

The Role of Case Method and Team Based Projects in Bridging the Vocational Skill Gap in Appropriate Technology Design

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Abstract

Backgorund:

The gap between graduate competencies and the ever-evolving demands of industry remains a major challenge in vocational education. Although many vocational curricula have adopted competency-based standards, their implementation often fails to develop complex 21st-century skills, such as critical thinking, creativity, communication, and collaboration.

Purpose

This study aims to investigate the need for a competency-based training (CBT) model that integrates the Case Method and Team-Based Project (TBP) in Appropriate Technology Design learning.

Method

A quantitative descriptive approach was used to analyze students' perceptions of the contribution of both approaches to job skill development. Data were collected from 493 Mechanical Engineering Education students enrolled in the Appropriate Technology Design course and analyzed using Structural Equation Modeling (SEM) through path analysis.

Results

The results indicate a hierarchical relationship within the 4C (Critical Thinking, Creativity, Communication, and Collaboration) framework, where critical thinking and creativity influence communication, while communication has a strong influence on collaboration. Creativity has both direct and indirect influences on collaboration, while the influence of critical thinking on collaboration is fully mediated by communication. The model exhibits high predictive power, explaining 86.6% of the variation in communication and 82.9% of the variation in collaboration.

Conclusion

The findings reveal that critical thinking and creativity function as foundational cognitive competencies that enhance communication skills, while communication serves as the key mechanism linking individual cognitive capacities to effective collaboration in appropriate technology design projects. The study provides empirical evidence that the synergy between the Case Method and Team-Based Projects constitutes an effective pedagogical pathway for bridging the vocational skills gap by integrating cognitive development with structured collaborative experiences. However, the study is limited by its reliance on self-reported competency measures and its focus on the 4C framework, suggesting the need

for future longitudinal research incorporating additional factors such as learning motivation, team leadership, and collaborative culture.

1. Introduction

Technical and Vocational Education and Training (TVET) plays a strategic role in economic development by preparing a skilled workforce capable of adapting to rapid industrial change. In the era of the knowledge-based economy and digital transformation triggered by the Industrial Revolution 4.0 and the vision of Society 5.0, the need for job competencies is no longer limited to procedural technical skills. Instead, the modern labor market increasingly demands complex skills that integrate cognitive, social, and collaborative abilities. The Future of Jobs report indicates that approximately 44% of workers' core skills are expected to change by 2027, with an increasing need for analytical thinking, creativity, communication, and teamwork [1]. Various global competency frameworks have emphasized the importance of 21st-century skills, often summarized as the 4Cs: critical thinking, creativity, communication, and collaboration [2, 3]. The implementation of 4C skills in various educational contexts has resulted in significant improvements in both cognitive and non-cognitive domains [4–8]. These four competencies are seen as important foundations for an adaptive workforce capable of addressing complex problems and dynamic work environments [9].

Although many countries have adopted a Competency-Based Training (CBT) approach to align education with industry needs, the skills gap between TVET graduates and workforce demands persists. An International Labour Organization report indicates that many employers perceive TVET graduates as having adequate technical skills, but lacking the diagnostic, problem-solving, and adaptive social skills needed in complex work environments (International Labour Organization, 2021). Nouatin et al. [11] identified a persistent gap between the competencies developed through TVET programmes and labour market needs, further underscoring the need for vocational education reforms that more closely align skills development with occupational demands. Other research also indicates that graduates often struggle to transfer technical competencies to real-world work situations that require team coordination, professional communication, and context-based decision-making [12, 13]. This situation indicates limitations in CBT implementation, which tends to emphasize the achievement of individual competency units through checklist-based assessments rather than the development of integrated problem-solving skills [14, 15]. As a result, students may meet individual competency standards, but may not be able to integrate that knowledge into complex teamwork.

This gap becomes even more apparent in the context of Appropriate Technology design learning. Developing appropriate technology requires not only technical engineering skills but also a contextual understanding of community needs, local resource constraints, and the ability to work collaboratively in multidisciplinary teams to produce sustainable technological solutions [16–18]. Therefore, pedagogical approaches that integrate higher-order thinking skills with teamwork are becoming increasingly important in TVET. Various studies have shown that case-based learning effectively enhances students' critical thinking and creativity through authentic case analysis and reflection on alternative solutions [19,

20]. Meanwhile, project-based learning has been shown to develop communication, collaboration, and problem-solving skills through collective solution design and implementation activities [21, 22]. The integration of case-based and project-based approaches has great potential to link cognitive capacity development with collaborative practice in engineering learning environments [23].

Although the effectiveness of the Case Method and Team-Based Projects (TBP) has been widely demonstrated individually, research examining their synergy in the TVET context is still relatively limited. Most previous studies have focused on general medical, business, or engineering education without specifically exploring the dynamics of employability skills development in project-based vocational education environments [24, 25]. Furthermore, research using a structural modeling approach to analyze the relationships among 21st-century competencies in the implementation of active pedagogy remains rare. Therefore, this study aims to evaluate how integrating the Case Method and TBP can help bridge the skills gap in the context of Appropriate Technology Design and Construction learning. This study analyzes how critical thinking and creativity influence communication, and how communication shapes collaboration in the context of appropriate technology design learning.

2. Literature Review

2.1. 21st-Century Competencies in TVET

TVET is increasingly expected to prepare graduates with not only technical skills but also adaptive competencies to navigate the dynamics of technological and industrial change. This situation underscores the need to shift from merely being "technical work-ready" to broader, more sustainable competencies. TVET curricula need to be designed in collaboration with industry and reviewed regularly to keep pace with technological developments [26]. In the context of high-tech jobs, soft skills such as critical and analytical thinking, problem-solving, communication, creativity, and flexibility are highly sought after because they foster adaptability [27]. 21st-century skills such as creativity, communication, collaboration, and critical thinking (4Cs) are considered essential to integrate [28, 29]. These competencies serve as a bridge between mastery of technical knowledge in TVET implementation and the ability to apply it in real-world work situations, which are often complex and unstructured. In practice, the 4Cs competencies do not develop in isolation but rather form an interrelated system of abilities [30]. Critical thinking and creativity generally play a role in the cognitive dimension of problem-solving, namely the ability to analyze situations, evaluate alternative solutions, and generate innovative ideas [31]. Meanwhile, communication and collaboration play a role in the social dimension of solution implementation, namely the ability to convey ideas, negotiate, and work effectively in teams [32]. Understanding the relationships between these competencies is crucial in designing learning strategies that develop integrated work skills.

One widely used learning approach to developing higher-order thinking skills is the Case Method. This approach is rooted in constructivist learning theory, which emphasizes that knowledge is built through interaction with real-world or contextual situations [19]. Students are faced with authentic, complex,

open-ended problems that require them to analyze the situation, evaluate alternative solutions, and make rational decisions [20]. The case study method can help students develop analytical and reflective thinking skills when facing technological problems that lack a single definitive answer [33, 34]. The case study process encourages students to identify the root cause, consider multiple perspectives, and formulate innovative solutions appropriate to the problem context [28]. The Case Method serves as a pedagogical mechanism that activates critical thinking and creativity skills, which are fundamental to the design of technological solutions.

In addition to analytical skills, implementing technological solutions also requires the ability to work effectively in teams. Therefore, collaborative project-based learning approaches are increasingly being used in engineering and vocational education. Project-based learning is a learning approach that places students in work groups to complete a project or produce a technological product collaboratively [22]. Students not only apply technical knowledge but must also coordinate with team members, discuss ideas, assign roles, and resolve conflicts that may arise during group work [35]. Previous research has shown that team-based learning can significantly improve students' interpersonal communication and teamwork skills [36]. Through intensive interaction throughout the project, students learn to articulate ideas clearly, listen to others' perspectives, and integrate individual contributions into collective solutions [37]. TBP can be viewed as a learning approach that specifically strengthens communication and collaboration skills, which are critical to professional practice in engineering and technology.

2.2. Integration of Case Method and Team-Based Projects (TBP)

In technology design practice, the problem-solving process typically begins with situation analysis and the development of solution ideas, which involve critical and creative thinking skills. However, these ideas cannot be effectively implemented without clear communication and strong teamwork coordination [38]. Communication skills can serve as a transition mechanism that bridges individual cognitive abilities with collaborative team performance. When students present and discuss ideas generated through critical and creative thinking processes, communication enables the creation of shared understanding within the team [39, 40]. This interaction supports effective collaboration in the development of technological solutions. However, most previous research has focused on the impact of learning methods on learning outcomes in general, without deeply examining the dynamics of the relationships between competencies that underlie the learning process [7, 8, 35, 41]. This demonstrates the need for research using a structural modeling approach to understand how cognitive competency can influence collaborative competency through communication processes in project-based learning environments.

The integration of the Case Method and TBP aligns with numerous findings on Project-Based Learning as a pathway from problem analysis to collaborative implementation of concrete solutions [21, 42–44]. The Case Method activates the cognitive dimension (critical thinking, creativity), while TBP strengthens the social dimension (communication, collaboration) through authentic tasks [45]. This integration can

be understood as a pedagogical approach that reflects the natural flow of the technological problem-solving process. In the initial stages, case-based learning encourages students to critically analyze problems and generate creative solution ideas [46]. This stage emphasizes the development of higher-order thinking skills as the foundation for problem-solving. Through team project-based learning, these ideas are communicated, discussed, and implemented collaboratively as technological solutions, thereby strengthening interpersonal communication and teamwork [44, 47]. These two approaches form complementary learning trajectories. The Case Method develops cognitive competencies, while the TBP strengthens social and collaborative competencies.

3. Methodology

3.1. Research Design & Participants

This study uses a quantitative, causal-comparative design to analyze the structural relationships among 21st-century skill competencies in the context of technical-vocational learning. The quantitative approach was chosen because it allows researchers to test relationships between variables through objective statistical modeling, specifically Structural Equation Modeling (SEM). The causal-comparative design was used to examine how variations in students' cognitive skills, namely critical thinking and creativity, contribute to the development of socio-collaborative skills, namely communication and collaboration, in the technology design learning process. This study models the competency transformation process that occurs during the implementation of two active learning approaches: the Case Method and the TBP. The Case Method is positioned as a pedagogical approach that develops analytical and creative thinking skills through case analysis and reflective discussion. These skills are then implemented in TBP activities, where students work collaboratively to design and develop appropriate technological solutions.

The participants in this study were 493 students ($N = 493$) from the Mechanical Engineering Education Study Program. All participants were students in the Appropriate Technology Product Design course, which explicitly integrates case-based learning and team projects into the contextual technology product design process. The sampling technique used in this study was total sampling, or census, involving the entire student population enrolled in the course during the research period. This approach was chosen to avoid potential sample selection bias and to obtain a comprehensive representation of the research population. Because the entire population was used as respondents, the research results are expected to more accurately describe the characteristics of student competencies in the context of appropriate technology design learning. The homogeneity of participant characteristics helps minimize irrelevant variability in the data, allowing the structural relationships among the variables analyzed in the research model to be interpreted more clearly.

3.2. Data Collecting & Instruments

Data collection was conducted at the end of the semester after students completed the entire project-based learning cycle within the Outcome-Based Education (OBE) curriculum. Data collection at the final

stage of learning was intended to ensure that all participants experienced a relatively uniform learning process, both in case analysis activities and in the implementation of team projects. Student responses were expected to reflect the learning experiences internalized during the course.

Table 1
Questionnaire Items

Learning Model	Assessment Aspects	Key Indicators	Statement Items
Case Method	Critical Thinking Skill	Interpretation	3
		Analysis	3
		Evaluation	3
		Inference	3
		Explanation	3
		Self-Regulation	3
	Creativity / Innovation Skill	Fluency	3
		Flexibility	3
		Originality	3
		Elaboration	3
		Risk Taking	3
		Problem Solving	3
Team-Based Project (TBP)	Communication Skill	Clarity	3
		Organization	3
		Technical Language Appropriateness	3
		Audience Awareness	3
		Medium Proficiency	3
		Responsiveness/ Interaction	3
	Collaboration Skill	Contribution	3
		Team Interaction	3
		Responsibility	3
		Conflict Management	3
		Decision Making	3
		Goal Orientation	3
Total		24	72

Data collection was conducted using a non-test instrument, a Self-Rating Scale questionnaire, with a Likert scale of 1–4. The instrument consisted of four main constructs, as shown in Table 1: i) Case Method: Measured through Critical Thinking and Creativity variables; and ii) Team-Based Project: Measured through Communication and Collaboration variables. All instrument items underwent validity and reliability testing. The content validity test involved expert judgment, while construct validity and internal consistency met the established psychometric requirements (Cronbach's alpha > 0.70), indicating that the instrument has good accuracy and consistency in measurement.

3.3. Data Analysis

Path analysis was employed to test the plausibility of the hypothesized causal relationships, as endorsed by Kline [48] for complex mediation models. Prior to hypothesis testing through Path Analysis, a series of prerequisite tests was conducted to ensure data integrity. Given the large sample size (N = 493), the Shapiro-Wilk test results were expected to be sensitive. Visual inspection of the Q-Q Plots showed a data distribution that followed a diagonal line, and the Skewness and Kurtosis values in Table 2 were still within the tolerance range (± 2.0). Therefore, parameter estimation continued using the Maximum Likelihood method, which is robust to violations of the normality assumption in large samples [49].

Table 2
Descriptive Statistics and Assumption Checks

Variable	Mean	SD	Skewness	Kurtosis	Tolerance	VIF
Critical Thinking	3.10	0.71	-0.926	0.504	0.133	7.51
Creativity	3.05	0.69	-0.897	0.620	0.098	10.13
Communication	3.02	0.68	-0.922	0.693	0.134	7.44
Collaboration	2.95	0.69	-0.895	0.579	-	-

Furthermore, a multicollinearity test was conducted to ensure independence between predictor variables. The Variance Inflation Factor (VIF) calculation indicated a strong correlation among cognitive variables, with Creativity showing a VIF value slightly above the conservative threshold (VIF = 10.13). However, given the low Standard Error (SE < 0.06) in the path estimation, this indication of multicollinearity is not considered to disrupt the stability of the structural model. According to O'brien [50], multicollinearity becomes a threat only when the SE increases to the point that the coefficient becomes insignificant. The assumptions of linearity and homoscedasticity are met based on visual inspection of the residual plots, which show a random distribution with no discernible curvilinear pattern.

4. Results

4.1. Model Fit and Validity

A goodness-of-fit evaluation was conducted to assess the extent to which the proposed structural model represents the relationships among variables based on empirical data. The analysis results indicate that the estimated model is saturated, namely, it has the same number of parameters as the number of observed covariances, leaving no degrees of freedom for model error. Under this condition, the model can perfectly reproduce the covariance matrix, as reflected in the ideal model fit index. The Root Mean Square Error of Approximation (RMSEA) index shows a value of 0.000, while the Standardized Root Mean Square Residual (SRMR) value is also 0.000, and the Comparative Fit Index (CFI) reaches a maximum value of 1.000. These values are within the recommended range in the SEM literature, where $RMSEA < 0.06$, $SRMR < 0.08$, and $CFI > 0.95$ are generally considered to indicate excellent model fit (Hu & Bentler, 1999; Kline, 2016). The theoretical relationship structure proposed in this study demonstrates strong model validity in explaining the relationships among competencies within the 4C framework.

4.2. Path Coefficients and Hypothesis Testing

The path parameter estimation results in Table 3 provide an overview of the dynamics of the relationship between cognitive skills and social skills in the research model. Path coefficient analysis indicates that creativity significantly influences collaboration, both directly and indirectly through communication. Directly, creativity has a positive influence on collaboration with a standardized coefficient of $\beta = 0.236$ ($p < .001$). Furthermore, creativity also has a very strong influence on communication ($\beta = 0.658$, $p < .001$). This relationship pattern indicates partial mediation, where communication functions as a mediator that strengthens the influence of creativity on collaboration, but the direct path between creativity and collaboration remains significant.

Table 3
Path Coefficients and Hypothesis Testing

Hypothesis Path	B	SE	β	z	p	Result
Direct Effects						
Critical Thinking → Collaboration	0.046	0.050	0.047	0.921	.357	Rejected
Creativity → Collaboration	0.236	0.060	0.236	3.981	< .001	Accepted
Communication → Collaboration	0.653	0.052	0.644	12.673	< .001	Accepted
Indirect Effects (Mediation)						
Critical Thinking → Communication	0.280	0.042	0.287	6.619	< .001	Accepted
Creativity → Communication	0.657	0.043	0.658	15.181	< .001	Accepted
Note: B = Unstandardized estimate; SE = Standard error; β = Standardized estimate. R^2 values: Communication = 0.866; Collaboration = 0.829.						

In contrast to creativity, the critical thinking variable shows a different pattern of relationships. The analysis results show that the direct effect of critical thinking on collaboration is not significant ($\beta = 0.047$, $p = 0.357$). However, critical thinking has a significant influence on communication ($\beta = 0.287$, $p < .001$). This pattern indicates full mediation, where the influence of critical thinking on collaboration is fully mediated by communication. Meanwhile, the communication variable was found to have the strongest influence on collaboration, with a standardized coefficient of $\beta = 0.644$ ($p < .001$).

4.3. Predictive Power and Structural Model Visualization

The model's predictive power in social skill development is considered very high. The R^2 analysis indicates that 86.6% of the variance in Communication ($R^2 = 0.866$) is explained by Critical Thinking and Creativity. Furthermore, this model collectively explains 82.9% ($R^2 = 0.829$) of the variance in Collaboration skills. This value indicates that these two cognitive competencies play a significant role in shaping students' communication skills in project-based learning. These values indicate that the proposed model has very high predictive power in explaining social skill development in technology learning environments. According to Cohen (2013), an R^2 value of 0.26 in behavioral science research is considered a large effect size. The R^2 value obtained in this study can be considered to demonstrate very substantial predictive power, indicating that the developed competency model can strongly explain the dynamics of students' work skills in the context of appropriate technology design learning.

The interpretation of the structural model visualization in Fig. 1 provides a clearer picture of the mechanisms underlying the relationships among these competencies. The relationship pattern seen in the model visualization indicates a gradual flow of competency development, where critical thinking and creativity skills first shape students' communication capacity before ultimately contributing to collaborative skills in technology project activities. The model diagram shows that Critical Thinking and Creativity serve as initial cognitive foundations that influence the development of students' communication skills. In this model, creativity makes a more dominant contribution to communication than critical thinking, suggesting that the ability to generate innovative ideas tends to encourage students to be more active in expressing ideas and engaging in group interactions. Communication acts as the main pathway connecting individual cognitive competencies with collaborative skills within teams. Ideas and reasoning generated by individuals can be understood, discussed, and integrated by other team members through communication, thereby fostering effective collaboration.

5. Discussion

5.1. Critical Thinking and Creativity from Case Method Output as the Strong Foundation for Team-Based Project

The results of this study indicate that the integration of the Case Method and TBP cannot be understood as two separate pedagogical approaches, but rather as a series of causally interconnected learning processes. The high coefficient of determination for the Collaboration variable ($R^2 = 0.829$) indicates that

nearly 83% of students' success in working collaboratively can be explained by a combination of pre-existing cognitive skills. This finding indicates that the quality of collaboration in team projects is highly dependent on the cognitive capacities of each team member. Effective teamwork in project-based learning is influenced not only by the group's social dynamics but also by the intellectual readiness of the individuals involved in the collaborative process. This finding is consistent with the principles of the CDIO Framework, which state that collaboration in engineering practice is rooted in the individual's ability to understand, analyze, and design solutions to technical problems [52]. Empirical studies in engineering education also show that integrating collaborative activities with the development of critical thinking skills can simultaneously improve students' analytical abilities and teamwork performance [53]. Several studies in engineering and STEM education have also shown similar patterns. For example, Mora et al. [54] demonstrated that collaborative learning models in engineering education can strengthen students' cognitive engagement through discussion and collaborative problem-solving. Other research has found that structured collaborative learning environments can encourage students to engage in higher-order thinking processes such as analysis, synthesis, and evaluation of ideas during teamwork [55].

Creativity also plays a crucial role in supporting collaboration in technology projects. Creative ideas generated by each individual often trigger discussions, exploration of alternative solutions, and development of technological designs within the team. Previous research has shown that project-based learning can simultaneously enhance students' creative thinking and collaborative skills because both competencies develop through interaction and collaborative exploration of ideas [56, 57]. Creativity is not only about generating new ideas but also about integrating multiple perspectives to produce innovative technological solutions [21]. These research findings reinforce the view that cognitive competencies are a key foundation for collaboration in project-based learning. Students trained in analyzing cases through the Case Method possess intellectual capital in the form of critical thinking skills and creative ideas that can contribute to teamwork. These two competencies serve as cognitive resources, enabling students to participate in discussions actively, offer alternative solutions, and contribute to the development of technological designs in team projects. The integration between the Case Method and TBP can be understood as a pedagogical mechanism that connects the development of individual cognitive capacity with collaborative implementation in a teamwork environment [21, 58].

5.2. The Necessity of Synergy: Why Critical Thinking Needs Communication

One of the most important findings of this study is the occurrence of full mediation in the relationship between critical thinking and collaboration. The analysis showed that the direct path from critical thinking to collaboration was not statistically significant, while the effect of critical thinking on communication was significant. These results suggest that students' analytical skills do not automatically translate into teamwork skills unless the ideas and reasoning generated through the critical thinking process can be effectively communicated to other team members. Communication serves as a connecting mechanism that transforms individual cognitive abilities into collaborative group performance. Communication enables students to coordinate tasks, build consensus, and integrate

individual contributions into collaborative technological solutions [59]. Communication serves as a medium that allows individual reasoning to develop into collaborative action within a team. This finding aligns with several studies on collaborative and project-based learning that enhance critical/creative thinking, as well as communication and collaboration, as evidenced by task coordination, compromise, and team member contributions [47, 60].

Studies in higher education show that communication plays a primary role in externalizing critical thinking processes through discussion, argumentation, and negotiation of ideas within teams [61, 62]. In group work activities, students not only think individually but also need to convey their analysis to other team members for collective evaluation and development. Without effective communication, critical thinking processes remain at the individual cognitive level and do not significantly enhance teamwork quality. Other studies also show that intensive communication, such as exchanging ideas, providing feedback, and clarifying arguments, plays a crucial role in improving the quality of collaboration and problem-solving within learning teams [63, 64]. This finding can be explained through Vygotsky's [65] view that higher psychological functions develop through social interaction before becoming internalized within the individual. Critical thinking is essentially an internal process within the individual's mind. Individuals need to express their thoughts through language or communication so others can understand them. This communication process allows for the exchange of perspectives, clarification of ideas, and the development of shared understanding within the group. The findings of this study also reinforce the view that communication is an integral component of collaboration in team-based learning. Several studies have shown that the quality of collaboration within a team is significantly influenced by team members' ability to articulate ideas, present arguments, and respond to input from others [40, 66].

A different relationship pattern was found for the creativity variable, indicating a significant direct effect on collaboration. This indicates that creative ideas can directly trigger collaborative interactions within a team without always going through a lengthy verbal communication process. This phenomenon can be explained through the concept of boundary objects, where creative artifacts such as design sketches, prototypes, or concept models can serve as shared media that enable team members to collectively understand and develop ideas [67]. The collaboration process can occur through visual or material representations that bring together diverse team members' perspectives. In CBT pedagogy, these findings provide important implications regarding the synergistic role of the Case Method and TBP. The Case Method has proven effective in developing students' analytical skills through the process of interpreting and evaluating cases. However, the results of this analysis are essentially internal and do not necessarily contribute to teamwork. Therefore, TBP function as an externalization mechanism that allows these ideas to be communicated and negotiated within a teamwork environment. Without the communication process facilitated by TBP, individuals' critical thinking skills will not translate into effective collaboration on technology projects.

5.3. Implications for Competency-Based Training Models

Several literature reviews have shown that case-based, problem-based, and project-based learning are actually complementary approaches to real-world problem-based learning [68, 69]. Various studies have

shown that case-based learning consistently improves students' critical thinking and creativity, especially when the cases are designed in stages with increasing levels of complexity, encouraging students to analyze, evaluate, and reflect on solutions to realistic engineering problems [19]. Active student-centred learning in case- and problem-based settings enables students to analyse authentic problems, make decisions, construct knowledge collaboratively, and develop critical thinking, communication, collaboration, and problem-solving skills [70]. The implementation of CBT in various engineering programs has also been reported to simultaneously improve students' problem-solving, communication, and teamwork skills [23, 71]. Furthermore, several studies have also shown that project-based learning consistently strengthens students' communication and collaboration skills, as students must interact intensively in the process of designing, testing, and implementing technological solutions. Studies in engineering education show that project-based learning not only improves problem-solving skills but also develops team communication skills, task coordination, and collective decision-making [21, 72].

This study shows that the cognitive skills developed through the Case Method are not merely complementary components of the learning process but constitute a structural foundation that determines the quality of the social skills that emerge in TBP. The high coefficient of determination for the collaboration variable indicates that the quality of student teamwork is strongly influenced by individual cognitive readiness, particularly in critical thinking and creativity. These findings have important implications for the development of CBT models in vocational education. An effective CBT model should not only focus on collaborative activities but also ensure that students possess adequate analytical and ideational capacity before engaging in project-based teamwork. These results strengthen the argument that a CBT model integrating the Case Method and TBP is an effective pedagogical approach for developing 21st-century work skills in engineering education. The Case Method provides a cognitive foundation through critical thinking and creativity. In contrast, TBP provide a social environment in which ideas can be communicated, tested, and implemented collaboratively. The integration of these two approaches enables a coherent learning trajectory in which individual cognitive capacities develop into collaborative performance in solving complex technological problems.

6. Conclusions

This study aims to validate the competency architecture in CBT-based learning in engineering education by positioning the Case Method as a mechanism for building cognitive foundations and TBP as a vehicle for developing social skills. The results of the structural analysis indicate that the relationships among competencies within the 4C framework (critical thinking, creativity, communication, and collaboration) follow a hierarchical pattern. Critical thinking and creativity serve as initial cognitive capacities that influence students' communication skills, while communication is the primary mechanism linking individual cognitive abilities to collaborative teamwork. However, creativity has both direct and indirect influences on collaboration, while the influence of critical thinking on collaboration is entirely mediated by communication. These results confirm that analytical thinking skills do not automatically lead to effective teamwork when ideas and analyses are not clearly communicated to other team members.

Communication acts as a transitional mechanism that transforms individual cognitive capacities into collaborative performance in technology projects.

The high coefficient of determination indicates that the proposed model has a very strong predictive ability in explaining the development of students' social skills in the context of appropriate technology design learning. These findings provide empirical support for the notion that developing work skills in vocational education requires integrating cognitive capacity-building with structured collaborative experiences. This research demonstrates that the synergy between the Case Method and TBP can be an effective pedagogical approach to bridge the skills gap between academic learning and practical work in engineering education.

The results confirm that developing students' collaborative skills cannot be achieved solely through group work. Rather, the quality of collaboration is strongly influenced by each team member's cognitive readiness. Therefore, learning activities aimed at improving teamwork need to be preceded by activities that stimulate students' critical thinking and creativity. The integration of the Case Method and TBP can be understood as a logical pedagogical pathway in engineering learning. The Case Method can be used early in the learning process to train students to analyze technological problems, evaluate alternative solutions, and generate innovative ideas. Afterward, TBP provide an implementation context in which these ideas can be communicated, discussed, and collaboratively developed into concrete technological solutions. The curriculum should emphasize not only analytical skills and technological design but also provide students with space to practice conveying ideas, engaging in technical discussions, and building shared understanding within teams.

7. Limitations and Future Research

This study has several limitations: the measurement of 4C competencies is based on student perceptions, making it subjective. Furthermore, the research model focuses solely on four core competencies, neglecting other factors that may influence teamwork dynamics. Therefore, further research is recommended to develop a more comprehensive model by incorporating additional variables such as learning motivation, team leadership, and group work culture. Furthermore, longitudinal studies are needed to explore the ongoing integration of the Case Method and TBP into the curriculum and understand the long-term development of student competencies.

Declarations

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Author contribution

Batumahadi Siregar: Conceptualization, Methodology, Investigation, Data Curation, Project Administration, Funding Acquisition, Writing – Original Draft. Sapitri Januariyansah: Methodology, Investigation, Formal Analysis, Resources, Original Draft. Eka Daryanto: Methodology, Validation, Resources, Writing – Review & Editing. Sumarno: Validation, Supervision, Writing – Review & Editing. Fatihul Ihsan: Formal Analysis, Data Curation, Visualization, Writing – Review & Editing. Abdul Hamid: Supervision, Validation, Writing – Review & Editing. All authors contributed to the interpretation of the results, critically reviewed the manuscript, and approved the final version.

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Data availability

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

This study received ethical approval from the Institute for Research and Community Service (LPPM), Universitas Negeri Medan, under Ethical Approval No. 3646/UN33.8/LL/2026. The approval was granted by Dr. Novita, S.Pd., M.Pd., Head of the Institute for Research and Community Service (LPPM), Universitas Negeri Medan, with the ethical review and approval provided by the Ethics Committee of Universitas Negeri Medan by Dr. Agung Setia Batu Bara, S.Pi. The study was conducted in accordance with relevant ethical guidelines and institutional regulations and adhered to the principles of the Declaration of Helsinki. Informed consent was obtained from all participants before their participation in the study. All participants were informed of the purpose of the study, the voluntary nature of their participation, and the confidentiality and anonymity of their responses. As all participants were university students aged over 16 years, informed consent from parents or legally authorized representatives was not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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Figures

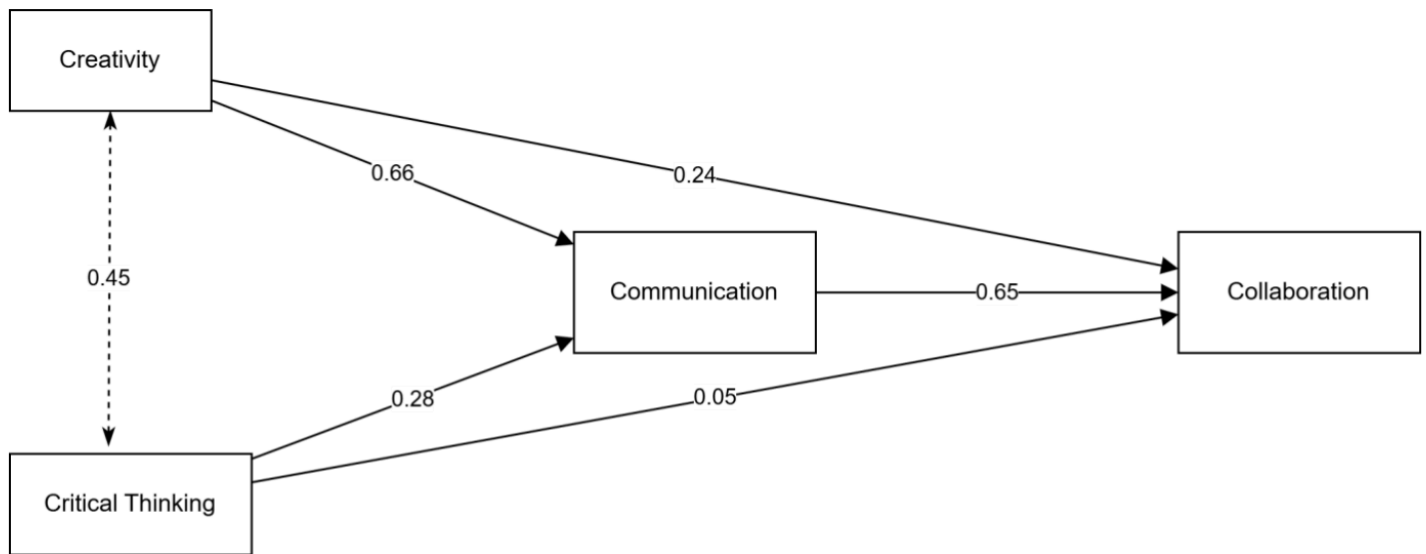


Figure 1

Path Diagram