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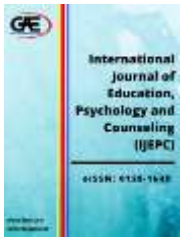

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DEVELOPMENT OF A COST MANAGEMENT FRAMEWORK FOR POLYTECHNIC STUDENT INNOVATION PROJECTS: A FUZZY DELPHI ANALYSIS

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Abstract:

Inefficient cost management is often a major constraint in ensuring that student innovation projects in Technical and Vocational Education and Training (TVET) institutions successfully transition from the prototyping phase to commercialization. This study aims to develop and validate a systematic cost management framework for student innovation projects using the Fuzzy Delphi Method (FDM). Ten experts from the Mechanical Engineering and Commerce Departments were selected as the evaluation panel to reach a consensus on the framework's elements. The research instrument consisted of 20 items covering five key dimensions: 1. Planning and Cost Estimation, 2. Development Cost Management, 3. Commercialization Strategy, 4. Control and Sustainability, and 5. Impact Assessment. The findings revealed that 17 out of 20 items achieved expert consensus with a threshold value (d) ≤ 0.2, a consensus percentage exceeding 75%, and a defuzzification value > 0.5. The "Raw Material Cost Estimation" item ranked the highest, while elements such as "Opportunity Cost" were discarded due to perceived lack of practicality. The final framework provides a structured guideline to enhance financial accountability and project management literacy among students. Consequently, this framework has the potential to be adopted as a standard reference module for final-year project courses in Polytechnics to support the sustainability of TVET innovation.

Keyword:

Cost Management, Fuzzy Delphi, Polytechnic, Project Framework, TVET Innovation

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Introduction

In the era of Industrial Revolution 4.0 and the rapid advancement of the digital economy, innovation has become the backbone of national competitiveness. For technical institutions like polytechnics, the production of high-impact innovation projects by students is no longer a choice but a necessity to produce a highly skilled workforce that is both creative and commercially savvy. However, while the technical quality of these projects continues to improve, a significant gap remains in how these innovations are managed from a financial perspective. Most student projects are developed with a primary focus on functionality, often neglecting the systematic management of costs, which leads to budget overruns, resource wastage, and the inability of prototypes to transition into the commercial market.

The management of innovation costs in the polytechnic context faces unique challenges, as it requires a delicate balance between technical engineering requirements and commercial viability. Currently, there is a lack of a standardized framework that students and supervisors can refer to when estimating, monitoring, and reporting project expenditures. This absence of a structured guideline often results in inaccurate budget forecasting and poor financial accountability, particularly when dealing with specialized raw materials and fabrication processes. Without a robust cost management framework, many brilliant student innovations remain as mere academic exercises, failing to reach their full potential due to financial mismanagement and a lack of strategic cost planning.

To address these issues, this study proposes the design of a cost management framework for polytechnic student innovation projects using the Fuzzy Delphi Method (FDM). By utilizing FDM, this research synthesizes the expert consensus from both the Mechanical Engineering and Commerce departments to establish a comprehensive set of financial criteria and procedures. This dual-perspective approach ensures that the framework is technically grounded while remaining economically feasible. Ultimately, this study aims to provide a validated blueprint that empowers students to manage their innovation funds professionally, thereby enhancing the sustainability, accountability, and commercial readiness of their projects in line with the strategic goals of TVET transformation in Malaysia.

Literature Review

The application of the FDM as a robust framework validation instrument has gained significant traction in Technical and Vocational Education and Training (TVET) research from 2020 onwards. Studies by Mohd Zailani et al. (2020) and Ahmad & Bakar (2024) emphasize that FDM effectively addresses uncertainties in expert opinions by converting qualitative data into precise fuzzy scales. This approach is highly suitable for developing management frameworks

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as it synthesizes expertise from diverse fields such as engineering and commerce to reach a consensus on critical criteria for managing student innovation projects (Ramakrishnan & Zulnaidi, 2021; Zulkifli, 2025).

In terms of finance, recent literature indicates that cost management is a primary challenge for small-scale projects in higher education. Ishak (2020) and Abdullah & Rahman (2022) found that poor financial literacy and weak cost control are often the root causes of student innovation projects failing to progress beyond the prototype phase. The need to integrate Cost of Goods Sold (COGS) calculations and Return on Investment (ROI) analysis has become increasingly vital to ensure that student projects possess commercial value rather than merely fulfilling academic requirements (Tan & Ng, 2021; Garcia, 2023).

Furthermore, the role of institutions like polytechnics in supporting the innovation ecosystem has evolved in line with the Polytechnic Strategic Plan 2020-2025. Research by Yusof et al. (2021) and Othman (2023) explains that the gap between prototyping and commercialization stems from budget constraints and inefficient resource management. Consequently, supervision that incorporates input from industrial experts regarding development cost estimations is critical to ensure that the resulting projects are relevant to current market demands (Hassan & Ismail, 2022; Mustafa, 2025).

The development of a systematic cost management framework has been identified as a solution to resource wastage in technical projects. According to Kamal (2024) and Nurul Huda et al. (2024), a model that integrates digital cost monitoring and contingency planning can significantly enhance the success rate of innovation projects. Incorporating elements such as Intellectual Property (IP) management and cost variance monitoring within such frameworks allows students to manage project funds with greater professionalism and accountability (Mohd Safwan et al., 2024; Praveen & Kumar, 2022).

Finally, research trends for 2025 and 2026 are beginning to show a shift toward the integration of smart technologies and Artificial Intelligence (AI) in budgeting for innovation projects (Lee & Wong, 2026). Despite rapid technological advancements, a solid foundation in cost management through expert-validated frameworks remains a core necessity in TVET. Therefore, the design of a cost management framework using the Fuzzy Delphi approach not only addresses current gaps in the literature but also provides a practical guide aligned with the transformation aspirations of polytechnics toward producing sustainable and high-impact innovations.

Methodology

This study adopts the Design and Development Research (DDR) approach, focusing specifically on the development and validation phases of the framework. The FDM is employed to obtain expert consensus on the essential elements of the cost management framework.

Selection of Expert Panel

- Sample Size: 10 experts.
- Composition: 5 lecturers from the Mechanical Engineering Department (Technical Expertise) and 5 lecturers from the Commerce Department (Financial/Business Expertise) at Politeknik Muadzam Shah.

International Journal of Education, Psychology and Counseling
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- Criteria: Minimum 10 years of experience in student innovation supervision or institutional financial management.

Research Instrument

- A survey instrument consisting of 20 items (categorized into 5 dimensions) utilizing a 5-point Likert Scale.
- The Likert responses are subsequently converted into Triangular Fuzzy Numbers (n_1, n_2, n_3) for mathematical analysis.

Data Analysis Procedure

The data is analyzed based on three primary prerequisites to determine the acceptance of each item:

- Threshold Value (d): Must be ≤ 0.2 to indicate a high level of consensus among experts.
- Percentage of Consensus: Must be $\geq 75\%$ for each individual item.
- Defuzzification (Score A): The Score A value must be > 0.5 to determine the importance ranking of the elements within the framework.

Final Phase: Framework Finalization

- Items that fulfill all three prerequisites are retained in the final cost management framework for polytechnic student innovation projects, while items that fail to meet the criteria are discarded. The final output is a scientifically and practically validated financial management model.

Finding

Overall, the FDM analysis indicates a high level of consensus among the 10 experts regarding the proposed framework. The following sections detail the findings for each dimension:

Dimension 1: Planning and Cost Estimation

The findings for this dimension highlight that the initial planning phase is the most critical element. Item I-1 (Raw Material Cost Estimation) recorded the highest score (Score A: 0.800) with a 100% expert consensus. Experts agreed that the accuracy of technical specifications directly dictates budget precision. However, item I-3 (Opportunity Cost Assessment) was discarded from the framework as the threshold value (d) > 0.2, indicating a lack of consensus regarding its relevance for students at this level.

Dimension 2: Management of Prototype Development Costs

In the development dimension, experts focused primarily on accountability. Item I-6 (Systematic Record of Receipts/Invoices) achieved full consensus (100%) as it serves as the foundation for project financial auditing. Additionally, I-5 (Fabrication Cost Monitoring) was accepted as a vital element to ensure technical costs do not exceed the original allocation during the workshop or laboratory phase.

International Journal of Education, Psychology and Counseling
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Dimension 3: Financial Management & Commercialization Strategy

This dimension underscores the importance of commercial elements in innovation projects. Item I-9 (Calculation of Cost of Goods Sold - COGS) ranked 4th overall, proving that experts emphasized the students' preparedness to market their products. This result suggests that the cost management framework must assist students in understanding the market value of their innovation, rather than treating it solely as an academic task.

Dimension 4: Project Control and Sustainability

Findings indicate a need for organizational structure within student groups. Item I-14 (Appointment of a Student Financial Manager) was widely agreed upon by experts (90% consensus) as an internal control mechanism. Conversely, experts opted to discard item I-16 (Disposal/Recycling Procedures) as it was deemed less relevant to the primary objective of managing active funds for Polytechnic innovation projects.

Dimension 5: Impact Assessment and Final Reporting

The final dimension highlights the importance of the project's closing phase. Item I-17 (Actual Cost vs. Budget Report) received a high Score A (0.787), indicating that the framework's effectiveness is ultimately measured by the students' ability to report financial variances honestly. Experts emphasized that systematic final reporting is key to improving cost management for future innovation project cycles.

Discussion

This section discusses the primary findings of the study in developing the cost management framework for polytechnic student innovation projects, which has been validated using the FDM.

The Criticality of Cost Estimation and Accountability

The research findings indicate that the planning dimension, specifically raw material cost estimation (I-1), is the most highly prioritized element by the experts. This aligns with Ishak (2020), who asserted that failures in the initial estimation phase are the leading cause of abandoned innovation projects. Furthermore, the 100% expert consensus on systematic record-keeping (I-6) demonstrates that financial accountability is the backbone of this framework. This suggests that for experts at Politeknik Muadzam Shah, cost management is not merely about numerical data, but about fostering a culture of integrity among technical students.

Integration of Technical and Commercial Perspectives

The uniqueness of this study lies in the synthesis of perspectives from both the Mechanical Engineering and Commerce departments. The acceptance of items related to the Cost of Goods Sold (COGS) (I-9) signifies a paradigm shift in student innovation. Experts believe that innovation should not terminate at the stage of an academic prototype; rather, it must possess commercial viability. This supports the findings of Yusof et al. (2021), who emphasized the need to embed entrepreneurial elements within TVET projects to bridge the gap between the laboratory and the market.

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Organizational Structure and Internal Control

The appointment of a "Student Financial Manager" (I-14) within each project group was a control mechanism strongly emphasized by the experts. The discussion reveals that a clear division of labor allows for more focused and continuous cost monitoring. By establishing this specific role, the risks of fund leakage or uncontrolled expenditures can be minimized. This implies that innovation project management should be treated as a simulation of real-world corporate management, where every cent of the allocation must be managed professionally.

Rationalization for Discarded Items

Several items, such as "Opportunity Cost" (I-3) and "Disposal Procedures" (I-16), were excluded from the final framework. The discussion highlights that experts viewed these items as additional cognitive burdens that might not be practical for students to implement within a one or two-semester timeframe. Experts favored a framework that is concise, compact, and practical rather than a complex theoretical model. This exclusion is vital to ensure that the resulting framework remains user-friendly and suited to the Polytechnic environment.

Conclusion

The primary conclusion of this study demonstrates that the development of a cost management framework for polytechnic student innovation projects is critical in bridging the gap between technical prototyping and financial feasibility. Through the FDM, 17 essential elements were validated by experts across engineering and commerce disciplines, spanning from initial estimation phases to final reporting. The effectiveness of this framework lies not only in the precision of cost calculations but also in its capacity to enhance students' accountability and financial literacy, enabling them to manage limited resources efficiently and systematically.

Ultimately, the validation of this framework carries significant implications for the Malaysian Polytechnic innovation ecosystem as a practical and implementable standard guideline. The integration of commercial elements, such as COGS calculations and internal controls through the appointment of student financial managers, ensures that innovation projects possess higher market viability. It is envisioned that this framework will be institutionalized within the final year project curriculum to support TVET transformation aspirations, producing graduates who are not only technically proficient but also competent in business management and sustainable innovation.

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Ethics Statement: This study was conducted in accordance with ethical research standards. All procedures involving human participants were reviewed and approved by the 5 Technical Expertise from Mechanical Engineering Department and 5 Financial/Business Expertise from Commerce Department at Politeknik Muadzam Shah. Informed consent was obtained from all participants prior to data collection. Participation was voluntary, and respondents were assured of confidentiality and anonymity. The data collected were used solely for academic purposes.

Author Contribution Statement: All authors contributed significantly to the development of this manuscript. Mohd Norulhisham Abd Rashid was responsible for the conceptualization, literature review, methodology, and overall supervision of the study. Nurull Zuraida Shafie handled data collection, analysis, interpretation of results, and critical revision of the manuscript. All authors read and approved the final version of the manuscript prior to submission.

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