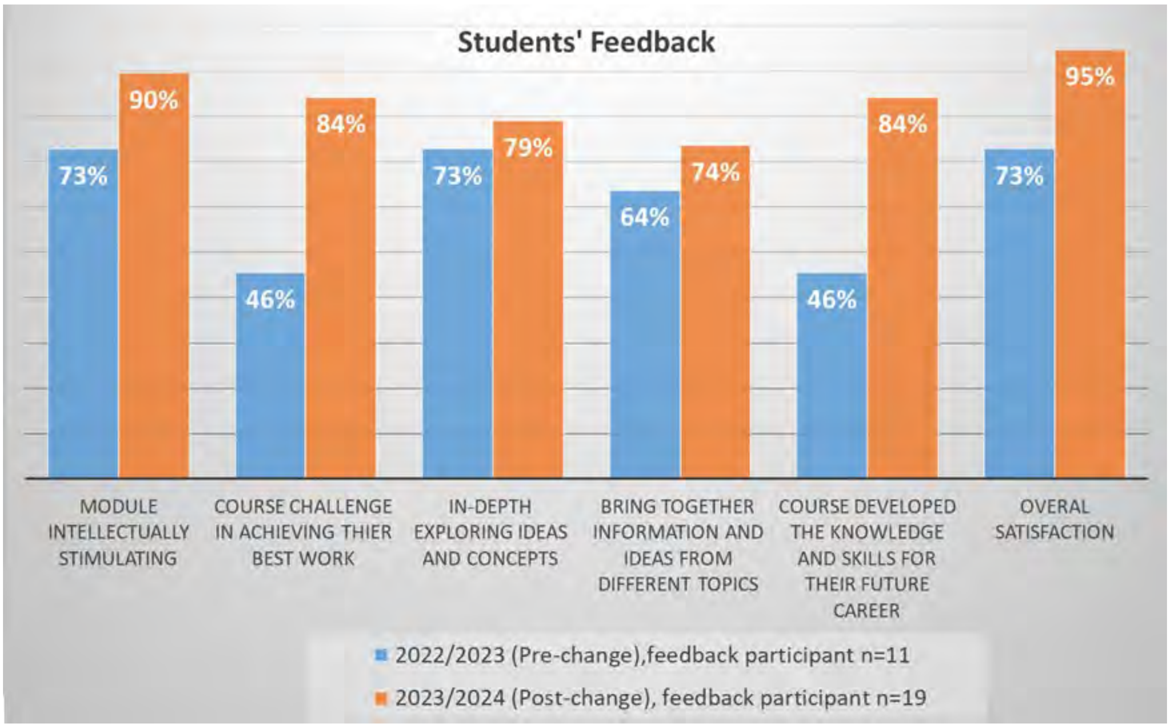

Figure 2. Students feedback data of cohorts before and after implementing change

Academic Performance

The performance data across the two cohorts show a clear positive trend following the implementation of SF-PBL using ANSYS. The cohort exposed to SF-PBL achieved higher average marks, a substantial improvement (from 66% to 86%) in first-time pass rates, and a small but positive rise (91% to 94%) in the overall pass rate compared with the previous year. The pattern clearly indicates that learners performed more strongly when simulation-based problem tasks formed the core of their learning.

This improvement aligns with well-established findings in engineering education that active and inquiry-driven approaches lead to higher student achievement compared with traditional lecture-centred instruction. Freeman et al. (2014) found that active learning consistently improves success rates in STEM subjects, mainly because students must apply, evaluate, and test their understanding rather than simply memorise concepts. SF-PBL achieves this by requiring learners to build, run and refine simulation models to solve authentic engineering problems. This encourages deeper engagement and more frequent interaction with the subject matter.

Also, simulation environments like ANSYS provide learners with visual and interactive representations of abstract engineering phenomena (e.g. stress concentrations, flow separation, or thermal gradients) which helps in accelerating the conceptual understanding. Sweller’s Cognitive Load Theory emphasises that well-designed visual tools reduce unnecessary mental burden, allowing learners to focus on core conceptual relationships (Sweller, 1988). The higher average marks observed in the SF-PBL cohort are consistent with this principle: simulation-driven tasks enabled learners to better internalise and apply theoretical content. The increased performance also aligns with literature showing that simulation-enhanced PBL develops transferable engineering competencies such as problem-solving, design judgement and critical evaluation (Negahban A., 2024). These competencies help students navigate complex assessment tasks more confidently, which aligns with the trend seen in the performance data.

Students’ Feedback

The feedback data also showed a similar positive shift. Across the evaluated modules, apprentices from the SF-PBL year reported stronger levels of satisfaction, deeper intellectual engagement, and higher perceptions of relevance to their professional practice. Notably, there were large increases in students agreeing that the module “challenged [them] to achieve [their] best work” and that the module developed “knowledge/skills useful for [their] career.” These findings highlight that learners viewed SF-PBL not only as academically rigorous but also as directly applicable to real-world engineering tasks.

This aligns well with adult learning theory, which emphasises that adult learners are most motivated when tasks are relevant, problem-centred and connected to their workplace experiences (Knowles et al., 2014). Because the simulation tasks mirrored the types of analysis apprentices encounter in industry (e.g. structural evaluation, fluid flow modelling, and design optimisation etc.) learners recognised immediate value in the approach. Their feedback therefore reflects the increased authenticity and applicability that SF-PBL offers.

The marked rise in overall satisfaction clearly indicates that students experienced SF-PBL as a more coherent and meaningful learning approach. SF-PBL provides a structured way for apprentices to integrate theory with practice, aligning well with the principles of situated cognition, which argue that meaningful learning occurs when knowledge is embedded in authentic tasks and contexts (Raelin, 2008). The improvements in the feedback also relate strongly with previous studies showing that integrating simulation with PBL strengthens learners' confidence, encourages independent exploration, and supports higher-order cognitive skills such as analysis, evaluation, and creation (Savery, 2006, 2015).

Although this study focuses on engineering apprenticeships and uses ANSYS as an illustrative tool, the SF-PBL framework itself is highly transferable to other vocational and professional domains. Many sectors already rely on simulation-based environments—such as clinical decision-making in healthcare (Souza et al., 2025), flight and safety simulators in aviation (Cross and Ryley, 2024), digital twins in manufacturing (Cao et al., 2024), and immersive scenario training in emergency services (Eisenhardt and Ninassi, 2016). In these contexts, learners engage in problem-centred decision-making, reflective practice, and iterative experimentation, which align directly with the principles of constructivism, experiential learning, and adult learning. SF-PBL therefore offers a flexible pedagogical model that can be adapted to different simulation platforms and disciplinary needs, supporting deeper understanding, skill development, and authentic workplace engagement across a wide range of industries.

Conclusion

The introduction of SF-PBL using ANSYS has had a noticeably positive impact on both the performance and the experience of learners within the engineering degree apprenticeship programme. The performance data of CFD module show clear improvements in average marks (increased from 53% to 61%), first-attempt pass rates (increased from 66% to 86%) and overall student satisfactions (increased from 73% to 95%), indicating that apprentices were better able to meet assessment expectations and apply engineering principles when learning was blended in simulation-driven problem-solving. These improvements align with well-established evidence that active, inquiry-based pedagogies support deeper conceptual understanding and higher academic achievement in STEM disciplines.

Learners' feedback results also reinforce these improvements. Apprentices reported higher levels of engagement, stronger perceptions of intellectual challenge and, importantly, a significantly enhanced sense of relevance to their professional practice (Increased from 46% to 84% in the students' agreement that the course developed the knowledge and skills for their future career). This reflects key principles of adult learning and situated cognition, where learners value tasks that closely relate to the real-life contexts and allow them to apply theory directly to practice. The use of ANSYS within SF-PBL precisely provided this realism, enabling apprentices to explore complex engineering phenomena in a realistic, iterative, and visually intuitive manner. Such experiences support the reduction of cognitive load and promote the kind of experiential learning emphasised in Kolb's learning cycle.

Overall, the results suggest that SF-PBL offers a powerful pedagogical framework for engineering apprenticeship curricula. It supports and enhances conceptual understanding, increases learner confidence, and strengthens the development of transferable design and analysis skills. All these skills are central to producing work-ready engineers. While continued evaluation will allow for a more comprehensive assessment of long-term impact, the present findings demonstrate that embedding SBPL in the curriculum is both pedagogically sound and highly valued by learners. As engineering education continues to evolve in response to industry needs, SF-PBL provides a robust, theory-informed approach that effectively bridges academic study with professional practice. Although the SF-PBL framework demonstrated here in engineering, it is widely transferable. Many sectors already use simulation-based environments, and the model's emphasis on problem-centred learning, reflection, and experiential practice aligns well with their training needs. As a result, SF-PBL offers a flexible approach that can enhance skill development and authentic workplace learning across diverse professional domains.

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