Advances in Technology Innovation, vol. x, no. x, 20xx, pp. xx-xx

Design-Led Innovation and Triple-Helix Collaboration for MSME Product Development: The PROPEL Project in Bohol, Philippines

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Received 19 November 2025; revised 26 April 2026; accepted 29 April 2026

DOI: https://doi.org/10.46604/aiti.2026.15898

Abstract

This study aims to examine design-led pedagogy as a mechanism for knowledge and technology transfer within a triple helix collaboration supporting product development among micro, small, and medium enterprises (MSMEs) in a resource-constrained rural setting. Using a qualitative case study of the PROPEL Project in Bohol, Philippines, it analyzes how collaboration mechanisms, design-led processes, and boundary conditions shape product outcomes. The findings show that innovation outputs depend not only on institutional alignment but also on enacted coordination, iterative prototyping, mentoring, and feasibility-based refinement among university, government, and MSME actors. The decline from 148 approved concepts to 58 exhibited prototypes reveals selective translation under time, material, and organizational constraints. Prototype realization is influenced by mentorship intensity, coordination quality, and MSME absorptive capacity. The study refines the triple helix interpretation by clarifying design-led pedagogy as a transfer pathway and identifying boundary conditions that shape the visibility of innovation outputs in rural innovation ecosystems.

Keywords: triple helix, design-led innovation, prototyping, rural innovation systems

1. Introduction

Micro, small, and medium enterprises (MSMEs) are important to economic growth in developing countries because they generate employment and support local value chains and livelihoods. In the Philippines, MSMEs are key actors in local development [1]. However, many rural MSMEs still operate without systematic product development processes, formal design methods, or effective integration of new technologies. In Bohol, enterprises often rely on craft traditions and informal testing while facing limited access to technical mentoring, fabrication support, and institutional coordination. As a result, promising ideas often fail to progress toward commercialization.

Collaborative models such as the triple helix, as shown in Fig. 1, were developed to align university capabilities, government support, and industry needs [2-5]. The model explains innovation through recursive interactions among university, industry, and government actors [6] and has been extended to institutional hybridization, knowledge-based development, and regional and rural contexts [7-10]. However, many applications assume the availability of resources, iteration time, fabrication support, and organizational capacity needed to sustain experimentation. In rural settings, these conditions are often limited, creating gaps between institutional alignment and prototype realization. Thus, the theoretical problem is not simply that rural triple helix collaboration remains underexplored, but that existing interpretations do not fully explain how collaboration mechanisms hold, weaken, or break down under constraints of time, materials, mentorship, and enterprise readiness.

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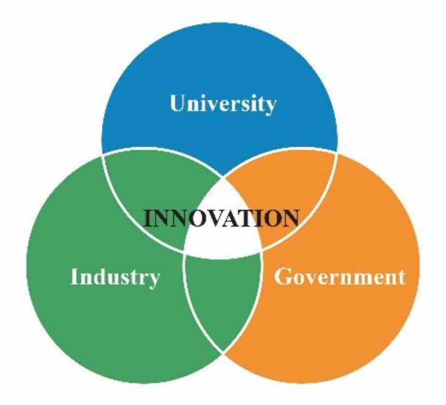

Fig. 1 Triple helix innovation model

This study addresses this theoretical problem through an empirical case in Bohol, Philippines. It examines design-led pedagogy as a mechanism for knowledge and technology transfer within a triple helix arrangement. This study also highlights boundary conditions that shape the effectiveness of collaboration, including mentorship intensity, time compression, resource limitations, and enterprise absorptive capacity. Although prior studies suggest that structured problem framing and iterative prototyping can strengthen MSME innovation capability [11-12], few explain how design-led pedagogy functions as a concrete transfer mechanism in rural triple helix settings. Accordingly, this study examines how micro-level coordination mechanisms enable, mediate, or constrain the translation of design knowledge into innovation outputs in a rural setting.

Following the IMPACT framework for theory selection [13], this study adopts the triple helix model as the primary theoretical lens because it best aligns with university-industry-government interaction in MSME product development and explains collaboration mechanisms in a rural, resource-constrained setting. The IPOO structure serves as a supporting qualitative process-tracing scaffold that organizes the translation of institutional inputs through collaboration and design-led processes into observable outputs and near-term outcomes.

In line with recent guidance on theory development, the study contributes by refining mechanisms and specifying context rather than proposing a wholly new theory [14]. Its novelty lies in clarifying design-led pedagogy as a technology-transfer pathway within a triple helix arrangement, while its contribution lies in showing that institutional alignment alone does not sufficiently explain innovation outcomes. Instead, the effectiveness of collaboration depends on enacted coordination and boundary conditions, such as time compression, material feasibility, mentorship intensity, and MSME absorptive capacity.

1.1 Case context: The PROPEL design-led collaboration model in Bohol, Philippines

The Product Development Partnership for Empowering MSMEs by Learning (PROPEL) Project in Bohol, Philippines, illustrates design-led triple helix collaboration. Co-implemented with the Department of Trade and Industry–Bohol (DTI–Bohol), the project addresses constraints on MSME product innovation in a resource-limited provincial setting. Industrial Design students, faculty advisers, and MSMEs engaged in ideation, material experimentation, prototyping, refinement, and exhibition-based validation. PROPEL treats technology transfer not only as the delivery of artifacts, but also as the transfer of tacit design knowledge, skills, and organized development processes into MSME production. Through iterative co-creation, students translated academic design competencies into tangible product outputs while providing MSMEs with more systematic innovation methods.

In line with this theoretical positioning, the triple helix model guides the interpretation of inter-institutional roles, coordination, and collaboration dynamics, while the IPOO structure organizes the translation of inputs into processes, outputs, and near-term outcomes in the PROPEL case [15]. As shown in Fig. 2, the framework links BISU design expertise, MSME participation, DTI facilitation, and IP support to design collaboration, product development, and exhibition activities. These processes generated curated products, IP-protected outputs, stronger partnerships, and near-term capability gains observed qualitatively. This interpretation is consistent with university-based technology transfer studies that emphasize the role of higher education institutions in fostering entrepreneurship, technology transfer, and startup ecosystem development [16].

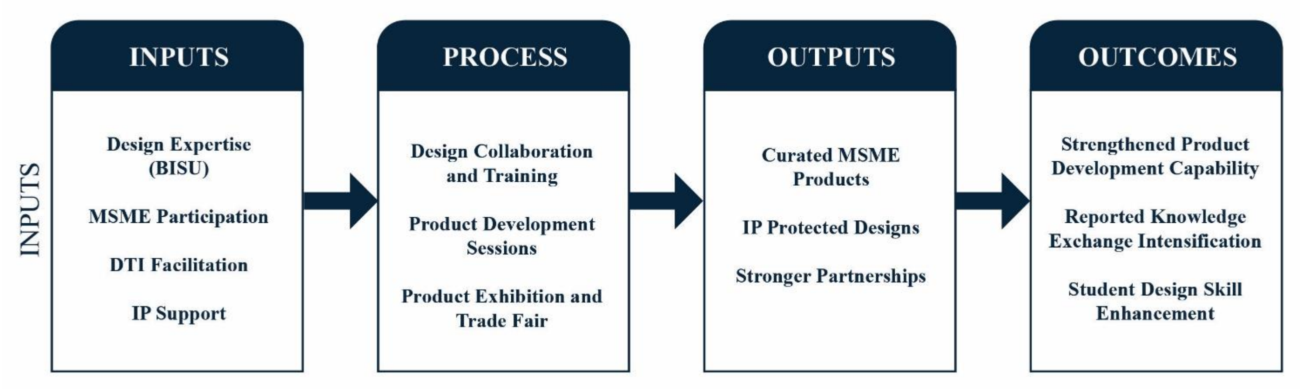

Fig. 2 PROPEL project framework using IPOO

This study asks: How does design-led pedagogy facilitate knowledge and technology transfer within academia–industry–government interactions for MSME product development in a resource-constrained rural context? Using the first implementation round of PROPEL, the study examines how collaboration tools, iterative design processes, and contextual boundary conditions shape product outcomes within a provincial innovation ecosystem. The focus is on mechanism-based explanation rather than impact evaluation.

2. Materials and Methods

This study used a qualitative case study design to examine design-led pedagogy as a mechanism for knowledge and technology transfer within a triple helix collaboration in a resource-limited rural context. The goal was not to evaluate statistical impact, but to explain how institutional alignment translated into observable product outcomes through a mechanism-based approach. Guided by the triple helix as the primary lens and the IPOO structure as a process-tracing scaffold, the researchers developed a semi-structured interview guide around three themes: collaboration mechanisms, design-led knowledge and technology transfer processes, and boundary conditions. All participants received comparable guiding questions with follow-up prompts as needed.

2.1 Data collection

Key informant interviews (KIIs) served as the primary data source and were complemented by a documentary review for triangulation. KIIs were selected because they allow in-depth exploration of collaboration dynamics, knowledge exchange, and enabling or constraining conditions within the project. Ten informants were interviewed, including three MSMEs partners, three Industrial Design faculty advisers, three student designers, and one DTI project staff member who served as the focal institutional mediator. Participants were interviewed individually for 30 to 50 minutes after providing informed consent for audio recording. Interviews were conducted in person or online, depending on participant availability. To minimize potential bias, interviews were conducted by researchers not directly involved in implementing the PROPEL Project.

Documentary sources were consulted to confirm timelines, output variation, IP formalization, exhibition results, and the scale of collaboration. Documents included the PROPEL Project Profile, Portfolio Volumes (Volumes 1-3), IP documentation records, the Sandugo Trade Fair Report, and the Accomplishment Report, which are summarized in Table 1. The documents were analyzed to verify structural time allocation, breadth of approved designs (n = 148), number of prototypes made and displayed (n = 58), formal copyright registration (n = 3), and magnitude of collaboration involving 30 student teams, 16 MSMEs, 10 faculty advisers, and 1 DTI staff member.

Table 1 Documentary Sources

Document Category	Description	Analytical Use
PROPEL Project Profile	Schedule of Activities and Timeline	Verified the four-month project timeline, including design research, ideation, one month of prototyping, and exhibition week, to assess iteration windows and time constraints.
Portfolio Volumes (Vols. 1-3)	Portfolio of Designs Approved for Prototyping	Confirmed the ideation and evaluation process, with 148 design concepts formally approved for prototyping, and was used to verify output variation and iteration filtering.
IP Documentation Records	Intellectual Property Applications	Verified the formal codification and protection of knowledge through three copyright registrations across PROPEL Volumes 1-3.
Sandugo Trade Fair Report	Prototypes Produced and Exhibited	Confirmed the production and public exhibition of 58 prototypes as market-facing outputs.
Accomplishment Report	Participants involved	Validated the collaboration scale: 30 student design teams, 16 MSME partners, and 10 faculty advisers supported by DTI personnel within the triple helix interaction.

2.2 Sampling strategy

This research adopted a qualitative single-case study design focused on a bounded collaboration to explain mechanisms of design-led knowledge and technology transfer. Participants were selected using purposive, role-based sampling to obtain information-rich accounts from the key actor categories directly involved in the collaboration (MSME partners, students, faculty advisers, and the government facilitator). The intent was not statistical representativeness across MSME sectors in Bohol, but an analytic explanation of how collaboration roles, routines, and boundary conditions shaped prototyping and capability development within this case.

Recruitment and interviewing continued until role coverage was achieved, yielding convergent explanations of the core collaboration mechanisms and boundary conditions, supported by triangulation with project documents and outputs. To measure variation in collaboration intensity and innovation outcomes, participants were categorized into different levels based on the number of prototypes developed and exhibited:

(1) 1-2 prototypes produced and exhibited

(2) 3-4 prototypes produced and exhibited

(3) 5 or more prototypes produced and exhibited

Within a design-led triple helix configuration, this categorization is analytically significant since prototype output reflects the depth of iteration, mentorship intensity, communication frequency, and production feasibility. A higher prototype output signifies a longer engagement and greater alignment with the institutions, whereas a lower output may reflect more limited participation and alignment. This approach enabled a fine-grained examination of how academic knowledge informed physical product innovation among resource-constrained MSMEs through design-led pedagogy within the triple helix framework [17]. This was designed to capture variation in mechanisms within a delimited innovation configuration, rather than to achieve sectoral representativeness across all MSME sectors in Bohol.

Only one DTI personnel member was interviewed, as this individual served as the principal institutional coordinator overseeing project implementation. All participants were informed of the study’s purpose, and confidentiality was maintained through anonymization and participant coding (P1-P10).

2.3 Data analysis

Data were analyzed using thematic analysis following Braun and Clarke’s (2006) six-phase approach. All interviews were audio-recorded, transcribed verbatim, and coded in NVivo 14.24.3 using a hybrid strategy that combined deductive sensitizing concepts from the triple helix and IPOO frameworks with inductively generated codes grounded in the data. Two researchers conducted initial coding independently to support systematic comparison across stakeholder groups. Discrepancies were resolved through discussion and consensus, and a shared codebook was refined to ensure analytic consistency. Given the study's interpretive, mechanism-focused qualitative design, rigor was established through independent coding, consensus-based theme refinement, and triangulation with project documents, rather than through calculation of inter-coder reliability coefficients.

Project documents and outputs were reviewed using the same analytic lens as methodological triangulation to corroborate timelines, output variation, and implementation conditions [18-19]. These documentary materials were used to strengthen credibility and contextual verification rather than to generate themes independently. A total of 29 initial codes were consolidated into 10 subthemes and subsequently synthesized into three theoretically aligned themes:

(1) Collaboration mechanisms within the triple helix configuration
(2) Design-led knowledge and technology transfer processes
(3) Enabling and constraining boundary conditions

Themes were iteratively refined to enhance internal coherence, conceptual clarity, and alignment with the study's theoretical framing. Emerging interpretations were compared across stakeholder groups and prototype-output categories to assess whether additional interviews introduced substantively new mechanisms, relationships, or boundary conditions. Analytic sufficiency was reached when later interviews no longer required substantive modification of the developing explanatory model. Consistent with recent guidance on moving from data saturation to theoretical saturation, new insight in this study was defined not simply as the emergence of additional codes but as evidence that challenged, refined, or stabilized the explanation of how collaboration mechanisms, design-led transfer processes, and boundary conditions interacted [20].

For example, an early working explanation suggested that complementary institutional roles within the triple helix arrangement were sufficient to support the realization of prototypes. However, later interviews, especially from lower-output collaborations, showed that role complementarity alone did not ensure outcomes without sustained communication, adviser mediation, and material feasibility. The explanation was therefore refined from formal role complementarity to enacted coordination under constraint. A second example concerned an exhibition. Initially treated mainly as a stage of validation and dissemination, the process was later understood as a selection mechanism, with only designs that remained feasible under time-and-material constraints progressing to public display. This led to the interpretation of exhibitions not only as an endpoint of visibility, but also as part of mechanisms through which ideas were selectively translated into observable innovation outputs. Although not statistically generalizable to MSME populations, the analysis supports analytic generalization for theory development in comparable resource-limited, design-led triple helix collaboration settings.

3. Results and Discussion

This section presents the results through the triple helix lens, focusing on design-led knowledge and technology transfer in a resource-constrained rural setting. Rather than treating collaboration as a set of project outputs, it examines how the academe, government, and MSMEs interacted to generate outcomes and navigate structural constraints. The findings are organized around three interrelated themes, as illustrated in Fig. 3.

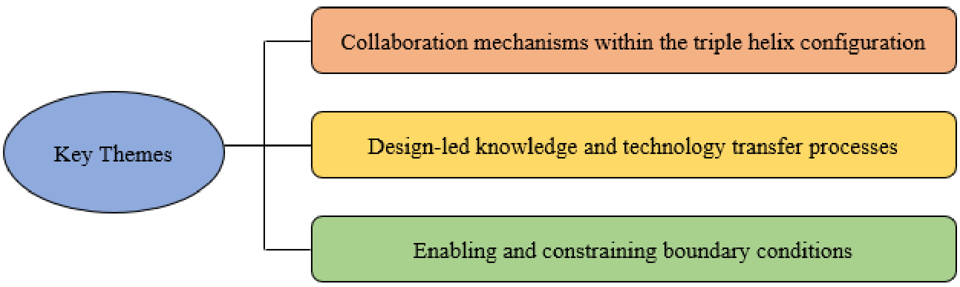

Fig. 3 Thematic map of the three major themes

3.1 Collaboration mechanisms within the triple helix configuration

The PROPEL Project adopted the triple helix format, with particular emphasis on planned role complementarity, the mediating role of government in institutions, and iterative coordination among participants. Rather than an informal team-up process between organizations, collaboration was facilitated by clear interaction modalities that enabled the translation of design knowledge into MSME product development in a resource-constrained environment.

3.1.1 Structured role complementarity

Cooperation in PROPEL was organized around complementary institutional roles. MSMEs contributed market and production knowledge, while students and faculty advisers provided structured design methods and technical refinement, and government actors enabled coordination and inter-institutional linkages.

MSME partners described the collaboration as bringing new ideas and learning opportunities, while students viewed it as a chance to apply classroom knowledge in real-world design and prototyping contexts. Advisers also acted as intermediaries. As P5 explained, they "act like a bridge" during the processes of validation and modification. Documentary evidence further shows the scale of the collaboration, involving 30 student teams, 16 MSMEs, 10 faculty advisers, and one DTI coordinator, demonstrating a distributed innovation network rather than isolated dyads.

This pattern is consistent with prior studies showing that effective triple helix collaboration depends on complementary institutional roles and coordinated university–industry interaction [3-4, 6-7]. However, the PROPEL case adds rural empirical evidence by showing that role complementarity became productive only when it was enacted through repeated design mediation, feasibility negotiation, and time-sensitive coordination, rather than assumed at the level of formal institutional participation.

3.1.2 Institutional mediation by government

The case contributes to the triple helix by showing that the government did not merely provide policy support or external facilitation; it also functioned as an operational intermediary that synchronized academic timelines, MSME readiness, and exhibition-related deadlines. In this setting, government intermediation was not peripheral but constitutive of the effectiveness of collaboration. As P7 (DTI) stated, "we match our MSME clients with the need to agencies or academe…," illustrating the government's bridging role within the innovation system. MSME participants reinforced this view by describing DTI support as both enabling and legitimizing.

DTI also conveyed deadlines, prototype requirements, and exhibition readiness. By coordinating outputs with market-facing events such as the Sandugo Trade Expo, the agency aligned academic activities with commercialization-oriented timelines. This mediation reduced uncertainty, strengthened legitimacy, and shaped MSMEs' willingness to engage in product development experimentation. These findings are consistent with studies highlighting the role of intermediary and public actors in entrepreneurial ecosystems and rural collaboration [10, 21-23]. The case further suggests that, in a resource-constrained provincial setting, government intermediation involved not only policy support or network brokering, but also the operational synchronization of collaboration activities across institutional actors.

3.1.3 Iterative coordination and cooperative engagement

Iterative coordination and cooperative engagement helped sustain ongoing collaboration throughout the project. Across stakeholder groups, communication, feedback, and mutual learning were consistently emphasized. One MSME partner described the interaction as "very cooperative" (P1), while students highlighted the need for sustained contact, especially when actual designs diverged from initial concepts. Advisers also supported ongoing coordination by helping resolve validation and design choices during iteration.

Differences in engagement intensity appeared to shape prototype output: higher-output partnerships showed more frequent consultation and continuous communication, whereas lower-output teams were more often interrupted by delays. This interaction between role complementarity and iterative coordination is consistent with literature highlighting the role of intermediary actors, including government agencies, in orchestrating collaboration and supporting knowledge co-creation within entrepreneurial ecosystems [22-23]. These patterns suggest that iterative coordination was not merely a procedural feature of the collaboration, but a mechanism through which institutional roles were continuously aligned and knowledge exchange was sustained under a resource-constrained setting.

3.2 Design-led knowledge and technology transfer processes

Beyond formal institutional roles, the PROPEL partnership also functioned as a design-led process of knowledge and technology transfer. Rather than merely transferring codified technological knowledge, the project enabled the transfer of tacit design knowledge, evolutionary problem-solving sequences, and market-oriented product development routines. Three associated processes were prevalent: learning-by-doing through prototyping, exposure to professional design specifications, and market validation through exhibitions.

3.2.1 Learning by doing through prototyping

The findings suggest that, within the triple helix configuration, design-led pedagogy can be understood as a concrete transfer mechanism through which university-based knowledge becomes actionable for MSMEs. Rather than a linear transfer of expertise, knowledge moved through iterative prototyping, feedback, and feasibility adjustment, positioning pedagogy itself as part of the innovation process. Students described applying design and prototyping knowledge in practice, while advisers emphasized that learning emerged through hands-on experience and negotiation with MSME production preferences. As one adviser noted, students often had to “meet halfway” with enterprise needs (P5). MSMEs likewise reported gaining new design perspectives, indicating mutual rather than one-way learning.

Documentary evidence from the PROPEL Portfolio Volume shows that 148 design concepts were officially approved for prototyping, illustrating the scale and systematic nature of the process under resource constraints [24]. These findings align with the design-led innovation literature, which suggests that structured prototyping and design thinking can strengthen SME innovation capability [11-12, 24]. The case further indicates that pedagogy functioned not only as a learning strategy, but also as a mechanism for translating university knowledge into feasible and market-oriented outputs.

3.2.2 Exposure to formal design standards

Beyond technical iteration, collaboration increased participants’ awareness of structured design practices and evaluation criteria. Students came to view design as a systematic rather than purely aesthetic process, stressing the importance of iterative approval, technical drawing, digital modeling, and business considerations. One student emphasized that design is “not about just random colors,” but requires deliberate consideration of combinations, perspective, and refinement (P8). MSMEs likewise perceived improvements in product presentation and market positioning, while documentary evidence showing three copyright applications suggests a shift from informal design adaptation toward formal intellectual property recognition [6]. These findings align with studies showing that structured design thinking can strengthen SME innovation capability through systematic evaluation cycles [11-12]. In theoretical terms, the findings suggest that design-led collaboration transferred not only technical skills, but also evaluative standards that helped MSMEs and students move from informal product adaptation toward more systematic innovation approaches.

3.2.3 Market validation via exhibition

The Sandugo Trade Fair served as a validation mechanism by aligning design iterations with commercialization goals and anchoring the collaboration timeline. P7 (DTI) noted that prototypes gained visibility through public display. MSME similarly reported increased recognition and, in some cases, limited sales outcomes. For students, exhibition preparation heightened learning and accountability, as feedback was obtained from an actual market setting rather than a classroom critique alone. Documentary evidence confirms that only 58 of the 148 approved concepts were produced and exhibited, reflecting filtering shaped by feasibility, material availability, and time constraints. The exhibition thus determined which designs achieved public visibility and generated feedback for further refinement [25].

In this respect, the findings align with studies emphasizing market-facing validation and value proposition development in design practice [24-25]. However, the PROPEL case indicates a sharper filtering effect in a resource-constrained rural setting, where public exhibition simultaneously functioned as validation and as a selection mechanism for selecting feasible and time-realizable concepts to gain visibility.

3.3 Enabling and Constraining Boundary Conditions

Although the structured mechanisms of collaboration and design-led processes facilitated knowledge transfer, their effectiveness was shaped by boundary conditions specific to the rural, time-bound implementation context. Empirical material depicts that time compression, resource constraints, variation in mentorship intensity, and MSME absorptive capacity shaped both the depth of iteration and prototype outcomes.

3.3.1 Time compression as an iteration constraint

Time emerged as a key structural constraint affecting collaboration intensity and prototype realization. Participants across MSMEs, DTI personnel, advisers, and students consistently described compressed timelines linked to exhibition preparation and academic schedules, which limited opportunities for refinement before public presentation. Documentary review of the PROPEL Project Profile supports these accounts. The four-month project cycle allocated three months for design development and approvals, one month for prototyping, and the final week for exhibition. This structure significantly constrained the time available for refinement before market exposure. Time compression thus functioned as a structural boundary condition that shaped output, consistent with configurational perspectives on SME technology transfer [6]. Differences in prototype volume, therefore, reflected not only design capability but also the severity of temporal constraints.

3.3.2 Resource and material constraints

Collaboration was also constrained by material availability and production capacity. Students and advisers reported delays in sourcing materials and limitations in fabrication scheduling. DTI personnel noted that prototyping entailed additional costs, including labor, utilities, and materials, which MSMEs might be hesitant to commit without market assurance. Configurational work on technology transfer similarly suggests that even well-designed collaborations may underperform when material feasibility is limited [6]. In this case, resource constraints narrowed experimentation, leading some teams to simplify prototypes and reduce design exploration.

3.3.3 Mentorship intensity variation

Another differentiating condition was variation in adviser involvement and communication frequency. Advisers generally served bridging roles, but the level of guidance differed across teams. Where adviser engagement and feedback routines were sustained, prototype development proceeded more smoothly, whereas delayed or intermittent feedback slowed iteration cycles. This trend is consistent with research identifying the role of structured coordination mechanisms in university–industry collaboration [3] and with studies showing that intermediary actors significantly affect collaboration dynamics and innovation performance [22]. Mentorship intensity thus served as a moderating factor that influenced the depth of collaboration. Stronger alignment among advisers, students, and MSMEs tended to produce higher iterative productivity, as reflected in greater prototype output.

3.3.4 MSME absorptive capacity

Differences in MSME readiness and receptiveness to design innovation also shaped the effectiveness of collaboration. DTI personnel described MSME selection in terms of capacity and readiness, while interview data indicated that some enterprises were more open to modern designs and innovation partnerships than others. Advisers further noted that some MSMEs were "not always familiar with the technical design process" (P5), which required additional explanation and adjustment.

Communication responsiveness also affected workflow, with limited internet connectivity delaying updates (P9). Prior studies on SME innovation emphasize the importance of absorptive capacity and the ability to internalize external knowledge in shaping innovation outcomes [6]. In the PROPEL case, MSMEs with stronger absorptive capacity integrated design suggestions more readily, while others required prolonged negotiation, slowing iteration and reducing output volume.

3.4 Interaction of mechanisms, processes, and boundary conditions

Viewed through the IPOO scaffold, the findings show how institutional inputs were translated through collaboration and design-led processes into observable outputs, such as approved concepts, prototypes, exhibition-ready products, and IP-related filings. However, the near-term outcomes depended on the quality of coordination and boundary conditions within the rural innovation setting. In this study, IPOO contributed not only as an organizing framework but also as a process-tracing device that clarified how collaboration mechanisms were enabled, filtered, or constrained across the movement from inputs to processes, outputs, and near-term outcomes. Taken together, the findings support triple helix scholarship that views innovation as an outcome of recursive interaction among university, industry, and government actors [6-8]. They also reinforce prior research emphasizing intermediation, coordination, and rural collaboration [3, 10, 22-23].

However, the PROPEL case suggests several important refinements to these interpretations. First, complementary institutions alone did not generate innovation outputs. Roles became productive only when enacted through repeated mediation, feasibility negotiation, and mentorship-supported coordination. Second, coordination quality, not merely the presence of interaction, shaped whether approved concepts progressed to prototypes and exhibition-ready outputs. Third, the findings illustrate that hybridization dimension of triple helix in a rural, resource-constrained setting by showing that hybrid functions were enacted operationally rather than through formal institutional restructuring. The government acted as a synchronizing intermediary, while design-led pedagogy itself functioned as a bridging mechanism between university knowledge and MSME production practice.

In this sense, the findings highlight the importance of inter-institutional interaction while showing that enacted coordination, rather than institutional co-presence or formal alignment, shaped innovation outcomes. Distinctive to this rural, resource-constrained context is that collaboration outcomes were shaped not only by institutional interaction itself, but also by practical limits on time, materials, mentorship continuity, and enterprise readiness. These conditions translated approved concepts into visible outputs more selectively than in better-resourced innovation environments. Compared with prior empirical studies that describe coordination and intermediation primarily as enabling conditions, this case shows that these same mechanisms may also function as selective filters determining which collaborative efforts become visible innovation outputs.

The decline from 148 approved concepts to 58 exhibited prototypes illustrates this mediated translation process. Prototype realization depended on the intensity of mentorship, MSME absorptive capacity, coordination frequency, and resource availability. Prototyping externalized tacit knowledge through feasibility and market validation, while exhibition consolidated refinement into market-facing outputs. Overall, the study demonstrates how design-led pedagogy operates as a concrete transfer mechanism and how boundary conditions shape the selective translation of approved concepts into visible innovation outputs.

3.5 Practical implications for technology innovation programs

The findings suggest that design-led collaboration programs in resource-limited MSME ecosystems benefit from clearer institutional roles, stronger coordination protocols, and more deliberate management of time and feasibility constraints. Prior studies show that effective triple helix collaboration depends on clearly defined institutional roles and coordination mechanisms [3-4, 7]. Accordingly, responsibilities among students, faculty advisers, MSMEs, and government actors may help reduce ambiguity and delays in key processes such as approvals, feasibility checks, prototype development, and exhibition readiness. Given that compressed timelines and limited resources can weaken iteration depth, staged implementation, earlier feasibility assessment, advanced material planning, and stronger links with fabrication facilities may help support more effective prototyping processes [2, 6, 9]. Planned mentorship checkpoints and structured university-industry coordination may further enhance alignment between design goals and production viability [3-4, 10]. Differences in MSME absorptive capacity, together with strategically timed public exhibitions, may also strengthen knowledge integration, accountability, and market validation in rural MSME settings [3, 6, 10].

4. Conclusions

This study contributed to triple helix literature by offering process-oriented evidence from a rural, resource-constrained innovation setting. It positioned design-led pedagogy as a mechanism for translating university knowledge into MSME product development and demonstrated how enacted coordination and boundary conditions—including time pressure, material access, mentorship intensity, and MSME absorptive capacity—shape innovation outputs. Conceptually, the case confirmed the value of recursive university-industry-government interaction while extending triple helix interpretation by highlighting enacted coordination and rural hybridization. Based on a qualitative case analysis of the PROPEL Project in Bohol, Philippines, four main conclusions emerge:

(1) Institutional alignment alone did not explain collaboration effectiveness. Observable outputs, including approved concepts, realized prototypes, exhibition-ready products, and IP-related filings, emerged through enacted coordination under constraint across collaboration mechanisms, design-led transfer processes, and enabling and constraining boundary conditions.

(2) Structured prototyping, multi-level concept approval, and exhibition-based validation and selection showed how experiential academic processes can generate tangible innovation outputs in MSME ecosystems. The decline from 148 approved concepts to 58 exhibited prototypes reflects the combined influence of feasibility assessments, mentoring, iterative refinement, access to materials, and time constraints.

(3) Time compression, material availability, mentorship intensity, and MSME absorptive capacity shaped the translation of design concepts into prototypes. Variation in these conditions influenced the depth of iteration and prototype productivity across teams.

(4) Embedding students within structured collaboration cycles provides a viable pathway for product upgrading and enterprise capability development in contexts where formal R&D infrastructure is limited.

This study was based on a single implementation cycle within a single provincial context, with participants limited to key actors directly involved in the PROPEL case. The results are therefore analytically transferable to comparable innovation ecosystems rather than to sectors with substantially different technological and organizational conditions. Future research may compare triple helix configurations across rural industries and develop quantitative indicators of interaction intensity and absorptive capacity. Future implementations may also benefit from earlier technical screening, earlier concept approval, and scheduled coordination checkpoints to reduce the design-to-production gap.

Acknowledgments

The author extends sincere gratitude to Bohol Island State University for allowing us to conduct the study. Appreciation is also given to the participants for generously sharing their time and insights. Their collaboration made this study possible.

Conflicts of Interest

The authors declare no conflict of interest.

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