

Design-Based Learning and Sustainable Competitive Advantage in Mechanical Education: Role of Engineering Learning Outcomes and Change Management Awareness

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ABSTRACT

Purpose: This study examines how Design-Based Engineering Learning contributes to Sustainable Competitive Advantage in engineering colleges by explaining the underlying role of Technology change management and the conditional influence of Change Management Awareness. Although design-oriented pedagogies are widely promoted in mechanical education, empirical evidence remains limited regarding their translation into change-handling capabilities and long-term strategic outcomes. This research addresses this gap by investigating both the direct and indirect relationships among the study variables. **Method:** Data were collected from 253 students enrolled in different engineering programs across engineering colleges using a structured questionnaire. Established measurement scales were adopted from prior studies. Partial Least Squares Structural Equation Modeling (PLS-SEM) was employed to test the proposed relationships, including mediation and moderation effects. **Findings:** The results reveal that Design-Based Engineering Learning has a significant positive influence on Technology change management and Sustainable Competitive Advantage. Technology change management plays a significant mediating role in the relationship between Design-Based Engineering Learning and Sustainable Competitive Advantage, indicating that learning-driven design capabilities are realized through effective management of technological change. Additionally, Change Management Awareness significantly strengthens the relationship between Design-Based Engineering Learning and Technology change management. **Originality/Implications:** This study provides a process-based explanation linking Design-Based Engineering Learning to Sustainable Competitive Advantage by integrating Technology change management and Change Management Awareness into a unified model, offering theoretical and practical insights for engineering education institutions.

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1. Introduction

Design-based engineering learning has become a prominent nexus of mechanical education discourse especially with engineering curricula facing the twin challenges of accelerating technology change and the need to achieve sustainable competitive advantage. According to scholars, the conventional content-based pedagogies do not adequately prepare engineers to operate in the setting that is marked by pervasive technological disruption and intense strategic competition (Sidik et al., 2024). Design-based engineering learning has responded by being marketed as a process by which students are exposed to real-world problems of design, system-level integration, and iterative experimentation, and hence are able to bring educational processes to alignment with engineering complexity in the real world (Malhotra et al., 2023). Although this increased focus, the level of design-based engineering learning contribution to long-term strategic achievements in mechanical-education is a debated subject (Hazrat et al., 2023).

The central problem facing the discipline is the poor transfer of the pedagogical innovation into organizational and

technological flexibility (Idogawa et al., 2023). Institutions of mechanical education spend a lot of money in design oriented curriculum but fail to handle change that occurs in technology well or transfer learning in to Sustainable Competitive Advantage (Kossyva et al., 2024). According to previous research, design-based engineering learning boosts technical competence, but cannot necessarily provide learners and institutions with the ability to handle technology transitions (Ali Mohamad et al., 2023). This lack of connection has literally raised fears that design-oriented learning would result in the creation of competent engineers who are ill equipped to negotiate technology change processes entrenched within the modern engineering systems.

Previous studies have made efforts to solve this problem in various aspects. A branch of the literature provides positive cognitive and experiential outcomes of design-based engineering learning, where people have said they have improved their problem framing, creativity, and systems thinking (Khang et al., 2023). The other stream further expands this argument and states that openness to iterative design processes implicitly develops adaptability, which is a precondition to technology change management (Ullrich et al., 2023). But empirical evidence is still incongruent. The design-based pedagogies suggest that the pedagogies do not have formal structures to address the technological transitions, so they cannot be applied to change-oriented contexts (Malik et al., 2023). Likewise, according to Popoola et al. (2024), the success of learning is in most empirical studies, operationalized in the form of the academic (or project-based) results, as opposed to the technology change management capabilities.

Simultaneously, the literature in strategic management offers evidence to the fact that Sustainable Competitive Advantage is the result of the successful harmonization of the learning, innovation, and change potentials (Ajiga et al., 2024). However, this literature mostly does not address the origins of such abilities in education. Although learning is recognized to be a prerequisite resource, the contribution of design-based engineering learning as a precursor of sustainable competitive advantage is seldom investigated empirically (Jatobá et al., 2023). Consequently, current literature presupposes either a direct relationship between learning advantage and the competitive performance or explains competitive performance in terms of organizational processes that are independent of the educational design (van den Beemt et al., 2023). This division has created theoretical divisiveness between the education in engineering and strategic management research.

Still more recently, researchers have highlighted technology change management as a key process, which mediates learning-based capability with long-term strategic performance (Latifah et al., 2024). Technology change management can help organizations to assimilate, adopt, and freeze the changes in technology and, therefore, to make the available potential become realized advantage (van den Beemt et al., 2023). Nevertheless, the research of engineering education rarely places technology change management as a procedure that is shaped by design-based engineering learning (Ling et al., 2023). Rather, change management is regarded as a foreign managerial role, unaddressed questions that are the role of educational design in technological change preparedness in mechanical education systems remain (Kumar et al., 2024).

Another weakness of the previous research is related to the omission of change management awareness. The body of research on organizational change has shown that change rationale, processes, and implications awareness have a significant impact on the way individuals are introduced into the change initiatives (Abbasi Kamardi et al., 2025). Nevertheless, there is an implicit assumption in the studies of design-based engineering learning that there are no differences in the awareness of both learners and educators which is incorrect because it glosses over the difference in the results of technology change management in similar learning settings (Dash et al., 2023). Lack of change management awareness in the current models limits the knowledge of the factors in which design-based learning can be transformed into good technology change management. Taken together, the sets of debates demonstrate a vacuity in the literature (Washizaki, 2024). The design-based engineering learning, technology change management, change management awareness, and sustainable competitive advantage have not been adequately incorporated in one explanatory framework by previous studies (Slavković et al., 2023). In particular, the processes and conditions of the boundary under which design-oriented learning is involved in achieving sustainable strategic outcomes within the field of mechanical education are understudied (How & Cheah, 2024).

To fill this gap, the proposed research seeks to investigate design-based engineering learning as the underlying capability that can determine sustainable competitive advantage by the mediating effect of technology change management and explain this moderating effect through the moderating effect of change management awareness. Based on the dynamic capability theory (Abo-Khalil, 2024) and organizational change theory (Ugbebor et al., 2024), the current study offers a position of learning as a strategic antecedent, the value of which is achieved by the successful management of technological change. The research can make a contribution not only to the engineering education and strategic management literature, but also be able to explain the process through empirical integration of these constructs to create sustained competitive advantage in technologically dynamic, which would be relevant in mechanical education settings.

2. Literature Review

2.1 Design-Based Engineering Learning

Conceptualizations of design-based engineering learning the conceptualization of DBL as a pedagogical methodology that incorporates repetitive design, experimentation, and constraints of the real world into mechanical education (Li et al., 2024). Its effectiveness has been proven empirically in improving the depth of problem-solving and system level reasoning in engineering students (Kanitz et al., 2023). Nevertheless, its overall functional applicability is a contested issue in the literature. Although the proponents have described that design-based engineering learning prepares learners to meet the changing technology systems (Al Koliby et al., 2024), other researchers have found out that its learning outcomes are limited to technical cognition and do not have much spill to the capabilities related to change (Dziubaniuk et al., 2023). The lack of a resolution to this debate shows a gap as to whether design-based engineering learning (Bhatti & Otamurodov, 2025) has any effect much further than the instructional effectiveness to the technology-driven organizational processes and long-term strategic positioning.

2.2 Design-Based Engineering Learning impact on Technology Change Management

The studies on learning-based change capabilities provide conflicting evidence on the impact of design-based engineering learning on technology change management (Abumalloh et al., 2024). Research based on experience and design cognition paradigms indicates that the habitual practice of solving open design problems creates flexibility and openness to changes in technology (Sidik et al., 2024). On the other hand, empirical studies on engineering education document reports that design-based pedagogies do not have formal exposure to structured change mechanisms thus constraining their suitability to technology change management (Hazrat et al., 2023). Besides, Kossyva et al. (2024) observe that majority of design-learning researches focus on artifact production as opposed to technology transition management. The processual connection between design-based engineering learning and technology change management is thus theoretical with an empirically weak connection (Ali Mohamad et al., 2023). This gap implies a lack of knowledge on whether design-based learning contexts can in fact foster competencies to handle the technological change in mechanical education contexts.

H1: Design-based engineering learning significantly influences the technology change management.

2.3 Moderating Role of Change Management Awareness

The importance of change management awareness as a significant determinant of how individuals decipher and react to change initiatives has been established (Khang et al., 2023). Earlier research indicates that change rationale, process and consequences awareness predisposes the success of capability-building interventions (Malik et al., 2023). Engineering education literature does not however pay much attention to change management awareness when assessing learning model like design-based engineering learning (Ajiga et al., 2024). Available research has an implicit belief on the homogeneity of the readiness of learners to attend to change as it has been documented that changes in awareness asymmetries can significantly modify change-related consequences (van den Beemt et al., 2023). This exclusion could be the reason that has led to different technology change management outcomes when using similar design-based interventions in different settings (van den Beemt et al., 2023). Lacking change management awareness in previous models is a theoretical blind spot which prevents clarification of the boundary conditions in which design-based engineering learning is translated to effective technology change management.

H2: Change management awareness significantly moderates the relationship of design-based engineering learning and technology change management.

2.4 Design-Based Engineering Learning impact on Sustainable Competitive Advantage

Learning-based capabilities are linked with sustainable competitive advantage as a result of innovation and differentiation processes (Kumar et al., 2024). However, little empirical research uses design-based engineering learning to go beyond instructional results to the creation of strategic advantage (Dash et al., 2023). Although, on the one hand, design-oriented learning can facilitate the potential of innovation (Slavković et al., 2023), on the other hand, design-oriented learning has short-term effects and cannot be used to maintain the competitiveness without other organizational functions (Abo-Khalil, 2024). Li et al. (2024) also note that the majority of the studies do not associate the educational design practices with indicators of sustained value creation. This difference indicates the exclusion of whether design-based engineering learning per se can contribute to sustainable competitive advantage or whether the effect of this learning is mediated by intervening mechanisms that transform learning into strategic performance in technologically dynamic settings.

H3: Design-based engineering learning significantly influences the sustainable competitive advantage.

2.5 Mediating Role of Technology Change Management

Technology change management is generally accepted as a process that transforms capabilities into long performance benefits (Al Koliby et al., 2024). Previous studies, however, consider technology change management as a managerial role, isolated of educational design processes including design-based engineering learning (Abumalloh et al., 2024). Learning-related design competences are rarely discussed in engineering education, which explores the ways to transform these skills into the systematic management of technological transitions (Malhotra et al., 2023). This lack of connection restricts the insight into why design-based engineering learning creates inadequate impacts on sustainable competitive advantage (Idogawa et al., 2023). Prior models lack the accounting of technology change management as an intervening process and instead have made direct learning-advantage assumptions, which are empirically weak (Ali Mohamad et al., 2023). By filling this gap, it will be possible to provide a process-based explanation of how design-oriented learning leads to sustainable advantage because of the successful implementation of technology change (Figure 1).

H4: Technology change management significantly mediates the relationship of design-based engineering learning and sustainable competitive advantage.

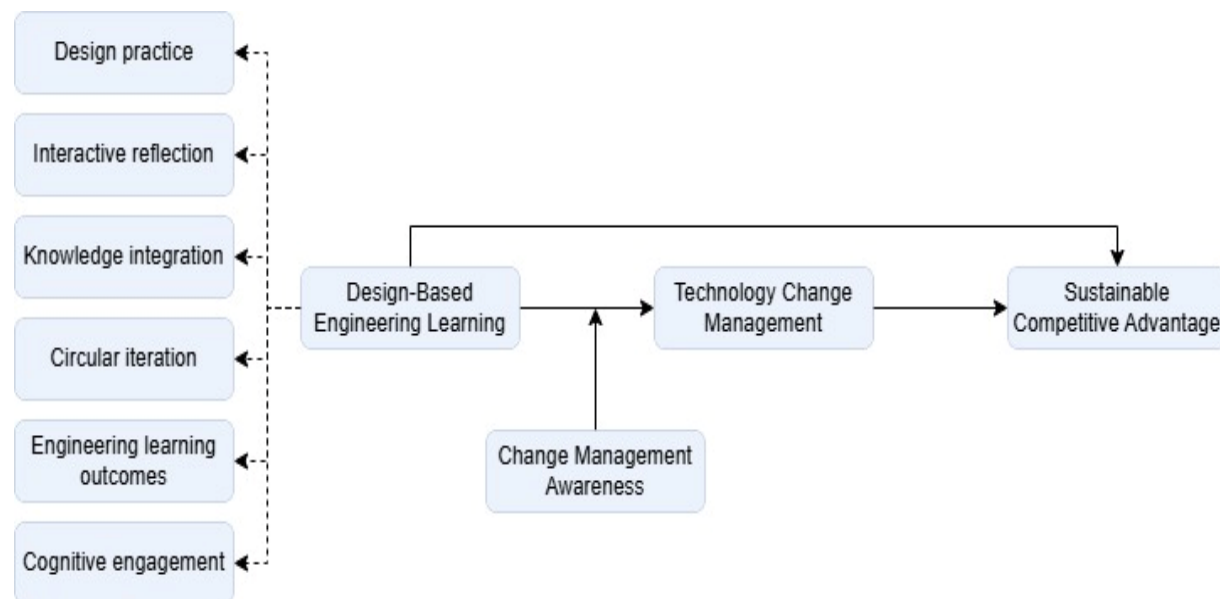


Figure 1: Conceptual Model

3. Method

3.1 Research Design and Context

The research design used in this study was quantitative and a cross-sectional research design because it achieved the objective of exploring the relationships between Design-Based Engineering Learning, Technology change management, Change Management Awareness, and Sustainable Competitive Advantage in the context of mechanical and allied engineering education. This study was done in engineering colleges where design-oriented pedagogies are becoming a part of the curriculum to deal with the challenges of technological advancement and institutional competitiveness. Cross-sectional approach was viewed to be suitable because the study was interested in capturing the perceptions of the students towards learning practices and capabilities relating to change at a given point in time, which has been consistent with previous empirical studies conducted in engineering education and studies concerning organizational change.

3.2 Sample and Data Collection

The target group was a group of undergraduate and postgraduate students undertaking engineering courses in various engineering colleges. The choice of these students was because they are direct beneficiaries of Design-Based Engineering Learning practices and because they are actively engaged in technology intensive learning settings. The structured questionnaire was used to collect 253 responses, which were valid. This is larger than the recommended minimum size of a sample to use in partial least squares structural equation modeling (PLS-SEM) so that there is

sufficient statistical power to estimate the models and test hypotheses. The respondents were representing different engineering programs, which allowed differences in the form of exposure to design-based learning practices and technology change situations. These data were gathered using self-administered questionnaire distributed in the academic sessions and this guaranteed the contextual relevance and accuracy of responses.

3.3 Measurement of Variables

Multi-item scales were used to measure all constructs in the study with the adoptive approach to address content validity and theoretical consistency based on previous studies as can be summarized in Table 1 (see appendix for details).

Table 1: Variables Measurement Profile

Variables	Items	Source
Design-Based Engineering Learning	30	(Wei et al., 2023)
Technology change management	7	(Aregbesola & Oluwade, 2014)
Sustainable Competitive Advantage	6	(Olaleye et al., 2024)
Change Management Awareness	5	(Baharudin et al., 2020)

3.4 Data Analysis Technique

Data analysis was performed with the Smart PLS software by using Partial Least Squares Structural Equation Modeling (PLS-SEM). The reason behind the choice of PLS-SEM was that it is used when the research is focused on prediction, more complex models with higher-order constructs, and non-normative data distribution. On top of that, PLS-SEM is also highly applicable in models that evaluate mediation and moderation simultaneously, which is needed in this study. The method can be used to estimate path relationships in a robust manner, as well as being able to introductively integrate learning, change management and strategic outcome constructs. The analysis was conducted in two phases, where the measurement model was evaluated first, and secondly, the evaluation of the structural model was done.

3.5 Measurement Model Assessment

To determine the reliability and validity of the constructs, the measurement model was tested. The evaluation of the indicator reliability was done using outer loadings whereas internal consistency was done using Cronbach alpha and composite reliability. Average Variance Extracted (AVE) was used to test convergent validity. The Heterotrait-Monotrait (HTMT) ratio was used to measure discriminant validity. The procedures are in line with the set guidelines of PLS-SEM, and this makes the constructs reliable and empirically differentiated before structural relationships are tested.

3.6 Structural Model Assessment

After the confirmation of the measurement model, it was determined that the structural model was analyzed with respect to the path coefficients, t-statistics, and p-values derived in the course of bootstrapping processes. The explanatory power of the endogenous constructs was measured with the help of the coefficient of determination (R-square), whereas the effect sizes (f-square) were obtained to measure the substantive contribution of exogenous variables. The interaction term of Change Management Awareness was tested as a moderating variable whereas the mediation role of Technology change management was analyzed as an indirect effect. The standardized root mean square Residual (SRMR) was also used to determine the model fit in order to evaluate the adequacy of the model in general.

4. Results

Table 2 shows measurement model evaluation and indicates good reliability and convergent validity of all the constructs. The indicator loading is much higher than the recommended limit of 0.70 (high reliability of items), and the rest of the acceptable exceptions are slightly above 0.60. The Cronbach alpha values of Change Management Awareness, Sustainable Competitive Advantage, Technology change management and all of the change management dimensions of Design -Based Engineering Learning are greater than 0.70 which validates internal consistency. The values of composite reliability are between 0.929 and 0.835, which is above the minimum threshold, and indicates a high construct reliability.

Table 2: Reliability and Validity Statistics

Variable	Indicator	Loading	Cronbach's Alpha	Composite Reliability	AVE
Change Management Awareness	CMA1	0.832	0.885	0.916	0.685
	CMA2	0.850			
	CMA3	0.844			
	CMA4	0.829			
	CMA5	0.780			
Sustainable Competitive Advantage	SCA2	0.747	0.833	0.879	0.593
	SCA3	0.828			
	SCA4	0.762			
	SCA5	0.744			
	SCA6	0.768			
Technology Change Management	TCM3	0.893	0.905	0.929	0.725
	TCM4	0.821			
	TCM5	0.859			
	TCM6	0.854			
	TCM7	0.827			
Design-Based Engineering Learning Cognitive Engagement	Design-Based Engineering Learning		0.947	0.952	0.516
	CE1	0.741	0.827	0.874	0.537
	CE2	0.768			
	CE3	0.741			
	CE4	0.751			
	CE5	0.757			
	CE6	0.633			
Circular Iteration	CI1	0.823	0.703	0.835	0.628
	CI2	0.796			
	CI3	0.756			
Design Practice	DP1	0.626	0.773	0.846	0.526
	DP2	0.722			
	DP3	0.784			
	DP4	0.774			
	DP5	0.709			
Engineering Learning Outcomes	ELO1	0.733	0.787	0.853	0.538
	ELO2	0.714			
	ELO4	0.672			
	ELO6	0.781			
	ELO7	0.764			
Interactive Reflection	IR1	0.795	0.865	0.903	0.650
	IR2	0.798			
	IR3	0.813			
	IR4	0.854			
	IR5	0.770			
Knowledge Integration	KI1	0.761	0.739	0.836	0.561
	KI2	0.794			
	KI3	0.732			
	KI4	0.705			

The values of Average Variance Extracted (AVE) of all constructs are above 0.50 which proves sufficient convergent validity. All these findings suggest that, the indicators have a good presence of their corresponding latent variables and the constructs explain over fifty percent of the variance of their measures, which is a good indication that the measurement modelling is appropriate to be used in the next structural analysis (Figure 2).

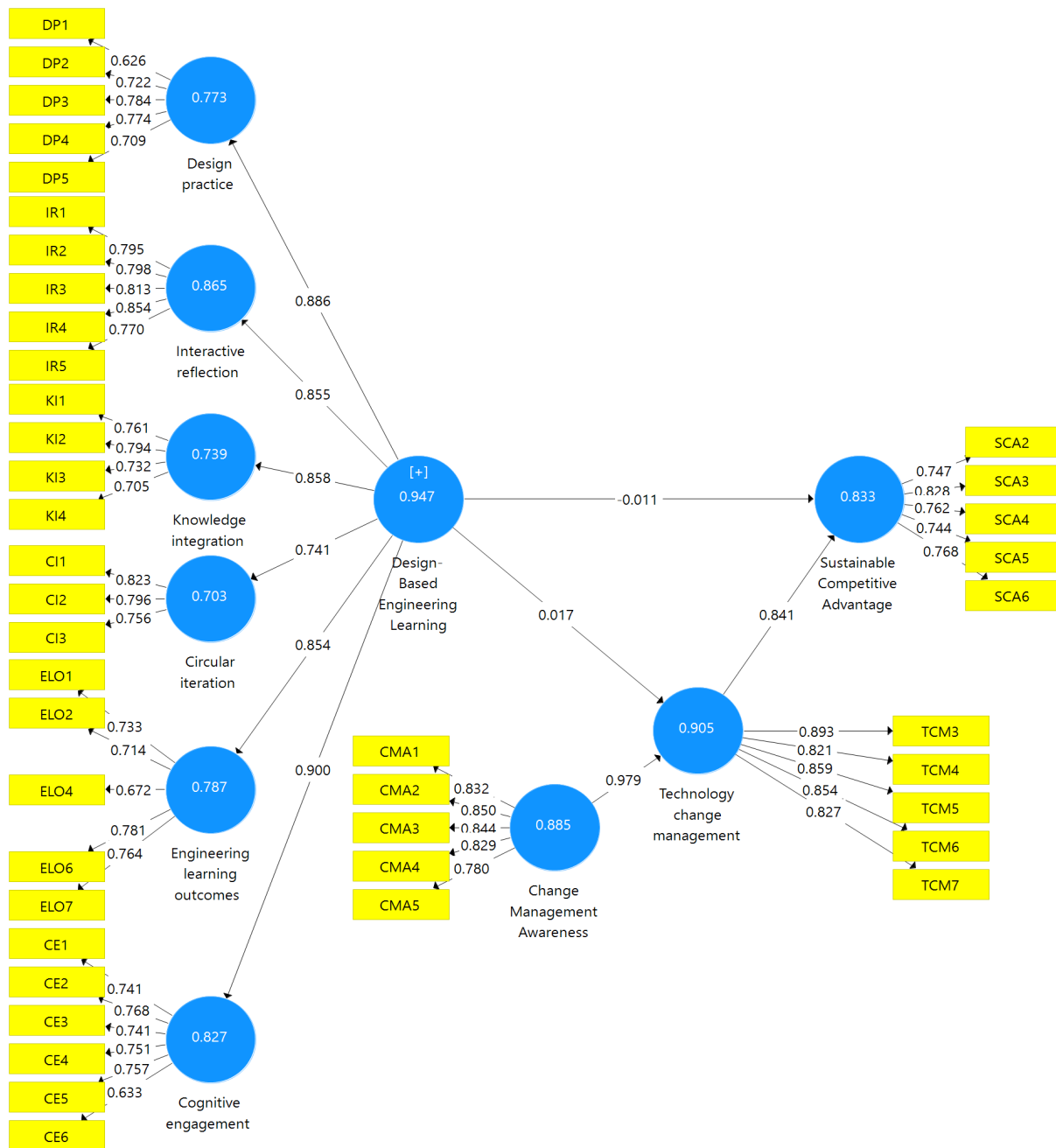


Figure 2: Estimated Model

Table 3 presents the results of Heterotrait-Monotrait Ratio to evaluate the discriminant validity among the research constructs. The values of all HTMT are under the conservative value of 0.90, which shows that all the constructs are statistically different. Specifically, Change Management Awareness can be characterized by low HTMT with the dimension of Design Based Engineering Learning that indicates a low degree of conceptual overlap. Equally Sustainable Competitive Advantage and Technology change management reflect HTMT values within reasonable boundary when compared to constructs associated with learning. Even though there is an increase in higher values of HTMT in some dimensions of learning, including Cognitive engagement and Engineering learning outcomes, these dimensions are below critical values and represent facts that are theoretically connected but have different aspects. All in all, the findings of the HTMT support the idea that the discriminant validity was achieved, and interpretation of the structural relationships is possible.

Table 3: Heterotrait-Monotrait Ratio (HTMT)

	1	2	3	4	5	6	7	8	9	10
Change Management Awareness										
Circular Iteration	0.069									
Cognitive Engagement	0.094	0.781								
Design Practice	0.117	0.695	0.806							
Design-Based Engineering Learning	0.100	0.508	0.412	0.820						
Engineering Learning Outcomes	0.120	0.271	0.855	0.873	0.803					
Interactive Reflection	0.068	0.663	0.824	0.756	0.857	0.741				
Knowledge Integration	0.083	0.406	0.885	0.550	0.742	0.847	0.879			
Sustainable Competitive Advantage	0.472	0.104	0.086	0.116	0.113	0.102	0.102	0.130		
Technology Change Management	0.189	0.072	0.086	0.114	0.092	0.106	0.050	0.088	0.811	

Table 4 shows the f-square effect sizes which show the substantive effects of the exogenous constructs on the endogenous variables. The Design-Based Engineering Learning shows high effect sizes in all the dimensions of Design practice, Knowledge integration, and Cognitive engagement, which suggests high explanatory power of the model. It is interesting to note that its impact on Technology change management is significant and thus shows meaningful contribution and not just statistically significant. The effect size of Change Management Awareness on Technology change management is extremely large, thus, demonstrating the power of Change Management Awareness in explaining the outcomes of change. Also, Technology change management demonstrates the significant impact on Sustainable Competitive Advantage, which supports the notion of its role as a transmission mechanism in the model. Such findings demonstrate that the noted relationships are not only meaningful, but also practical.

Table 4: F-Square

	Circular Iteration	Cognitive Engagement	Design Practice	Engineering Learning Outcomes	Interactive Reflection	Knowledge Integration	Sustainable Competitive Advantage	Technology Change Management
Change Management Awareness								23.282
Design-Based Engineering Learning	1.215	4.284	3.637	2.691	2.707	2.780	4.332	3.715
Technology Change Management							2.419	

Table 5 shows the coefficient of determination of the endogenous constructs. The values of the R-squared give high explanatory powers and the majority are above 0.70. The explanatory strength of technology change management has been found to be very high as it has a R-square of 0.959 implying that the model predictors have almost all the variance. The explanatory power of Sustainable Competitive Advantage is also high with a R-squared of 0.708. On the same note, the other Design-Based Engineering Learning dimensions such as Cognitive engagement and Knowledge integration show high R-square values. The adjusted R-Squares are very similar to the original ones, indicating that there is stability of the model and that there is a little overfitting. On the whole, the findings demonstrate that the structural model describes a significant level of variance in crucial outcomes.

Table 5: (a) R-Square

	R Square	R Square Adjusted
Circular Iteration	0.548	0.547
Cognitive Engagement	0.811	0.810
Design Practice	0.784	0.783
Engineering Learning Outcomes	0.729	0.728
Interactive Reflection	0.730	0.729
Knowledge Integration	0.735	0.734

Table 5: (b) R-Square

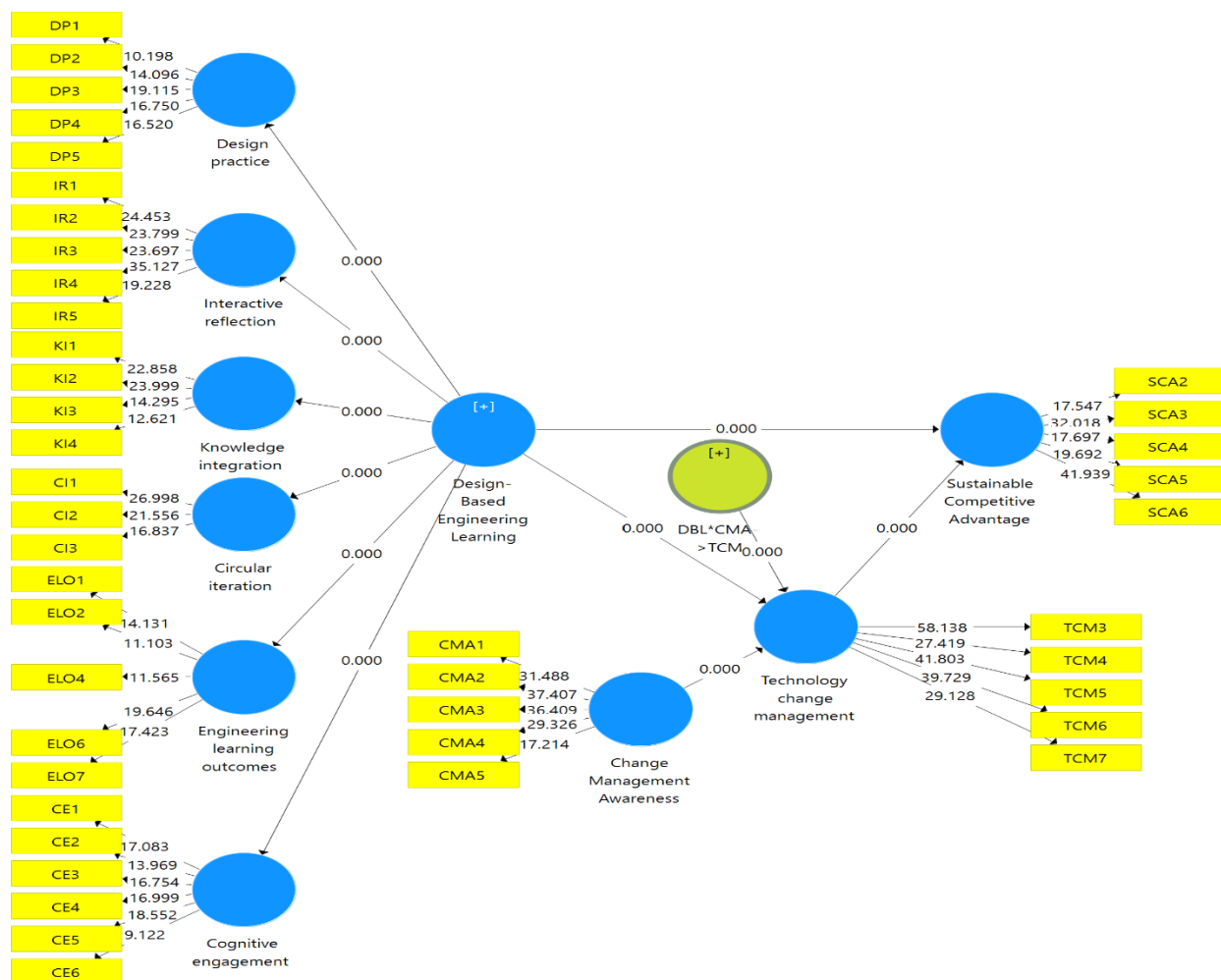
	R Square	R Square Adjusted
Sustainable Competitive Advantage	0.708	0.705
Technology Change Management	0.959	0.958

The Standardized Root Mean Square Residual (SRMR) of the saturated and the estimated model are reported in table 6. The SRMR of 0.079 and 0.081 are less than the recommended value of 0.10, a fact that implies that the overall model fit is acceptable. The proximity of the measured and structural specification is indicated by the fact that the saturated and estimated model values are nearly the same. These findings support the validity of the proposed model to reproduce the observed covariance matrix; thus, it is sufficient to understand that the model is suitable in testing hypotheses and interpreting structural relationships.

Table 6: Model Fit

	Saturated Model	Estimated Model
SRMR	0.079	0.081

Table 7 shows the structural path coefficients, SDs, t-statistics and p-values. There are high positive coefficients in the reported paths, which show that there are strong relationships between the constructs. Design-Based Engineering Learning has a significant predictive relationship with Technology change management since the effect is statistically significant and large. The interaction effect between Change Management Awareness has even higher coefficient and t-value implying a strong strengthening effect on Technology change management.

**Figure 3: Structural Model**

Moreover, Design-Based Engineering Learning has an extremely high t-statistic indicating that the effect on Sustainable Competitive Advantage is very strong (Figure 3). The indirect influence via Technology change management is also significant, which proves the existence of a significant mediating process. All the p-values are less than 0.001, which gives a significant statistical support to the structural relationships. Taken together these findings show the validity and reliability of the proposed model pathways.

Table 7: Path Analysis

Hypotheses	Original Sample	Standard Deviation	T Statistics	P Values
Design-Based Engineering Learning Significantly Influences the Technology Change Management.	0.741	0.057	2.992	0.000
Change Management Awareness Significantly Moderates the Relationship of Design-Based Engineering Learning and Technology Change Management.	0.854	0.031	7.222	0.000
Design-Based Engineering Learning Significantly Influences the Sustainable Competitive Advantage.	0.841	0.012	69.046	0.000
Technology Change Management Significantly Mediates the Relationship of Design-Based Engineering Learning and Sustainable Competitive Advantage.	0.824	0.013	6.717	0.000

5. Discussion

The modern environment of mechanical education is becoming progressively influenced by the conflict between pedagogical creativity and the strategic requirements depicted by hastened technological transformation. With changes in engineering systems, the value in teaching and learning is no longer assessed based on the effectiveness of the institution but its ability to produce capabilities that would maintain relevancy, flexibility, and competitive advantage. In this context, design-based engineering learning has outgrown its pedagogical roots to become strategic, in the sense that it organizes the ways that future engineers are exposed to complexity, uncertainty, and technological change. The current discussion understands the empirical results by placing them into the current academic theoretical debates on learning-based change processes and long-term value creation, where design-based engineering learning functions by a technology change management based on different degrees of change management awareness to impact sustainable competitive advantage.

The results prove that design-based engineering learning has a strong impact on technology change management, which supports the claims that design-oriented pedagogies go beyond the technical skill development to the process level change capacities. The previous research argues that, after recurrent exposure to iterative design tasks, the ability of learners to identify technological dependencies and react to emergent system demands will increase (Ullrich et al., 2023). The current findings contribute to this debate by constructively validating the fact that Design-Based Engineering Learning is something that can be useful in Technology Change Management and not just a factor that is relatable with adaptive behaviours. This finding contradicts previous criticisms which point out that design-based pedagogies are not relevant in structured change processes (Popoola et al., 2024). Rather, the results suggest that the exposure to design problem framing, prototyping, and evaluation develop competencies that have direct applications in the management of technological transitions in the context of mechanical education settings.

In addition, the findings indicate a Technology Change management possibility of design-based engineering learning because of the inclusion of change logic in the learning process. Jatobá et al. (2023) reasoned that engineering training tends to disconnect design cognition to the organizational reality, thus restricting its generalizability. In a differing stance to this ground, the current results suggest that design-based learning environments that model technological constraints and decision-making cycles in an iterative manner, are implicitly training people to handle technological change as a process and not an occurrence. This is in line with the fact that learning architectures mediate the way future engineers perceive and cope with technological change will provide empirical indication of the repositioning of design-based engineering learning as a precursor of technology change management as opposed to a similar result in terms of education.

This interpretation is further enhanced by the moderating effect of change management awareness which shows how the previous research studies found incongruent relationship between learning and change. The scholars of organizational change stress that the sense of change rationale and processes preconditions the behavior of an individual towards change initiatives (Latifah et al., 2024). The current results validate that change management awareness can reinforce the translation of design-based engineering learning into technology change management,

implying that design-based learning is not enough in case of low awareness. This is the reason as to why the same pedagogical intervention would present different results in different contexts as earlier noted by Ling et al. (2023). The study addresses the major controversy in the literature by proving empirically that this boundary condition holds true and that awareness serves as a catalyst that makes design-driven competencies come about as successful technology change capabilities.

The findings also verify that the design-based engineering learning is among the major contributors to sustainable competitive advantage, which fills a long-standing gap in the field of engineering education as well as in strategic management research. Although the strategic scholars suggest that sustained advantage rests on the ability to learn (Abbasi Kamardi et al., 2025), empirical research seldom develops a connection between sustained advantage and particular educational design. The current results indicate that design-based engineering learning produces more than just instant results of learning as it creates abilities that cannot be easily copied and are entrenched in mechanical education frameworks. This disputes previous hypotheses that design-oriented learning results in short-term or project-level returns (Washizaki, 2024), but instead, it would be a strategic resource that would help in long-term differentiation.

Nevertheless, it is also found that such contribution is not direct, and the role of technology change management as a mediation process is significant. According to dynamic capability theory, resources can only bring a long-lasting benefit when managed using organizational processes (How & Cheah, 2024). The results of the mediation process support this view by demonstrating that design-based engineering learning has an impact on sustainable competitive advantage mostly through its impact on technology change management. This explains why the earlier researches that have either studied learning or competitive results independently yielded weak or inconsistent findings (Ugbebor et al., 2024). The strategic potential of design-based learning is latent as opposed to actual without effective handling of the technological transitions.

Moreover, this assertion of technology change management as an intermediating process balances the gap between the misaligned literatures that have traditionally subdivided the areas of learning and change as two distinct entities. Kanitz et al. (2023) pointed out that technological value is created in the form of practices being enacted as opposed to being created by the technological artifacts. The current evidence builds on this observation to mechanical education by proving that design-based engineering learning can only lead to sustainable competitive advantage when it is converted into systematic technology change practices. It is a process-oriented account that goes beyond the linear accounts of learning and learning performance to present a more credible explanation of the nature of educational design in the strategically sustainable environments of the technologically dynamic world.

A combination of all of this leads to the conclusion that design-based engineering learning is a core competency whose strategic worth, in turn, depends on both procedural and contextual details. The validated correlations indicate that technology change management is the important channel by which learning is converted into sustainable competitive advantage and change management awareness is the determinant of the intensity of this conversion. The combination of these factors leads the study to a unified explanation of the ways in which mechanical education institutions could integrate the design of pedagogy with technological flexibility and sustainable competitive advantage. That way, it provides a solution to long-standing gaps between engineering education, change management, and strategic capability literature, providing empirical clarity to the arguments that remain undecided within these fields.

5.1 Theoretical Implications

The study contributes to the theory by incorporating Design-Based Engineering Learning into a processual explanation of Sustainable Competitive Advantage via Technology change management. In the previous literature, learning and change were still discussed as separate aspects; this paper theoretically links the two areas by showing that learning based design abilities only get the strategic pertinence when they are implemented in processes of change. Also, the introduction of Change Management Awareness as a boundary condition makes the study more refined to the organizational change theory since it explains the difference in learning-change linkages. The results offer an extrapolation of the dynamic capability theory by establishing Design-Based Engineering Learning as a precursor capability, the value of which will depend on managerial processes and contextual conditions of awareness.

5.2 Practical Implications

In practical terms, the results indicate that the mechanical education institutions must cease to be isolated in the redesign of the curriculum and start to consider the alignment of the Design-Based Engineering Learning with the Technology change management practices. Integration of organized change models and clear change justifications in design-based curriculum may result in improved institutional flexibility and longevity competitiveness. In addition, the effectiveness of learning initiatives can be highly enhanced by improving the Change Management Awareness of faculty and students. As such, change awareness training must be incorporated with design-based pedagogies by

policymakers and academic leaders to help them make sure that the investments made in learning are translated to Sustainable Competitive Advantage.

5.3 Limitations and Future Research Directions

This research has limitations though notwithstanding its contributions to the future of research to be opened. The cross-sectional design limits the use of causal inference on the dynamic development of Design-Based Engineering Learning and Technology change management with time. The future research can take a longitudinal design to follow learning-change patterns. Also, the contexts of mechanical education are the subject of the study, which can make it not as applicable to other types of engineering. The model could be tested in interdisciplinary or industry-integrated educational settings and this could be done in future research. In addition, though Change Management Awareness was analyzed as a modifier, other contextual factors like leadership support or organizational culture should be studied to contribute to the knowledge on learning-based strategic results.

6. Conclusion

This paper aimed at exploring the contribution of Design-Based Engineering Learning to the strategic gains of mechanical education by taking a step further in the evaluation of traditional pedagogical assessment. The results prove that the design-oriented learning is not a vacuum; the value is created by the well-organized Technology change management processes. The study concludes the issues of debate that have surrounded limited strategic relevance of design-based pedagogies by empirically verifying this pathway. The findings demonstrate that design practice-based learning structures foster learning capacities which facilitate technological flexibility hence establishing learning institutions in a better position to address changing engineering requirements more efficiently. Notably, the research also notes that Change Management Awareness conditions the success of the Design-Based Engineering Learning. Awareness is an initiator that can facilitate learners and institutions to transform design-oriented competencies into actionable change deliverables. The research provides some overall account of how Sustainable Competitive Advantage can be developed in mechanical education through the integration of learning, change processes, and awareness into a cohesive framework. In general, the research paper has provided a finer process-based vision of learning-based competitiveness with the provision of theoretical clarity as well as practical suggestions on further development of the engineering education in technologically evolving settings.

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8. Appendix

8.1 Design-Based Engineering Learning

Design Practice (DP)

1. I learn in real engineering problem situations.
2. I learn in explicit design tasks.
3. I am hands-on, using engineering-related knowledge in problem identification and analysis.
4. I produce experimental designs to develop, design, and improve systems/components/processes.
5. I apply techniques and tools to design solutions to engineering problems.

Interactive Reflection (IR)

1. I take the initiative to ask questions and participate in discussions with classmates.
2. I form groups with other students for learning and cooperation.
3. I debate and negotiate problems with my classmates.
4. I think about solutions to problems from the perspective of others.
5. I think about the shortcomings of my engineering studies by drawing on a wide range of opinions.

Knowledge Integration (KI)

1. I integrate knowledge and methods related to engineering, mathematics, science, or technology courses.
2. I combine theory with practice to explore solutions to problems.
3. I can link processes and synthesize my knowledge.
4. I can integrate ideas and solutions from peers to generate new ideas.

Circular Iteration (CI)

1. I keep trying until I do not repeat the mistakes I've made before.
2. I adjust my design ideas based on feedback from iterative progress.
3. I continue to find solutions to problems until I reach my final goal.

Engineering Learning Outcomes (ELO)

1. Significant improvement in theoretical engineering knowledge: Extensive knowledge and in-depth understanding and mastery of engineering-related theoretical knowledge, with more emphasis on learning rather than studying.
2. Significant improvement in engineering practical skills: significant improvement of engineering analysis, engineering design, engineering application, and other practical skills.
3. Significant improvement in engineering professional skills: a deeper understanding of one's own profession, and significant improvement of the ability to analyze and solve engineering problems systematically and professionally.
4. Significant improvement in engineering innovative thinking: to be able to creatively solve practical engineering problems, and to significantly improve critical thinking, innovation consciousness, and entrepreneurial spirit.
5. Significant improvement in engineering communication skills: significant improvement in teamwork, communication and coordination skills, organizational leadership skills, etc.
6. Significant improvement in engineering ethics: strong in aspects such as professional ethics, ethical responsibility, and sustainable development.
7. Significant improvement in professional identity: having a strong sense of the engineer's professional identity, and a significant increase in willingness to continue engaging in technical and research work related to this profession.

Cognitive Engagement (CE)

1. I look at problems holistically and think about a particular problem from a variety of perspectives.
2. I use diverse learning methods to solve problems.
3. I analyze and synthesize abstract information to solve practical problems.
4. I generalize, judge, and compare from different disciplinary directions before reaching an optimal conclusion.
5. I select, classify, and integrate course materials.
6. I apply theories

8.2 Technology Change Management

1. Does the organization follow a plan for managing technology changes?
2. Are new technologies evaluated to determine their effect on quality and productivity?
3. Does the organization follow a documented procedure for incorporating new technologies into the

- organization's standard software process?
4. Does senior management sponsor the organization's activities for managing technology change (e.g., by establishing long-term plans and commitments for funding, staffing, and other resources)?
 5. Do processes data exist to assist in the selection of new technology?
 6. Are measurements used to determine the status of the organization's activities for managing technology change (e.g., the effect of implementing technology changes)?
 7. Are the organization's activities for managing technology change reviewed with senior management on a periodic basis?

8.3 Sustainable Competitive Advantage

1. Access to raw materials
2. Efficient process and technology
3. Access to efficient product distribution and sales
4. Efficient company operations
5. Extensive business network
6. High profit rate

8.4 Change Management Awareness

1. How do you feel about the change management awareness activities?
2. How do you rate the content of the activities informatively?
3. The content of the awareness activities was well organized.
4. I know more about organizational change in my organization after experiencing these activities.
5. The change management awareness activities answered all my questions.