“Transforming 4Cs capabilities into incremental innovation: Mediating role of knowledge co-creation in manufacturing SMEs”

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ARTICLE INFO	Kritsakorn Jiraphanumes and Kanittha Pattanasing (2026). Transforming 4Cs capabilities into incremental innovation: Mediating role of knowledge co-creation in manufacturing SMEs. *Problems and Perspectives in Management*, *24*(2), 582–595. doi:10.21511/ppm.24(2).2026.39
DOI	http://dx.doi.org/10.21511/ppm.24(2).2026.39
RELEASED ON	Thursday, 18 June 2026
RECEIVED ON	Friday, 20 February 2026
ACCEPTED ON	Monday, 01 June 2026

JOURNAL	"Problems and Perspectives in Management"
ISSN PRINT	1727-7051
ISSN ONLINE	1810-5467
PUBLISHER	LLC “Consulting Publishing Company “Business Perspectives”
FOUNDER	LLC “Consulting Publishing Company “Business Perspectives”

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
50	**2**	**4**

BUSINESS PERSPECTIVES

LLC "CPC "Business Perspectives"
Hryhorii Skovoroda lane, 10,
Sumy, 40022, Ukraine
www.businessperspectives.org

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TRANSFORMING 4CS CAPABILITIES INTO INCREMENTAL INNOVATION: MEDIATING ROLE OF KNOWLEDGE CO-CREATION IN MANUFACTURING SMEs

Type of the article: Research Article

Received on: 20th of February, 2026
Accepted on: 1st of June, 2026
Published on: 18th of June, 2026

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Abstract

This study examines how 4Cs capabilities, namely critical thinking, creativity, communication, and collaboration, contribute to incremental innovation through the mediating role of knowledge co-creation in resource-constrained manufacturing SMEs. Data were collected from 179 key informants, including owners, executives, engineers, and technicians, targeting manufacturing SMEs in Thailand between May and June 2025 using a structured questionnaire survey. These respondents were selected because they are directly involved in operational and innovation-related activities in their firms. The data were analyzed using partial least squares structural equation modeling (PLS-SEM). The results show that all four 4Cs capabilities have statistically significant positive effects on incremental innovation: critical thinking ($\beta = 0.194$, $p < 0.01$), creativity ($\beta = 0.255$, $p < 0.01$), communication ($\beta = 0.183$, $p < 0.05$), and collaboration ($\beta = 0.157$, $p < 0.01$). All four capabilities also positively influence knowledge co-creation, which in turn significantly affects incremental innovation ($\beta = 0.257$, $p < 0.01$). The findings further indicate partial mediation, suggesting that learning-oriented capabilities contribute to innovation both directly and through knowledge co-creation. These findings indicate that incremental innovation in resource-constrained manufacturing SMEs depends not only on the presence of learning-oriented capabilities but also on how these capabilities are integrated through knowledge sharing, integration, and application processes. Knowledge co-creation therefore functions as a central mechanism through which existing capabilities are translated into innovation outcomes.

Keywords knowledge co-creation, incremental innovation, learning-oriented capabilities, knowledge integration, resource-constrained SMEs, Thailand

JEL Classification D83, O31, O32, M10

Conflict of interest statement:
Author(s) reported no conflict of interest

INTRODUCTION

Small and medium-sized enterprises (SMEs), particularly those operating in developing or transition economies, often face resource and R&D-related limitations that constrain their capacity to innovate (Nguyen et al., 2019). These constraints are reflected in the financial and innovation-related barriers encountered in practice (De Silva et al., 2025). Under such conditions, incremental innovation becomes especially important, as it enables firms to improve existing products, processes, and practices through gradual changes that build on existing knowledge and resources rather than requiring large-scale investment (Al-Khatib & Al-Ghanem, 2022). For many SMEs, this form of innovation is therefore not simply one option among many, but a practical means of remaining competitive.

However, the challenges faced by such firms cannot be explained solely by resource limitations. Firms may possess useful learning-oriented capabilities but still struggle to translate them into meaningful innovation outcomes. This suggests that the key issue is not only whether

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such capabilities exist, but whether they can be mobilized collectively and translated into coordinated organizational action. This challenge is particularly relevant to the 4Cs, namely critical thinking, creativity, communication, and collaboration, which are often treated as individual competencies, with limited attention given to their collective enactment within organizations. As a result, it remains unclear how these strengths can move beyond individual potential to contribute to incremental innovation at the organizational level.

In this respect, the interest lies in the lack of a clear explanation of how learning-oriented capabilities are organized into a firm-level pattern of innovation. In resource-constrained SMEs, such outcomes depend on the ability to connect distributed knowledge, shared understanding, and coordinated action in ways that produce incremental improvements. Accordingly, the central research problem concerns the limited understanding of how learning-oriented capabilities are translated into organizational-level incremental innovation through knowledge-based processes in resource-constrained SMEs.

1. LITERATURE REVIEW AND HYPOTHESES

Innovation in resource-constrained firms is increasingly understood as more than a matter of possessing valuable assets. Competitive outcomes also depend on how organizations mobilize, recombine, and apply existing knowledge to support adaptation and incremental improvement. In this respect, the literature highlights several interrelated areas that are especially relevant to the present study: the resource- and knowledge-based foundations of innovation; the 4Cs as learning-oriented capabilities; knowledge co-creation as a transformation mechanism; and incremental innovation as an outcome particularly relevant to SMEs.

Research on innovation in constrained environments has often been framed through the resource-based and the knowledge-based view. From these perspectives, competitive advantage depends on valuable, rare, and inimitable organizational resources (Barney, 1991), with knowledge regarded as a particularly important strategic asset (Grant, 1996). While these perspectives clarify why knowledge matters, they offer more limited insight into how firms renew and reconfigure their knowledge base over time (Teece et al., 1997). This limitation is especially relevant for SMEs, where innovation depends less on resource abundance and more on the effective mobilization and recombination of what firms already possess. In such contexts, innovation is better viewed not as the product of isolated competencies, but as the outcome of organizational mechanisms that mobilize dispersed knowledge into coordinated action.

Within this broader problem, the 4Cs framework, namely critical thinking, creativity, communication, and collaboration, offers a useful starting point for understanding the learning-oriented capabilities that may support innovation. Originating in educational research, the 4Cs have been recognized as important competencies in contemporary learning contexts, particularly those emphasizing problem solving, active learning, and preparation for rapidly changing work environments (Berkinbayeva et al., 2023; Zakaria et al., 2025; Nurhayati et al., 2025). The framework is also conceptually consistent with experiential learning theory and constructivist perspectives, both of which emphasize knowledge development through reflection, interaction, and active engagement, as reflected in recent 4Cs-oriented learning research (Kolb, 2015; Saimon et al., 2023). However, many existing studies continue to treat the 4Cs primarily as individual-level skills and to examine them mainly in relation to learning outcomes, with less attention given to their enactment as organizational capabilities (Machado et al., 2023; Skrzek-Lubasińska & Malik, 2023; Supena et al., 2021). 4Cs are often developed through specific instructional activities and training practices, such as discussion, problem solving, collaborative tasks, and creative expression, rather than being theorized as organizationally enacted capacities (Salybekova et al., 2023). As a result, their collective and processual role in innovation remains underexplored.

From an organizational perspective, the 4Cs can be reinterpreted as learning-based microfoundations. In this study, the 4Cs are treated not as learning skills in a narrow sense, but as learning-

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oriented capacities enacted through organizational interaction and work routines. Higher-level organizational capacities may emerge from individual-level skills, interactional dynamics, and recurring routines (Wagner & Kurpjuweit, 2024; Lallemant et al., 2023). Critical thinking and creativity shape how organizational members define problems, evaluate alternatives, and generate ideas, whereas communication and collaboration support coordination, shared interpretation, and collective sense-making. Through repeated enactment in routines and collaborative interaction, these capabilities may contribute to broader organizational learning processes. This view is also consistent with evidence from problem-based digital making, where the development of the 4Cs has been shown to emerge through modeling, exploration, communication, and collaborative debugging (Weng et al., 2022). Yet their relevance for innovation is not automatic. Their contribution depends on whether the knowledge they generate can be mobilized, combined, and used in a structured manner. Empirical studies further indicate that the 4Cs develop more visibly in active and collaborative learning environments that combine shared inquiry with problem-solving and project-based activities (Hariyadi et al., 2023).

This requirement directs attention to knowledge co-creation. In this study, knowledge co-creation is treated not as simple sharing, but as the collective development and application of knowledge through interaction. Drawing on the knowledge conversion logic of Nonaka and Takeuchi (1995), knowledge co-creation involves more than simple information exchange. The SECI model explains how tacit and explicit knowledge interact through socialization, externalization, combination, and internalization. Subsequent studies suggest that knowledge co-creation is enacted through collaborative knowledge-sharing, integration, and application (Zhang et al., 2023; Du et al., 2021). Unlike open innovation, which is often associated with drawing on ideas and knowledge across organizational boundaries, knowledge co-creation emphasizes close interaction and the joint development of knowledge among participants (De Silva et al., 2023). It therefore depends not only on access to knowledge but also on relational exchange, dialogic interaction, and collective problem-solving (Ruhanen et al., 2021; Yoon et al., 2020).

Prior research has linked knowledge co-creation to service innovation and other network-based innovation processes (Zhang & Yi, 2024), while studies on incremental innovation have more often emphasized specific enablers such as leadership, knowledge sharing, and collaborative culture (Gui et al., 2022). Recent evidence suggests that research on innovation processes still provides limited insight at a granular level, particularly regarding the distinct conditions underlying incremental and radical innovation (Ferrigno et al., 2025). However, the question of how learning-oriented capabilities give rise to incremental innovation in resource-constrained firms remains insufficiently explained (de Barros et al., 2025). This gap is important because such capabilities may remain latent unless knowledge is collectively shared, integrated, and applied. In this sense, knowledge co-creation acts as a mechanism through which distributed capabilities become usable organizational knowledge.

Incremental innovation provides the context for the outcome in which this transformation becomes especially visible. It refers to the refinement of existing products, services, and processes through improvements that build on current knowledge rather than radical technological change (Gui et al., 2022). Prior research shows that incremental innovation is associated with knowledge accumulation capabilities and the refinement of existing products, processes, and methods (Forés & Camisón, 2016). It is also associated with recombination within established or technologically proximate domains, rather than with distant knowledge combinations or radically new technological trajectories (Kobarg et al., 2019). Related research further describes incremental innovation as building on existing knowledge and technology through cumulative improvements and small adjustments to existing products and technological principles (Shi et al., 2020). For SMEs, this mode of innovation is strategically appropriate because it involves lower financial risk and does not require high-cost technological investment (Al-Khatib & Al-Ghanem, 2022). Although prior studies have linked leadership to innovation capability (Nguyen et al., 2025), collaborative culture and digital adoption to incremental innovation (Le et al., 2020; Shi et al., 2024), research in this area remains fragmented. Existing work tends to emphasize specific enablers and pathways, such as leadership and knowledge sharing, rather than the broader transformation processes through which in-

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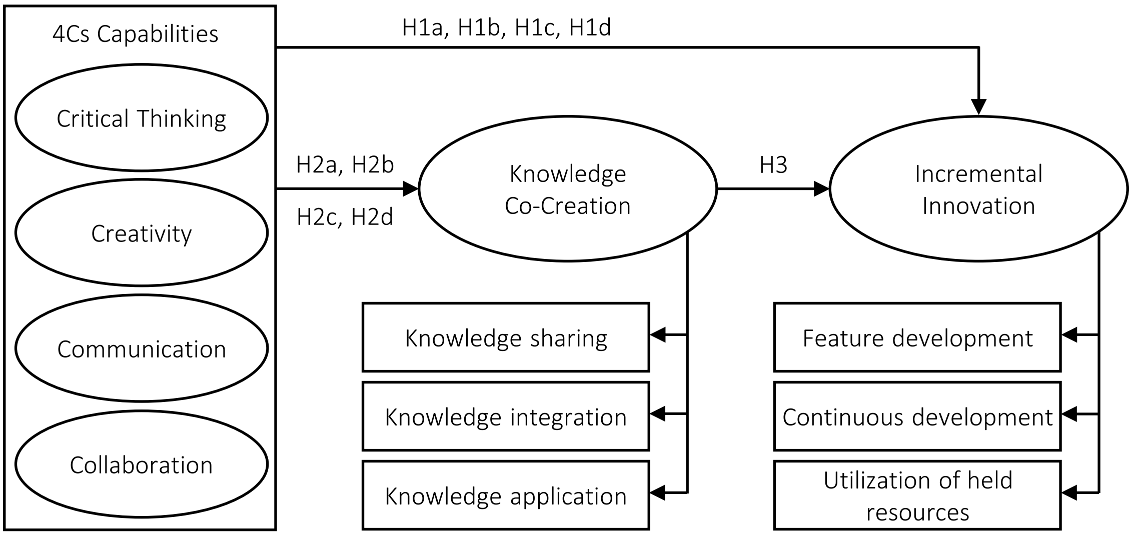

Figure 1. Conceptual framework

cremental innovation emerges (Gui et al., 2022; P. T. Le & P. B. Le, 2025).

To integrate these strands, the present study adopts a dynamic capability perspective, which explains how firms integrate, build, and reconfigure organizational competencies and assets over time in response to changing environments (Teece et al., 1997). This perspective is especially relevant for manufacturing SMEs operating under environmental volatility and resource constraints. Within this logic, the 4Cs function as learning-based microfoundations that support sensing, interpretation, and problem framing. Knowledge co-creation is the mechanism by which dispersed knowledge is combined and used, while incremental innovation is the observable organizational outcome of this process.

Taken together, prior research establishes that knowledge is central to innovation, that the 4Cs support learning and problem solving, and that knowledge co-creation enables the transformation of dispersed knowledge into collective outcomes. However, these strands remain insufficiently integrated into a coherent, mechanism-based explanation of how learning-oriented capabilities translate into organizational-level incremental innovation in resource-constrained SMEs. This gap highlights the need for a model that explicitly explains this transformation process.

Accordingly, this study aims to explain how 4Cs capabilities contribute to incremental innovation in manufacturing SMEs under resource-constrained conditions through the mediating role of knowledge co-creation. Based on this reasoning, Figure 1 presents the conceptual framework, and the following hypotheses are proposed:

H1a: Critical thinking positively influences incremental innovation.

H1b: Creativity positively influences incremental innovation.

H1c: Communication positively influences incremental innovation.

H1d: Collaboration positively influences incremental innovation.

H2a: Critical thinking positively influences knowledge co-creation.

H2b: Creativity positively influences knowledge co-creation.

H2c: Communication positively influences knowledge co-creation.

H2d: Collaboration positively influences knowledge co-creation.

H3: Knowledge co-creation positively influences incremental innovation.

2. METHODS

This study employed a quantitative cross-sectional research design to examine manufacturing SMEs in Thailand. The manufacturing sector was selected due to its substantial contribution to national GDP and its strategic relevance under the Thailand 4.0 policy, which emphasizes Industry 4.0 transformation. These firms were selected as the empirical context because they typically operate under resource constraints. Under such conditions, translating learning-oriented capabilities into incremental innovation is likely to depend more on organizational processes than on resource abundance. The unit of analysis was the organization. The sampling frame was obtained from the Department of Industrial Works database (updated on April 20, 2025). To ensure organizational stability and sufficient innovation experience, firms were required to

1) have operated for at least five years;
2) employ a minimum of 50 employees; and
3) maintain internal R&D or innovation-related activities.

Simple random sampling was conducted using computer software. Sample size was calculated using G*Power version 3.1, assuming a medium effect size ($f^2 = 0.15$), a significance level of 0.05, statistical power of 0.95, and five predictors. The minimum required sample was 138 firms. Questionnaires were distributed to 300 target companies via mail and email between May and June 2025, a period selected to reflect normal business operations and reduce time-related bias in responses. Two follow-up reminders were sent at two-week intervals. A total of 179 usable responses were obtained, yielding a response rate of 59.67%, which exceeded the required minimum sample size. Respondent characteristics (including position and work experience) are summarized in Table 1. The respondent profile reflects a mix of technical and managerial roles relevant to firm operations and innovation activities. To assess potential non-response bias, wave analysis was conducted by comparing early and late respondents following the procedure suggested by Duszynski et al. (2022). No statistically significant differences were identified, suggesting that non-response bias is unlikely to be a serious concern. The data used in this study were collected specifically for this research and have not been used in other publications.

The research procedure followed a structured sequence:

1) establishing the sampling frame and identifying eligible firms based on predefined criteria;
2) developing the questionnaire based on validated measures from prior studies and reviewing it for content validity;
3) securing the required ethical clearance;
4) conducting a pilot test to assess reliability and clarity;
5) collecting data through a survey; and
6) screening and analyzing the data using PLS-SEM to evaluate both the measurement and structural models.

The questionnaire consisted of five sections covering company information, respondent information, and the measurement items for the

Table 1. Characteristics of the respondents

Characteristics	Details	Frequency	Percentage
Position	Engineer	89	49.72
	Business Owner / Executive	34	18.99
	Technician	42	23.46
	Others	14	7.82
Work experience	< 1 year	8	4.47
	1–5 years	52	29.05
	5–10 years	67	37.43
	> 10 years	52	29.05

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study constructs across the focal dimensions of the model. All items were measured using a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). The 4Cs capabilities were measured using 12 items covering four dimensions: critical thinking (3 items; Supena et al., 2021; Nurhayati et al., 2025; Skrzek-Lubasińska & Malik, 2023), creativity (3 items; Berkinbayeva et al., 2023; de Barros et al., 2025), communication (3 items; Buayai et al., 2025), and collaboration (3 items; Lallemant et al., 2023; Abu Talib et al., 2025). Knowledge co-creation was measured using 9 items (Zhang et al., 2023; Zhang & Yi, 2024). Incremental innovation was assessed using 9 items (Le et al., 2020; Al-Khatib & Al-Ghanem, 2022; Ferrigno et al., 2025). The complete list of measurement items and their sources is presented in Table A1 (Appendix A). The measurement items were developed by synthesizing and adapting indicators from prior studies to ensure content validity and conceptual consistency with the constructs of interest. The selection and scope of items were guided by three considerations:

1) theoretical alignment with the constructs defined in the conceptual model;

2) consistency with prior empirical operationalizations to support measurement reliability; and

3) parsimony to reduce respondent burden and improve response quality in organizational surveys.

Knowledge co-creation and incremental innovation were conceptualized as multidimensional constructs composed of three theoretically distinct but conceptually related dimensions. Rather than modeling them as higher-order constructs, this study adopted dimension-level aggregation. This decision reflects the study's primary objective of examining the predictive relationships among theoretically meaningful dimensions, rather than testing hierarchical component structures. Item scores were averaged within each dimension (three items per dimension), and the resulting dimension scores were used as indicators in the structural model. This approach enhances parsimony and estimation stability while preserving the conceptual distinctiveness of each dimension.

Content validity was evaluated by three experts in business development, knowledge management, and innovation management. The Index of Item-Objective Congruence (IOC) was calculated using a minimum threshold of 0.50 (Turner & Carlson, 2003), and all items met this criterion. A pilot test was conducted with 30 executives from food manufacturing firms to assess internal consistency. Cronbach's alpha coefficients ranged from 0.72 to 0.83, exceeding the recommended threshold of 0.70, thereby indicating satisfactory reliability.

Data were analyzed using partial least squares structural equation modeling (PLS-SEM) with SmartPLS version 4.1.1.2. PLS-SEM was selected because the proposed model includes multiple indirect effects through a single mediator and aims to predict incremental innovation outcomes. Its suitability for estimating indirect effects, maximizing the explained variance of endogenous constructs, and handling moderate sample sizes makes it appropriate for this study. As the unit of analysis was the organization, one key informant response was obtained from each firm and treated as the organizational-level observation. Data screening indicated no missing values; thus, no imputation or case deletion was required before estimation. To assess potential common method bias associated with the single-informant design, the full collinearity test was conducted (Kock, 2015). The variance inflation factors (VIFs) for all latent constructs ranged from 1.346 to 2.155, remaining below the recommended threshold of 3.300. These results indicate that common method bias is unlikely to be a significant threat. However, given the single-informant design, residual bias cannot be entirely ruled out.

The analysis proceeded in several stages. First, the reflective measurement model was assessed by examining indicator reliability, internal consistency reliability, convergent validity, and discriminant validity. Second, the structural model was evaluated by assessing collinearity, coefficient of determination (R^2), effect sizes (f^2), and predictive relevance. Third, predictive performance was examined in line with current PLS-SEM reporting recommendations (Hair et al., 2019; Guenther et al., 2023). Finally, direct and indirect effects were tested using bootstrapping with 10,000 subsamples to assess the significance of path coefficients and construct confidence intervals. Because all hypotheses were theoretically directional, one-tailed tests were applied when evaluating path significance.

This study received ethical approval from the Human Research Ethics Committee of Mahachulalongkornrajavidyalaya University (IRB No. R.110/2024). The research was conducted in accordance with national and international research ethics standards and the COPE guidelines on good publication practice. Participation was voluntary, and written informed consent was obtained from all respondents before survey completion. No personally identifiable information was collected. Signed consent forms were stored separately from the survey data to prevent any linkage. All responses were anonymized before analysis and reported only in aggregated form. Data were securely stored with restricted access and will be retained for three years after publication before permanent destruction. The authors disclose all funding sources and report no conflicts of interest.

3. RESULTS

The reflective measurement model was then evaluated (Table 2) by examining indicator reliability, internal consistency reliability, convergent validity, and discriminant validity. All outer loadings exceeded the recommended threshold of 0.708. Cronbach's alpha, rho_A, and composite reliability values ranged from 0.70 to 0.95, satisfying the recommended thresholds. Convergent validity was supported, as all average variance extracted (AVE) values exceeded 0.50. Discriminant validity was established, as all heterotrait-monotrait (HTMT) values were below 0.85 (Guenther et al., 2023). Confirmatory tetrad analysis (CTA) was conducted to verify the appropriateness of the reflective model specification, and the results confirmed the reflective specification of all constructs (Hair et al., 2022).

Structural model assessment (Table 2) followed

Table 2. Reflective measurement and structural models

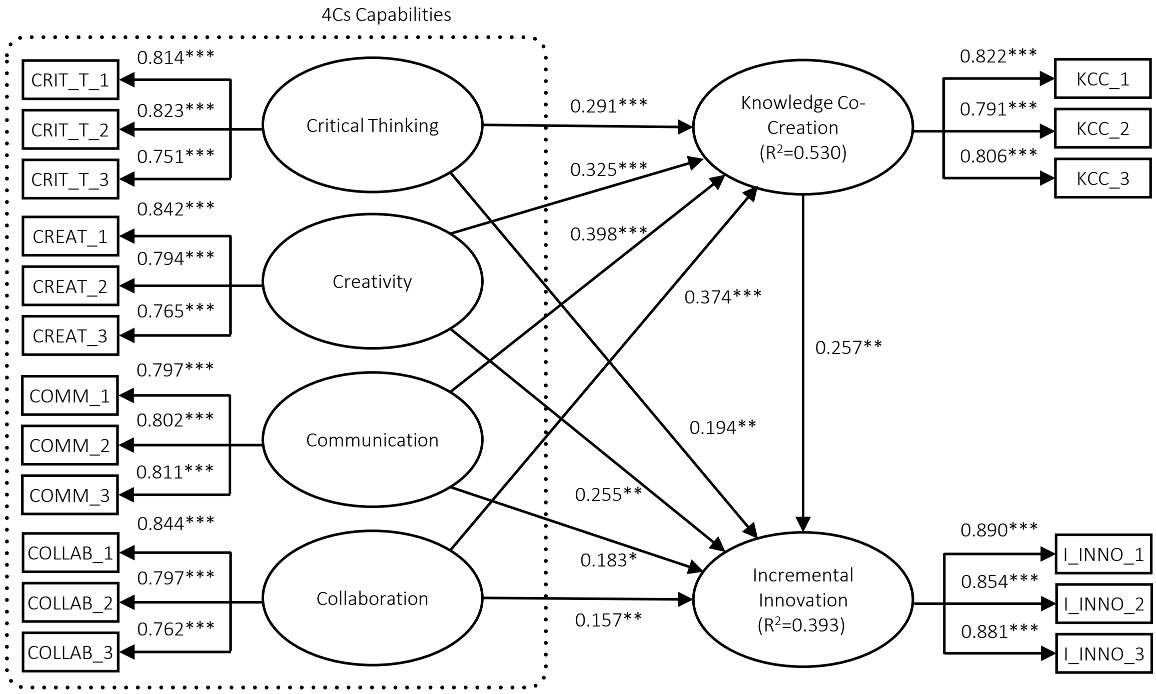
Constructs	Outer loading	VIF	Model type	HTMT	R^2	R^2 adjusted	PLSpredict
Critical Thinking (CRIT_T) (AVE = 0.635, α = 0.717, rho_A = 0.732, rho_c = 0.839)			Reflective	CREAT = 0.116 COMM = 0.138 COLLAB = 0.098 KCC = 0.435 I_INNO = 0.370	–	–	–
CRIT_T_1	0.814	1.346					
CRIT_T_2	0.823	1.466					
CRIT_T_3	0.751	1.420					
Creativity (CREAT) (AVE = 0.642, α = 0.724, rho_A = 0.743, rho_c = 0.843)			Reflective	COMM = 0.186 COLLAB = 0.089 KCC = 0.475 I_INNO = 0.450	–	–	–
CREAT_1	0.842	1.468					
CREAT_2	0.794	1.359					
CREAT_3	0.765	1.467					
Communication (COMM) (AVE = 0.642, α = 0.722, rho_A = 0.732, rho_c = 0.843)			Reflective	COLLAB = 0.089 KCC = 0.475 I_INNO = 0.450	–	–	–
COMM_1	0.797	1.506					
COMM_2	0.802	1.419					
COMM_3	0.811	1.361					
Collaboration (COLLAB) (AVE = 0.645, α = 0.726, rho_A = 0.728, rho_c = 0.845)			Reflective	KCC = 0.500 I_INNO = 0.303	–	–	–
COLLAB_1	0.844	1.419					
COLLAB_2	0.797	1.483					
COLLAB_3	0.762	1.395					
Knowledge Co-Creation (KCC) (AVE = 0.650, α = 0.731, rho_A = 0.732, rho_c = 0.848)			Reflective	I_INNO = 0.699	0.530 Moderate explanatory power	0.519 Moderate explanatory power	High predictive power
KCC_1	0.822	1.542					
KCC_2	0.791	1.426					
KCC_3	0.806	1.399					
Incremental Innovation (I_INNO) (AVE = 0.766, α = 0.847, rho_A = 0.852, rho_c = 0.907)			Reflective		0.393 Weak explanatory power	0.375 Weak explanatory power	High predictive power
I_INNO_1	0.890	2.155					
I_INNO_2	0.853	1.938					
I_INNO_3	0.881	2.074					

http://dx.doi.org/10.21511/ppm.24(2).2026.39

the guidelines of Hair et al. (2022). All VIF values were below 3, indicating no concerns about multicollinearity among the predictor constructs. In-sample explanatory power, assessed through R^2, indicated a moderate level of explained variance for knowledge co-creation, whereas incremental innovation showed a lower but still acceptable level. All $Q^2_{predict}$ values were greater than zero, confirming predictive relevance. Given the relatively symmetric distribution of prediction errors, root mean squared error (RMSE) was used as the primary evaluation metric. In all cases, the PLS-SEM model produced lower RMSE values than the naïve linear benchmark, indicating better out-of-sample predictive performance (Shmueli et al., 2019). Taken together, the model demonstrates acceptable explanatory power and strong out-of-sample predictive performance, despite only moderate to lower levels of explained variance. Model fit was further supported by an SRMR value of 0.071, which is below the recommended threshold of 0.08 (Hair et al., 2024). Effect size assessment (Table 3) indicated that the effects of the 4Cs capabilities on knowledge co-creation ranged from small to moderate, whereas the remaining relationships showed small effect sizes (Cohen, 1988).

Table 3. Predictor assessment

H	Paths	Beta	Mean	S.D.	t-value	p-value	f^2	Result
H1a	CRIT_T → I_INNO	0.194	0.199	0.066	2.955	0.003	0.052	Supported
H1b	CREAT → I_INNO	0.255	0.257	0.074	3.444	0.001	0.087	Supported
H1c	COMM → I_INNO	0.183	0.182	0.080	2.295	0.022	0.041	Supported
H1d	COLLAB → I_INNO	0.157	0.160	0.055	2.862	0.004	0.031	Supported
H2a	CRIT_T → KCC	0.291	0.290	0.055	5.268	0.000	0.178	Supported
H2b	CREAT → KCC	0.325	0.326	0.050	6.512	0.000	0.223	Supported
H2c	COMM → KCC	0.398	0.396	0.044	9.073	0.000	0.331	Supported
H2d	COLLAB → KCC	0.374	0.374	0.045	8.293	0.000	0.297	Supported
H3	KCC → I_INNO	0.257	0.254	0.081	3.175	0.002	0.051	Supported
–	CRIT_T → KCC → I_INNO	0.075	0.074	0.029	2.576	0.010	–	–
–	CREAT → KCC → I_INNO	0.084	0.083	0.031	2.729	0.006	–	–
–	COMM → KCC → I_INNO	0.102	0.100	0.033	3.138	0.002	–	–
–	COLLAB → KCC → I_INNO	0.096	0.095	0.033	2.959	0.003	–	–



Note: * p < 0.05, ** p < 0.01, and *** p < 0.001, one-tailed test.

Figure 2. Results of the structural model

The hypothesis-testing results (Table 3 and Figure 2) indicate support for all proposed relationships. Specifically, critical thinking (H1a), creativity (H1b), communication (H1c), and collaboration (H1d) were found to positively influence incremental innovation. Likewise, all four 4Cs capabilities positively influenced knowledge co-creation (H2a–H2d). Furthermore, knowledge co-creation exhibited a significant positive effect on incremental innovation (H3). In addition, all indirect effects of the 4Cs capabilities on incremental innovation through knowledge co-creation were positive and significant, providing support for the mediating role of knowledge co-creation. Collectively, these findings are consistent with the proposed structural model and the hypothesized relationships among the constructs.

4. DISCUSSION

The findings reveal a coherent pattern that is theoretically consistent with the proposed model. All direct effects of the 4Cs capabilities on incremental innovation were supported (H1a–H1d), and knowledge co-creation also exhibited a significant positive effect on incremental innovation. In addition, the significant indirect effects indicate that knowledge co-creation partially mediates the relationships between the 4Cs and incremental innovation. Taken together, these results suggest that incremental innovation in SMEs appears to depend not only on individual capabilities, but also on an interconnected learning system in which cognitive and relational capabilities operate both directly and through a structured transformation process. This pattern is consistent with prior empirical research indicating that individual learning capabilities and knowledge-related behaviors contribute to innovation outcomes when embedded within collective processes rather than operating independently (Le et al., 2020; Gui et al., 2022). However, whereas earlier studies have typically examined these drivers in isolation, the findings demonstrate their simultaneous and interdependent effects within a unified transformation model.

The direct effects indicate that critical thinking and creativity function as cognitive foundations for incremental innovation by enabling systematic problem evaluation, idea generation, and the refinement of existing solutions. These capabilities strengthen the organization's ability to reinterpret and recombine existing knowledge in ways that support continuous improvement. This interpretation aligns with research emphasizing the role of critical thinking in organizational problem-solving (Skrzek-Lubasińska & Malik, 2023) and with evidence that conceptualizes creativity and innovation as involving novelty, problem-solving, and implementation-oriented change processes (Beresford-Dey et al., 2022). Communication and collaboration, in turn, operate as relational enablers. Effective communication facilitates knowledge exchange and alignment, while collaboration supports the coordinated development and refinement of shared solutions, consistent with findings on communicative scaffolding and collaborative debugging (Weng et al., 2022). These results also align with prior evidence that collaboration-oriented organizational interaction and knowledge exchange support innovation outcomes (Le et al., 2020). However, unlike studies that give greater emphasis to particular capabilities, the results indicate that all four dimensions contribute significantly to incremental innovation, suggesting that innovation outcomes may depend on the presence of multiple capabilities rather than on any single dimension. In resource-constrained SMEs, where innovation relies more on coordination than on resource abundance, the integration of cognitive depth and relational connectivity becomes especially critical.

The mediation findings further clarify the underlying transformation logic. While the 4Cs create the cognitive and relational conditions necessary for innovation, knowledge co-creation functions as the process layer through which these capabilities are translated into coordinated knowledge processes that support innovation. The positive effects of 4Cs capabilities on knowledge co-creation (H2a–H2d) indicate that all four dimensions contribute to the development of shared and integrated knowledge processes. Through structured knowledge sharing, integration, and application, dispersed insights can be transformed into coordinated organizational knowledge that supports product, process, and service improvements (Zhang & Yi, 2024). Moreover, the significant effect of knowledge co-creation on incremental innovation (H3) confirms its central role in trans-

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lating learning-based capabilities into observable innovation outcomes. While prior studies have emphasized the importance of knowledge-sharing processes for innovation-related outcomes (Bhatti et al., 2021; Nasution et al., 2025), they have often failed to explicitly identify the mediating mechanism by which learning-oriented capabilities translate into innovation. The findings extend this line of research by empirically demonstrating that knowledge co-creation serves as a partial mediator linking learning capabilities to incremental innovation outcomes. This also responds to recent calls for a more fine-grained explanation of the distinct conditions underlying incremental and radical innovation (Ferrigno et al., 2025), while reinforcing related evidence on mediation effects in innovation research (P. T. Le & P. B. Le, 2025). In addition, whereas prior studies have often discussed the 4Cs as competencies in educational and learning contexts (Supena et al., 2021), the results are consistent with their organizational-level enactment through knowledge integration processes. From a dynamic capability perspective (Teece et al., 1997), the 4Cs can be interpreted as learning-based processes that support coordination, knowledge integration, and organizational adaptation. Knowledge co-creation, in turn, functions as the integrative mechanism through which these processes are translated into coordinated action, ultimately supporting observable incremental innovation outcomes.

Finally, the focus on manufacturing SMEs provides a clear boundary for interpreting the findings. In resource-constrained settings, firms tend to rely on the refinement of existing processes and offerings rather than on resource-intensive innovation strategies. Within this context, knowledge co-creation plays a central role by enabling the effective use and alignment of existing knowledge without requiring substantial additional resources. This interpretation is consistent with prior research highlighting the role of knowledge-sharing processes in supporting innovation capability (Gui et al., 2022), while the present study specifies the mechanism through which such outcomes occur, namely knowledge co-creation as the integrative process linking learning-oriented capabilities to incremental innovation. Accordingly, the findings should be understood as explaining incremental innovation in resource-constrained SMEs rather than as a generalized model for all innovation contexts.

Overall, the findings point to a process-based interpretation of incremental innovation, in which learning-oriented capabilities contribute to innovation outcomes when they are integrated through knowledge co-creation. Rather than acting as entirely independent drivers, these capabilities appear to become more effective when embedded in coordinated knowledge processes.

CONCLUSION

This study examined how 4Cs capabilities contribute to incremental innovation in manufacturing SMEs, particularly under resource-constrained conditions, through the mediating role of knowledge co-creation. The results indicate that critical thinking, creativity, communication, and collaboration are positively associated with incremental innovation both directly and indirectly through knowledge co-creation, suggesting partial mediation. These findings highlight the central role of knowledge co-creation in linking learning-oriented capabilities to innovation outcomes.

The findings suggest that incremental innovation in manufacturing SMEs depends not only on learning-oriented capabilities, but also on how these capabilities are integrated through structured knowledge practices. By demonstrating this mechanism, the study clarifies how learning-oriented capabilities become coordinated at the organizational level and contribute to innovation outcomes, extending prior research that has often examined these capabilities in isolation.

From a practical perspective, the results indicate that managers in resource-constrained SMEs should prioritize strengthening mechanisms that support knowledge sharing, integration, and application. Emphasizing the coordinated use of existing knowledge may be more effective than developing individual capabilities without supporting mechanisms for knowledge integration. This study is subject to several limitations, including the use of cross-sectional data and a focus on manufacturing SMEs in Thailand, which may limit generalizability. Future research may extend this work by examining other forms of innovation or adopting longitudinal and multi-method approaches to capture the dynamic nature of organizational learning capability development and knowledge processes.

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ACKNOWLEDGMENT

This research was supported by Prince of Songkla University (Grant No. LAM6802035S).

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APPENDIX A

Table A1. Constructs and measurement items

Construct	Item
Critical Thinking	Organization supports employees in using logical reasoning and systematically analyzing business data before decisions
	Organization provides tools and systems to help employees assess probability and uncertainty in business decisions
	Organization encourages employees to handle unconventional challenges proactively and find effective solutions
Creativity	Organization supports employees in creating new concepts and developing innovations that drive business growth
	Organization has programs to develop expertise and creative thinking skills for employees
	Organization has incentive systems and environments that encourage creative thinking and effective problem-solving
Communication	Organization trains employees to communicate complex information in easily understandable ways
	Organization trains employees to present information clearly and listen to others effectively
	Organization encourages employees to adapt language and communication style to suit audience level and role
Collaboration	Organization creates environments that promote effective teamwork with diverse teams
	Organization has an organizational culture that promotes respect and equality in interdisciplinary work
	Organization has processes that help employees integrate multiple perspectives in collaborative problem-solving
Knowledge Co-Creation	Organization openly shares knowledge and experience with stakeholders
	Organization listens to and learns from feedback from customers and partners
	Organization has appropriate systems and channels for knowledge exchange
	Organization gathers knowledge from various sources to create complete understanding
	Organization creates new knowledge by combining existing knowledge with external knowledge
	Organization coordinates cross-functional collaboration to integrate diverse knowledge
	Organization applies acquired knowledge to solve immediate problems quickly
	Organization uses shared knowledge as basis for strategic decision-making
	Organization monitors and evaluates results from knowledge application for continuous improvement
Incremental Innovation	Organization adds new features to existing products/services
	Organization regularly improves quality and performance of products/services
	Organization customizes products/services to meet customer needs in different markets
	Organization continuously improves its production and operational processes
	Organization regularly develops and maintains its work systems to enhance operational effectiveness
	Organization incrementally improves delivery procedures for products and services to customers
	Organization maximizes utilization of employee skills and expertise
	Organization uses existing tools, equipment, and technology cost-effectively
	Organization allocates and manages resources to increase efficiency and reduce costs