A Framework for Implementing Flexible Project-Based Learning for Computing Education in Resource-Constrained Environments: A Case Study of the Namibia University of Science and Technology

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Abstract
Project-based and problem-based learning (PBL) has gained recognition as an effective pedagogical method for developing essential for employability skills. However, implementing PBL in resource-constrained environments poses significant challenge in these environments due to the limited infrastructure and institutional barriers (Okai-Ugbaje et al., 2022). This paper introduces the Flexible Project-Based Learning (FPBL) framework designed to facilitate the adoption in such environments though a three-tiered approach: the Basic Tier (minimal resources), Standard-Tier (moderate resources) and Advanced-Tier (comprehensive resources). Each layer incorporates Aristotle's four causes as structural pillars. Prelimary results from a case study at the Namibia University of Science and Technology involving focus groups with faculty (N = 5), industry stakeholders (N = 15), student representatives (N = 2) and administrative support staff (N = 4). Preliminary results from a case study at the Namibia University of Science and Technology (NUST) indicate that access to industry-grade infrastructure, partnerships, and readiness are essential for effective PBL implementation. The framework offers a possibly scalable solution for computing education in resource-constrained environments.

Keywords: Project-based learning, computing education, resource constrained environments, flexible framework, developing economies

1 Introduction

The computing field has been experiencing exponential growth and transformation, requiring Higher Education Institutions (HEIs) to continuously adapt their curricula to equip graduates with skills relevant to industry demands (Saad & Zainudin, 2024). Traditional teaching methods, with their focus on knowledge transfer and acquisition, are increasingly inadequate for preparing students for the dynamic challenges of the modern workplace (Akour & Alenezi, 2022).

Project-Based Learning and Problem-Based Learning (collectively referred to as PBL) have emerged as viable alternatives to bridge the gap between academic knowledge and industry practices. These approaches engage students in authentic real-world challenges through extended projects and systematic problem-solving inquiries (Kokotsaki et al., 2016). However, while PBL has proven effective in well-resourced environments, its implementation in resource-constrained settings remains fraught with challenges.

Resource-constrained environments in this context are defined as settings characterized by limited access to reliable electricity, high-cost internet connectivity, low-bandwidth networks, insufficient access to industry-standard hardware and software, and cultural barriers such as limited digital literacy (Magunje, 2024). These constraints directly impact PBL implementation in several critical ways. The implementation of PBL practices in resource-constrained environments faces multiple interconnected challenges that significantly impact educational outcomes (UNESCO, 2025). These foundational constraints further limits students' ability to participate in authentic project experiences that mirror professional environments (Magunje, 2024). Moreover, persistent connectivity issues create additional obstacles by disrupting real-time collaboration capabilities and preventing consistent access to online resources that are critical for effective problem-solving activities (Wawak, Domingues & Sampaio, 2024). The challenges extend beyond technological limitations to encompass broader systemic issues, particularly the scarcity of industry partnerships which significantly reduces opportunities for students to engage with authentic project contexts (Bozalek et al., 2013). These interrelated barriers create a complex web of challenges that must be addressed holistically to enable effective PBL in resource-constrained educational settings.

The Namibia University of Science and Technology (NUST) exemplifies these challenges. Despite adopting flexible hybrid learning policies, NUST's Faculty of Computing and Informatics operates with limited digital infrastructure, large student cohorts, and internet connectivity challenges. These constraints hinder the effective implementation of transformative pedagogies, creating a critical gap between academic preparation and industry requirements (Chipere, 2017).

Computing industry stakeholders consistently report that graduates require up to six months of additional training before achieving workplace productivity (NUST Bachelor of Informatics Honours Programme Advisory Committee feedback, 2024). This highlights the pressing need for innovative pedagogical approaches that can function effectively within resource constraints while improving graduates' employability and professional proficiency.

This paper proposes the Flexible Project-Based Learning (FPBL) framework to facilitate the adoption of combined project-based and problem-based learning approaches for computing education in resource-constrained environments.

2 The FPBL Framework

The proposed FPBL framework attempts to address the challenges of implementing PBL in resource-limited settings by combining both project-based learning (focused on creating tangible products or solutions) and problem-based learning (emphasising systematic inquiry and problem-solving processes).

Based on Aristotle's four causes, the FPBL framework provides a systematic approach for PBL implementation, ensuring adaptability and effectiveness across varying resource contexts. The four causes serve as analytical pillars. The FPBL framework is structured around four fundamental causal dimensions that shape the educational experience.

The Material Cause encompasses the resources, tools, and infrastructure required for effective learning, serving as the foundational layer that enables all educational activities. This dimension includes everything from hardware and software to learning spaces and technological platforms that students and educators utilize. The Formal Cause defines the structure and methodology of learning experiences, establishing how educational content is organized, delivered, and assessed. It represents the pedagogical architecture that gives shape to the learning process, including project designs, curriculum frameworks, and instructional strategies.

The Efficient Cause focuses on the human agents and their roles in the learning process, recognizing that education is fundamentally a human endeavor driven by the interactions between faculty, students, industry partners, and other stakeholders. These agents serve as the catalysts who activate and guide the learning journey through their expertise, collaboration, and mentorship.

Finally, the Final Cause articulates the intended learning outcomes and objectives, representing the ultimate purpose and goals of the educational experience. This dimension encompasses the competencies, skills, and capabilities that learners are expected to develop, ranging from fundamental technical abilities to advanced innovation capacities and industry readiness. Together, these four causal dimensions create a comprehensive framework that addresses both the practical requirements and philosophical foundations of PBL in computing education.

2.1 The Basic Tier (Minimal Resources)

The Basic Tier provides an entry point for institutions with severely limited resources. This tier emphasizes offline capabilities and locally available technologies to minimize infrastructure dependencies. The tier emphasises the need of institutions to operate with minimal resources, for example, utilising open-source software, offline educational materials, basic computing equipment, and locally available technology. This tier specifically addresses contexts where reliable internet connectivity and expensive software licenses are unavailable (Agbeyangi & Suleman, 2024), ensuring that resource constraints do not become barriers to quality computing education.

The formal cause suggests that institutions should emphasise small-scale, contextually relevant projects that combine both product creation and problem-solving inquiry, where students engage in community-based challenges using available resources to develop both technical solutions and analytical thinking skills. The driver of the implementation is primarily faculty and student-driven initiatives with minimal external stakeholder involvement. The ultimate goal is the development of fundamental computing competencies, adaptability skills, and context-specific problem-solving abilities that directly address local community needs, ensuring that even in resource-constrained environments, students acquire essential skills that are immediately applicable to their local context.

2.2 The Standard Tier (Moderate Resources)

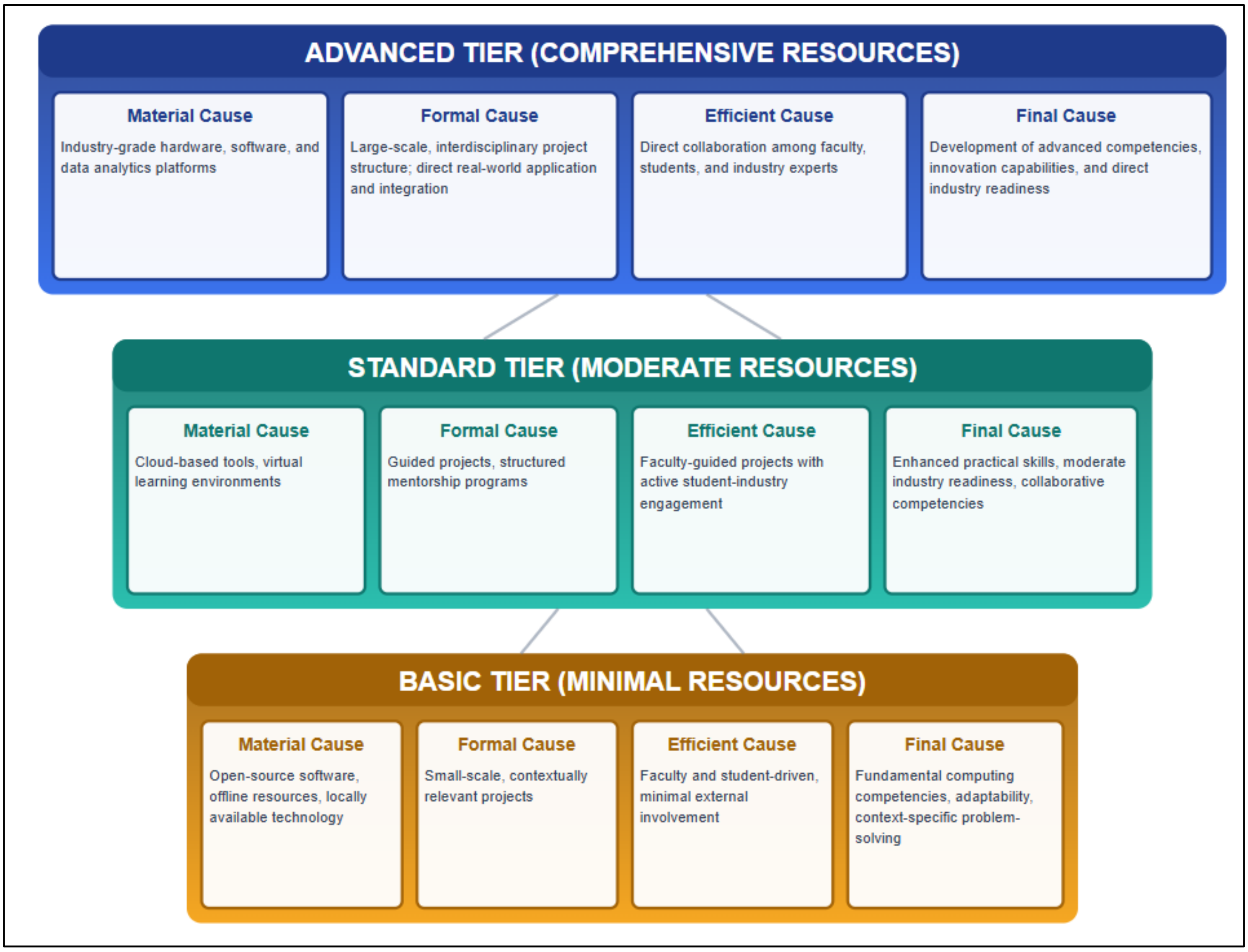
The Standard Tier targets institutions with moderate resource availability and some infrastructure stability. These institutions have the ability to leverage cloud-based tools, virtual learning environments and have periodic access to industry-standard software. The institutions exhibit improved connectivity infrastructure and the potential to harness emerging technologies while maintaining cost-effectiveness (Hu & Raman, 2024). The formal cause encompasses guided projects and structured mentorship programs that integrate both extended project work and systematic problem-solving methodologies, enabling students to engage in medium-scale challenges with industry relevance. The efficient cause manifests through enhanced collaboration involving faculty, students, and limited industry partnerships, where external mentors provide periodic guidance while faculty maintain primary oversight responsibilities. These final cause represents an integrated approach that ensures that students develop both technical proficiency and professional capabilities within a resource-conscious framework.

2.3 The Advanced Tier (Comprehensive Resources)

The Advanced Tier targets institutions with comprehensive resources and strong infrastructure capabilities, providing the foundation for sophisticated project-based learning experiences. At its material foundation, this tier leverages industry-grade hardware, professional software licenses, advanced data analytics platforms, and reliable high-speed connectivity, creating an environment that enables authentic professional experiences (Hernández-de-Menéndez et al., 2019). The formal structure encompasses large-scale, interdisciplinary projects that incorporate both extensive product development and complex problem-solving scenarios, establishing direct industry collaboration and real-world application that extends beyond traditional academic boundaries. This ambitious scope is realized through the efficient cause of direct collaboration among faculty, students, and industry experts, which creates dynamic learning environments that effectively bridge academic and professional contexts. However, as Khlaif, Hamamra, and Hussein (2025) cautions, institutions must carefully maintain educational objectives and avoid unhealthy dependence on industry partners that might compromise pedagogical goals, ensuring that commercial interests don't overshadow learning outcomes. The ultimate purpose of this tier manifests in the development of advanced competencies, innovation capabilities, direct industry readiness, and leadership skills necessary for immediate professional contribution, preparing graduates who can seamlessly transition into demanding professional roles.

It's crucial to understand that the framework's tiered structure should not be viewed as strictly hierarchical, where the Advanced tier is inherently "best" or most desirable. Rather, each tier represents an appropriate adaptation to specific resource contexts while maintaining educational quality and relevance, acknowledging that excellence in education can be achieved through different pathways. The choice of tier depends on institutional capacity, student needs, and available resources rather than prestige or aspiration. It is important to recognise that effective PBL can be implemented successfully across varying resource environments when thoughtfully adapted to local contexts and constraints (Omelianenko & Artyukhova, 2024).

Figure 1: The FPBL Framework



3 Implementation and Evaluation Methods

The FPBL framework is currently in the design phase at NUST, with planned integration into new postgraduate certificate programs emphasizing combined project-based and problem-based learning philosophies. The implementation follows a phased approach tailored to NUST's specific resource constraints and institutional context.

3.1 Implementation at NUST:

The initial framework development involved extensive consultation with NUST's Programme Advisory Committee (PAC), which includes industry representatives, faculty, students, and alumni. The PAC ensured alignment between the preliminary framework and both industry requirements and institutional objectives. This collaborative approach addressed curriculum standards, exit-level outcomes, content structure, and industry partnership facilitation essential for authentic project and problem-solving experiences.

3.2 Evaluation Methods:

While comprehensive evaluation is pending implementation, initial feedback from comparative case studies informed framework development. Analysis of successful PBL implementations at Aalborg University (Denmark), known for its problem-based learning model, and Riga Technical University (Latvia), recognized for project-based approaches, provided valuable insights for adapting the FPBL framework to NUST's context.

3.3 Data Collection:

Initial data collection included PAC focus group interviews (N = 26), individual interviews with experts from benchmarking institutions, and observational studies at Aalborg University to evaluate framework components and their significance for resource-constrained environments.

3.4 Future Implementation:

The FPBL framework will be piloted in upcoming postgraduate certificate programs at NUST using the tiered approach. Each tier will be assessed for effectiveness in addressing resource constraints while achieving educational outcomes. The PAC will maintain oversight responsibilities, providing continuous feedback to ensure framework effectiveness and relevance.

4 Challenges, Lessons Learned, and Future Perspectives

4.1 Challenges

The PAC identified several implementation challenges specific to resource-constrained environments. Insufficient technological infrastructure remains a primary barrier, as limited access to industry-standard tools restricts authentic project and problem-solving experiences. Institutional resistance to pedagogical change, particularly from faculty perceiving PBL as additional workload, presents significant obstacles. Faculty and administrators often hesitate to transition from traditional lecture-based methods to PBL approaches, especially with large student cohorts common in developing contexts.

Resource volatility poses unique challenges for small economies like Namibia, where limited access to industry partnerships can hinder sustained project progression and long-term initiative maintenance. Additionally, policy constraints and rigid national educational frameworks may limit pedagogical innovation beyond resource limitations alone.

4.2 Lessons Learned

Several critical insights emerged from the framework design process. Flexibility is paramount; the tiered approach enables institutions to adapt to varying resource levels while ensuring continuity and sustainability. Industry collaboration proves essential but must be carefully managed to maintain educational objectives while providing authentic learning experiences. Faculty development emerged as crucial, requiring regular professional development workshops to equip educators with necessary pedagogical skills for confident PBL facilitation.

4.3 Future Perspectives

Future developments focus on framework expansion and refinement. Extending the framework to additional institutions with similar socio-economic contexts may enhance relevance and applicability, enabling broader student access to innovative pedagogical approaches. Incorporating FPBL into formal institutional policies could facilitate wider adoption, embedding it more thoroughly within computing education programs across developing contexts.

5 Critical Reflections and Implications for Other Contexts

The FPBL framework represents both a pedagogical and institutional approach to computing education in resource-constrained environments. While maintaining core PBL educational principles of active learning, collaboration, and authentic problem-solving, FPBL necessarily incorporates organizational and technical adaptations to function within resource limitations.

Key educational differences between traditional PBL and FPBL include: (1) explicit resource-constraint consideration in pedagogical design, (2) flexible implementation allowing for offline and low-technology approaches, (3) community-based problem contexts replacing industry-standard scenarios when necessary, and (4) tiered progression enabling institutional growth and development over time.

The framework addresses industry expectations, institutional challenges, and resource variability while fostering an educational ecosystem connecting theoretical learning with practical applications. The tiered approach enables effective PBL implementation regardless of resource limitations, thereby improving computing education quality and impact in developing contexts.

The framework's adaptability, collaboration focus, flexibility, and practical application orientation make it a significant resource for practitioners and policymakers implementing technology-enhanced learning in constrained contexts. Implementation insights from NUST provide guidance for other institutions facing similar challenges, facilitating transformation toward sustainable educational practices that maintain pedagogical integrity while acknowledging resource realities.

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