INTERNATIONAL JOURNAL OF RESEARCH AND INNOVATION IN SOCIAL SCIENCE (IJRISS)
ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VI June 2026

A Socio-Technical Activity Ecology for Networking Education in TVET: Integrating Activity Theory and Activity-Centered Analysis and Design

Erman Hamid[1], Norharyati Harum[1], Zuraini Othman[1], Ibrahim Ahmad[1], Akhdiat Abdul Malek[2]

[1]Fakulti Teknologi Maklumat dan Komunikasi, Universiti Teknikal Malaysia Melaka, Malaysia

[2]Faculty of Major Language Study, Universiti Sains Islam Malaysia, Negeri Sembilan, Malaysia

DOI: https://dx.doi.org/10.47772/IJRISS.2026.100600441

Received: 05 June 2026; Accepted: 10 June 2026; Published: 20 June 2026

ABSTRACT

Computer networking is increasingly recognized as an essential competency across Technical and Vocational Education and Training (TVET), yet its instruction for non-specialist learners often emphasizes procedural knowledge rather than authentic vocational learning. This conceptual paper proposes a socio-technical activity ecology framework by integrating Cultural-Historical Activity Theory and Activity-Centered Analysis and Design (ACAD). The framework conceptualizes networking learning as an interaction among learners, technological artifacts, learning tasks, social arrangements, and institutional contexts. By synthesizing these perspectives, the study offers a coherent theoretical foundation for curriculum design, laboratory development, assessment innovation, and future empirical research in TVET networking education.

Keywords— Activity Theory; Activity-Centered Analysis and Design; TVET; Computer Networking Education; Socio-Technical Learning; Networking Simulation; Learning Design.

INTRODUCTION

The rapid digitalization of industrial sectors has fundamentally transformed the competency profile expected of technical graduates. Contemporary manufacturing, automation, and engineering environments increasingly rely on interconnected devices, cyber-physical systems, cloud platforms, and Internet of Things (IoT) infrastructures. According to Cisco's Annual Internet Report, the number of global networked devices and connections increased from 18.4 billion in 2018 to approximately 29.3 billion by 2023, with machine-to-machine and IoT connections accounting for nearly half of all connected devices [7].

The implications of this transformation extend directly into Technical and Vocational Education and Training (TVET). The World Economic Forum reports that more than 1,000 global employers representing over 14 million workers identify technology literacy, networks, and cybersecurity among the fastest-growing skills required for the future workforce [25]. Consequently, networking competence can no longer be viewed as a specialist capability exclusive to information technology graduates. Rather, it has become a transversal vocational competence that underpins multiple technical disciplines, including mechatronics, electrical engineering, manufacturing technology, and other digitally connected technical disciplines.

Despite this shift, networking education for non-specialist learners often remains pedagogically fragmented. Many modules are adapted from conventional networking curricula designed for specialist IT students. These curricula commonly emphasize IP addressing, subnetting, routing, switching, and configuration syntax. While such knowledge is necessary, it may be insufficient for non-networking learners if it is not connected to meaningful vocational contexts. Students may learn to complete commands without understanding how network functionality relates to wider technical systems.

The difficulty of networking education is partly cognitive. Concepts such as protocol layering, encapsulation, routing logic, and addressing schemes are abstract and relational. Learners must reason about invisible communication processes and interpret symbolic representations. However, these difficulties are also socio-technical. Learning is shaped by available tools, laboratory infrastructure, peer collaboration, assessment rules, instructor practices, institutional resources, and the perceived relevance of networking to students' primary vocational identities.

Simulation tools such as Cisco Packet Tracer can support practical skill development by allowing students to design, configure, test, and troubleshoot virtual networks [17]. However, simulation tools alone do not guarantee meaningful learning. Their educational value depends on how they are embedded within tasks, social arrangements, assessment structures, and vocational scenarios. This is consistent with broader technology-enhanced learning research, which suggests that learning benefits depend not merely on technology use but on the learning activities that technology enables [21].

The present study argues that networking education in TVET should be conceptualized as a socio-technical activity ecology. Such a framework treats learning as an emergent process shaped by the interaction of learners, tools, tasks, communities, rules, and vocational objects. To develop this framework, the paper integrates Activity Theory and Activity-Centered Analysis and Design. Activity Theory offers a systemic language for examining mediated activity systems, contradictions, and object transformation [10], [11], [18]. ACAD provides a design-oriented perspective on how epistemic, set, and social design dimensions shape learning activity [12].

The guiding conceptual question underpinning this paper is as follows:

How can the integration of Activity Theory and Activity-Centered Analysis and Design provide a more comprehensive framework for understanding and designing computer networking education for non-specialist learners in TVET?

LITERATURE REVIEW

The literature reviewed in this study spans four interrelated domains that collectively inform the proposed socio-technical activity ecology framework. The first examines the pedagogical challenges associated with computer networking education for non-specialist TVET learners. The second and third review Activity Theory and Activity-Centered Analysis and Design (ACAD) as complementary perspectives for understanding and designing learning activity. The final domain considers recent developments in TVET digital competence and institutional readiness. Taken together, these strands reveal that although each offers valuable insights, existing research remains theoretically fragmented, highlighting the need for a more integrated conceptual framework for networking education in TVET.

Computer Networking Education for Non-Specialist TVET Learners

Computer networking education has traditionally been associated with specialist computing programs. In such contexts, learners are expected to acquire detailed technical knowledge about protocols, addressing, routing, switching, security, and network management. However, in TVET, networking may be introduced to learners whose primary disciplinary orientation is not computing. For these learners, networking is often a supporting competence needed to operate, maintain, or troubleshoot networked technical systems.

The growing importance of networking education is closely associated with the expansion of digitally connected industrial ecosystems. Cisco forecasts indicate that IoT devices alone represented approximately 50% of all global networked devices by 2023, compared with around one-third in 2018 [7]. This trend suggests that future technical professionals are increasingly likely to work within environments where networking technologies function as enabling infrastructures rather than isolated computing systems. Accordingly, TVET curricula must prepare learners to understand not only technical devices themselves, but also the

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VI June 2026

communication architectures that integrate them into larger socio-technical systems.

For many TVET programmes, this shift introduces a less obvious but important pedagogical dilemma. Non-networking students may not initially perceive networking as central to their professional identity. If instruction is delivered as a sequence of abstract concepts and isolated configuration tasks, students may struggle to connect networking knowledge to vocational practice. The result may be surface-level procedural competence without deeper systems understanding.

Networking simulation environments have become a popular response to this challenge. Simulation tools can reduce dependency on expensive physical laboratories, allow repeated practice, and provide visual representations of network behavior. Mwansa et al. [17] highlight the value of Cisco Packet Tracer in enhancing practical networking skills in resource-constrained higher education settings. Nevertheless, simulation studies often focus on tool effectiveness rather than the broader learning ecology within which tool use occurs.

A socio-technical perspective is therefore required. In actual learning environments, tools, tasks, peer interactions, institutional rules, and assessment expectations interact continuously. A student’s ability to troubleshoot a network does not depend only on knowing commands. It also depends on whether the task is meaningful, whether collaboration is structured, whether representations are understandable, whether feedback is timely, and whether the assessment rewards systems reasoning rather than isolated recall.

Activity Theory as a Lens for Mediated Learning

Cultural-Historical Activity Theory has its roots in Vygotsky's work [22] on sociocultural development, particularly the idea that cognition is mediated by tools, signs, and social interaction. Engeström [10] expanded this view into a systemic model of activity comprising subject, object, mediating artifacts, rules, community, and division of labor. In this model, the object of activity is central because it gives direction and meaning to collective action.

Activity Theory has been widely used in educational technology research because it allows researchers to examine learning as a situated and mediated process. Lim and Hang [15] applied Activity Theory to investigate ICT integration in schools, demonstrating how technology use is shaped by institutional and classroom conditions. Nussbaumer [18] reviewed the use of Cultural-Historical Activity Theory in classroom research and highlighted its value for examining learning as socially and culturally organized activity.

Contradictions are central to Activity Theory. Engeström [11] describes contradictions as historically accumulated tensions within and between activity systems. These contradictions are not simply problems to be eliminated; they can become drivers of expansive learning when participants reconceptualize the object of activity and reorganize practice. In networking education, contradictions may occur when assessment emphasizes individual configuration accuracy while authentic troubleshooting requires collaboration. They may also emerge when simulation tools simplify technical complexity while vocational practice requires dealing with messy, real-world infrastructures.

Activity Theory is therefore useful for understanding the systemic nature of networking learning. However, it is often used analytically rather than design-operationally. It helps explain what happens in a learning system, but it does not always provide direct guidance on how learning environments should be designed. This limitation creates an opportunity to integrate Activity Theory with a more explicit design framework.

Activity-Centered Analysis and Design

Activity-Centered Analysis and Design (ACAD) provides a useful complement to Activity Theory because it focuses on the design of learning situations. Goodyear et al. [12] describe ACAD as a framework that helps researchers and educators analyse and design complex learning environments. Rather than assuming that learning can be directly engineered, ACAD emphasizes that educators design conditions for activity.

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VI June 2026

ACAD distinguishes three design dimensions. Epistemic design concerns tasks, problems, and knowledge-oriented activities. Set design concerns tools, resources, physical spaces, and digital environments. Social design concerns roles, groupings, participation structures, and interaction patterns. Yeoman and Carvalho [27] further demonstrate how design tools can support educators in moving between material and conceptual structures, while Yeoman and Wilson [28] emphasize the relationship between material properties, designed form, and emergent learning activity.

The relevance of ACAD to networking education is clear. A networking laboratory is not only a technical environment; it is also an epistemic, material, and social arrangement. The epistemic dimension includes troubleshooting problems, configuration tasks, and scenario-based challenges. The set dimension includes routers, switches, simulation tools, cabling, diagrams, command-line interfaces, and worksheets. The social dimension includes whether students work alone, in pairs, or in teams; whether roles are distributed; and how instructors facilitate inquiry.

Recent work on ACAD also emphasizes its usefulness for connecting theory and practice in learning design [5], [4]. However, ACAD has been more commonly discussed in higher education and networked learning contexts than in vocationally intensive technical education. Its application to hardware-software integrated TVET settings remains relatively underdeveloped.

TVET Digital Competence and Institutional Readiness

Recent TVET literature emphasizes that digital competence development cannot be reduced to student skills alone. Zhong and Juwaheer [29] argue for a whole-institution approach to digital competence development in TVET, involving leaders, teachers, and learners. Liu et al. [16] similarly emphasize the need for professional development frameworks that strengthen TVET educators' digital competencies. These studies are important because they show that digital learning depends on institutional ecosystems, not only classroom-level interventions.

Rahmawati et al. [20] identify challenges in vocational teachers' digital competence, including access to resources, confidence, community support, and professional training. Wu et al. [26] similarly review teachers' digital competency in vocational education and highlight persistent gaps in preparation and practice. These findings support the argument that networking education must be situated within broader institutional and professional conditions.

From an Activity Theory perspective, these issues correspond to rules, community, division of labor, and mediating artifacts. From an ACAD perspective, they influence set design, social design, and epistemic design. For example, if a TVET institution lacks sufficient networking equipment, simulation tools become more important. If teachers are not confident in facilitating collaborative troubleshooting, social design may remain weak. If assessment systems focus only on written tests, epistemic design may not encourage authentic problem solving.

Recent international policy initiatives reinforce this direction. UNESCO's Strategy for TVET 2022–2029 explicitly positions digital transformation as one of the principal drivers reshaping vocational education and workforce preparation, emphasizing the need to integrate new digital competencies into both teaching practices and learning environments. This perspective supports the argument that networking education should be conceptualized not merely as technical content delivery but as participation within broader socio-technical ecosystems.

LITERATURE SYNTHESIS

The preceding review demonstrates that the literature relevant to networking education in TVET spans multiple but interconnected domains, including networking pedagogy, Activity Theory, Activity-Centered Analysis and Design (ACAD), technology-enhanced learning, and TVET digital competence. While each body of work contributes important insights, they have largely developed along separate trajectories with limited theoretical integration. To clarify these relationships and identify the conceptual gap addressed by this study, Table I synthesizes the principal contributions and limitations of the existing literature. This synthesis provides the foundation for proposing a socio-technical activity ecology that brings these otherwise fragmented perspectives into a more coherent explanatory and design framework.

TABLE I SYNTHESIS OF KEY LITERATURE RELEVANT TO THE PROPOSED FRAMEWORK

Literature Strand	Representative Sources	Main Contribution	Limitation for TVET Networking
Activity Theory	Vygotsky [22]; Engeström [10], [11]; Nussbaumer [18]	Explains mediated activity, object orientation, contradictions, and systemic transformation	Often used analytically rather than as an explicit design framework
Activity Theory in educational technology	Lim and Hang [15]; Batiibwe [3]; Grimalt-Álvaro and Ametller [13]	Demonstrates how technology-mediated learning can be examined as situated activity	Limited focus on networking education for non-specialist learners
ACAD and design for learning	Goodyear et al. [12]; Yeoman and Carvalho [27]; Yeoman and Wilson [28]; Carvalho et al. [4]	Provides epistemic, set, and social design vocabulary	Limited application in hardware-software integrated TVET laboratories
Design-based and technology-enhanced learning	Barab and Squire [2]; Wang and Hannafin [23]; Anderson and Shattuck [1]; Sailer et al. [21]	Supports iterative design, empirical refinement, and activity-sensitive technology use	Often not domain-specific to networking or TVET
TVET digital competence	Liu et al. [16]; Zhong and Juwaheer [29]; Rahmawati et al. [20]; Wu et al. [26]	Highlights institutional, teacher, and learner readiness for digital transformation	Does not specifically theorize networking learning as an activity ecology
Networking simulation	Mwansa et al. [17]	Demonstrates value of simulation tools for practical skill development	Focuses mainly on tool effectiveness rather than systemic socio-technical conditions

As shown in Table I, the reviewed literature offers complementary but only partially connected explanations of networking learning in TVET. A closer cross-reading reveals that the field remains theoretically fragmented.

A cross-reading of Table I reveals that the relevant literature is strong but fragmented. Activity Theory provides a powerful systemic ontology, yet it does not always translate directly into instructional design principles. ACAD provides a design vocabulary, yet it requires further extension into vocationally intensive technical domains. Networking simulation research shows practical promise, yet it often focuses on measurable skill development without fully explaining how learning emerges from the interaction of tools, tasks, rules, and social arrangements.

The proposed socio-technical activity ecology seeks to address this fragmentation. Rather than replacing Activity Theory, ACAD, or simulation-based learning research, it brings these perspectives together to better explain and inform networking education for non-specialist TVET learners.

PROPOSED SOCIO-TECHNICAL ACTIVITY ECOLOGY FRAMEWORK

The preceding synthesis suggests that existing research provides valuable but only partial explanations of networking learning in TVET. Activity Theory offers a systemic understanding of mediated activity, ACAD contributes a design-oriented perspective, and studies of networking simulation and digital competence highlight important contextual factors. However, these perspectives have rarely been brought together within a single conceptual framework. In response, this paper proposes a socio-technical activity ecology that integrates these complementary strands to provide a more comprehensive account of how networking competence develops in vocational learning environments.

Conceptual Rationale

The term “socio-technical activity ecology” is used deliberately. “Socio-technical” emphasizes that networking education involves both human and technical elements. Learners interact with devices, simulations, diagrams, command-line interfaces, peers, instructors, and institutional expectations. “Activity” emphasizes that learning is not merely the reception of information but participation in object-oriented practice. “Ecology” emphasizes interdependence, adaptation, and dynamic interaction.

Networking education, from this perspective, is not a linear process of transmitting concepts from instructor to student. It is an evolving arrangement in which learners progressively transform their understanding of networking through mediated participation. The object of activity may initially be “complete the lab task” but may later expand into “restore reliable system communication” or “diagnose a networked industrial process.”

Structural Components

The proposed framework consists of six interconnected components that collectively explain how networking competence develops through participation in socio-technical learning activities. Rather than functioning as isolated elements, these components interact dynamically to shape learners' engagement with networking tasks, technological artifacts, institutional expectations, and collaborative practices. Figure 1 illustrates how the core constructs of Activity Theory are conceptually integrated with the design dimensions of ACAD to form the proposed socio-technical activity ecology.

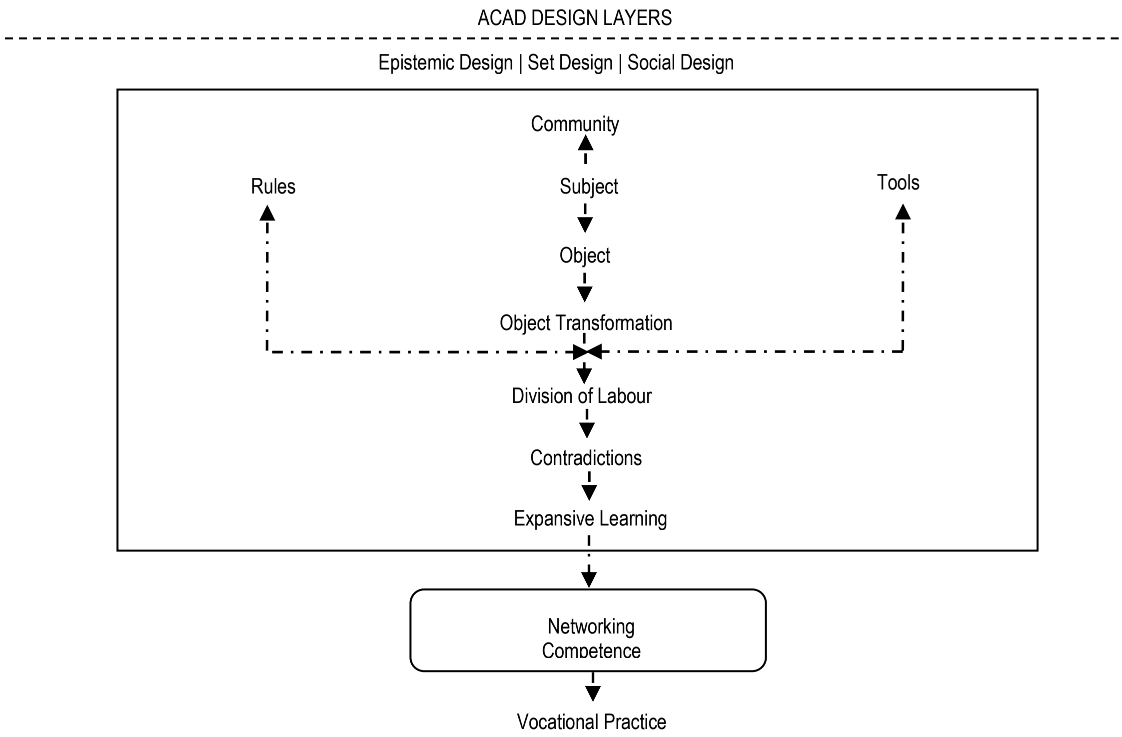

Fig. 1. Conceptual representation of the proposed socio-technical activity ecology integrating Activity Theory and Activity-Centered Analysis and Design for networking education in TVET

Figure 1 illustrates the relationships among Activity Theory constructs and ACAD design dimensions that collectively shape networking competence as a socio-technical outcome.

Subjects. The subjects are non-specialist TVET learners. They may come from mechatronics, electrical engineering, automation, manufacturing, or other technical programs. Their prior knowledge, disciplinary identity, confidence, and expectations shape how they engage with networking.

Object. The object is vocationally meaningful networking competence. This includes conceptual understanding, procedural fluency, systems troubleshooting, collaborative problem solving, and transfer to occupational contexts.

Mediating artifacts. These include simulation tools, routers, switches, cables, topology diagrams, diagnostic commands, worksheets, and assessment rubrics. These artifacts mediate how learners perceive and act upon networking problems.

Rules. Rules include curriculum requirements, assessment criteria, laboratory safety procedures, institutional policies, and norms of acceptable collaboration.

Community. The community includes peers, instructors, laboratory technicians, program coordinators, and industry stakeholders.

Division of labour. This concerns how responsibilities are distributed. In networking laboratories, division of labor may involve topology design, address planning, device configuration, documentation, and troubleshooting.

ACAD enriches this structure by clarifying how these components can be designed. Epistemic design shapes the tasks. Set design shapes the tools and environments. Social design shapes participation and collaboration. Collectively, these six components represent the internal structure of the proposed socio-technical activity ecology. Their relationships with the corresponding ACAD design dimensions are summarized in Table II.

TABLE II INTEGRATION OF ACTIVITY THEORY AND ACAD CONSTRUCTS

Activity Theory Construct	ACAD construct	Integrated Meaning for TVET Networking
Subject	Learner agency	Non-specialist learners bring different vocational identities and prior knowledge
Object	Epistemic design	Networking competence must be framed as vocationally meaningful
Mediating Artifacts	Set design	Simulators, devices, diagrams, and commands mediate understanding
Community	Social design	Peer and instructor interaction shapes troubleshooting practice
Rules	Institutional design conditions	Assessment and curriculum requirements influence learning priorities
Division of labour	Role configuration	Distributed roles support collaborative diagnosis and systems thinking
Contra-dictions	Design tensions	Misalignments become opportunities for redesign and expansive learning

An Illustrative Application of the Proposed Framework

Consider a group of mechatronics students completing a simulated networked systems activity. The task requires them to connect programmable logic controllers, monitoring stations, and a supervisory computer using a Packet Tracer-based topology. Initially, students approach the activity as a command-entry exercise. Their main concern is whether each command is typed correctly.

A communication failure occurs between two devices. Some students repeatedly check syntax, while others begin examining addressing schemes and topology structure. Informally, the group distributes roles: one student checks IP addressing, another traces connectivity, another verifies routing, and another records observations. The learning activity shifts from individual command completion toward collaborative diagnosis.

This episode reveals a contradiction between the assessment rule, which emphasizes individual configuration accuracy, and the practical object of restoring system-wide communication, which requires collaborative troubleshooting. From an Activity Theory perspective, this contradiction can stimulate object transformation. From an ACAD perspective, it suggests that epistemic design, set design, and social design need to be adjusted. The instructor may revise the task to include shared troubleshooting logs, assign explicit roles, and assess diagnostic reasoning alongside configuration accuracy.

The object of learning therefore expands. Students are no longer merely learning commands; they are learning to interpret network behavior as part of a socio-technical system.

While the foregoing scenario illustrates how the proposed socio-technical activity ecology may operate in practice, a further question remains: can the integration of Activity Theory and ACAD provide a theoretically coherent explanation of networking learning beyond simple conceptual aggregation? Although the example demonstrates how learners, tools, and social arrangements interact, it does not by itself establish the conceptual coherence of the framework. Table III therefore provides a theory-driven analytical validation.

TABLE III THEORY-DRIVEN ANALYTICAL VALIDATION OF THE PROPOSED FRAMEWORK

Analytical Question	Activity Theory Explanation	ACAD Explanation	Integrated Interpretation
Why do students struggle with networking abstraction?	Weak subject-object mediation	Misalignment of epistemic and set design	Vocational meaning is not sufficiently constructed
Why do simulations alone not guarantee learning?	Artifact mediation is incomplete	Set design alone cannot determine activity	Learning emerges from the interaction of all design dimensions
Why is collaborative trouble-shooting effective?	Community and division of labor support expansive learning	Social design promotes distributed cognition	Knowledge is socially co-constructed
What constitutes networking competence?	Transformation of the object of activity	Alignment of epistemic, social, and set design	A socio-technical accomplishment rather than an individual outcome

As shown in Table III, each analytical question can be interpreted through both Activity Theory and ACAD, yet neither framework independently provides a sufficiently comprehensive explanation of networking learning in TVET. Activity Theory primarily explains the systemic and developmental nature of mediated activity, whereas ACAD clarifies how learning environments can be intentionally designed. Their integration therefore represents a complementary rather than additive relationship, providing stronger theoretical justification for conceptualizing networking education as a socio-technical activity ecology.

Analytical Validation through Theory-Driven Questions and Answers

Building upon the illustrative scenario and the analytical synthesis presented in Table III, the coherence of the proposed socio-technical activity ecology can be further examined through a theory-driven analytical exercise. Rather than treating Activity Theory and Activity-Centered Analysis and Design (ACAD) as separate explanatory models, the present framework considers whether the key educational challenges encountered in networking education can be simultaneously interpreted through both perspectives.

A central question concerns why non-specialist TVET students often struggle to understand abstract networking concepts despite repeated exposure to simulation tools.

From an Activity Theory perspective, this difficulty emerges because learners engage with networking artifacts without fully aligning the object of activity with meaningful vocational purposes. The relationship between subject, object, and mediating artifact remains underdeveloped, creating tensions that limit deeper conceptual understanding [10], [11].

From an ACAD perspective, the same phenomenon can be interpreted as a misalignment between epistemic, set, and social design. Although simulation tools such as Cisco Packet Tracer provide appropriate material resources, the learning tasks and collaborative structures may not sufficiently support knowledge construction [12].

A second analytical question concerns why collaborative troubleshooting frequently produces deeper learning than individual configuration exercises.

Activity Theory explains this phenomenon through the concepts of community and division of labor. Collective activity enables learners to externalize and negotiate understanding while resolving contradictions embedded within the activity system. Simultaneously, ACAD suggests that appropriately designed social arrangements create opportunities for learners to engage in distributed cognition and shared problem solving.

Finally, the proposed framework asks whether networking competence should be regarded primarily as an individual cognitive outcome or as a socio-technical accomplishment.

The synthesis developed in this paper supports the latter interpretation. Networking competence emerges not solely through the acquisition of procedural knowledge but through participation in an ecology where tools, tasks, social interactions, institutional rules, and vocational objectives continuously shape learning activity. The convergence of Activity Theory and ACAD therefore provides a coherent explanation for how networking understanding develops within authentic TVET contexts.

Taken together, these theory-driven questions and answers provide an initial analytical validation of the proposed socio-technical activity ecology. They demonstrate that the integration of Activity Theory and ACAD is not simply additive, but complementary, with each framework addressing limitations inherent in the other.

Preliminary Empirical Validation

To complement the analytical validation presented above, a preliminary empirical validation was conducted involving 45 Bachelor of Information Technology (Games Development) students enrolled in a Data Communication and Networking course. The objective was to examine students' perceptions of the proposed socio-technical activity ecology framework in relation to networking knowledge confidence, collaborative troubleshooting, vocational relevance, and learning design effectiveness.

Students participated in networking laboratory activities involving IP addressing, subnetting, network troubleshooting, routing concepts, and Cisco Packet Tracer simulations. These activities were designed to reflect the interaction between Activity Theory constructs and ACAD design dimensions proposed in the framework.

Instrument Development

To operationalize the proposed socio-technical activity ecology framework, a survey instrument was developed

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VI June 2026

to capture students' perceptions of key constructs derived from Activity Theory and ACAD. The instrument focused on dimensions related to networking knowledge confidence, collaborative troubleshooting, vocational relevance, and learning design effectiveness.

A questionnaire consisting of 20 items was developed to evaluate four constructs associated with the proposed framework: Networking Knowledge Confidence, Collaborative Troubleshooting, Vocational Relevance, and Learning Design Effectiveness. Responses were measured using a five-point Likert scale ranging from strongly disagree (1) to strongly agree (5).

The questionnaire items were adapted from established constructs in self-efficacy [31], collaborative problem-solving [30], technology-enhanced learning [21], and learning design literature [12]. In addition, several items measuring vocational relevance were adapted and developed based on vocational relevance concepts discussed in TVET and digital competence literature [16], [20], [29]. The instrument was subsequently contextualized to Data Communication and Networking learning activities and reviewed by two academics with expertise in computer networking and technology-enhanced learning to establish content validity.

TABLE IV CONSTRUCTS USED FOR PRELIMINARY EMPIRICAL VALIDATION

Construct	Number of Items
Networking Knowledge Confidence	5
Collaborative Troubleshooting	5
Vocational Relevance	5
Learning Design Effectiveness	5

The four constructs were selected to represent key dimensions of the proposed socio-technical activity ecology framework. To ensure that the instrument was theoretically grounded, each construct was mapped to relevant literature that informed its conceptualization and operationalization. The mapping between constructs and supporting literature is presented in Table V.

TABLE V MAPPING OF CONSTRUCTS TO SUPPORTING LITERATURE

Construct	Supporting Literature
Networking Knowledge Confidence	Bandura [31]
Collaborative Troubleshooting	Zurita & Nussbaum [30]
Vocational Relevance	Liu et al. [16], Rahmawati et al. [20], Zhong & Juwaheer [29]
Learning Design Effectiveness	Goodyear et al. [12], Sailer et al. [21]

Reliability Analysis

Reliability analysis was performed using Cronbach's alpha to evaluate the internal consistency of the measurement instrument. Cronbach's alpha values above 0.70 are generally considered acceptable in educational research, indicating satisfactory internal consistency among measurement items. The results are presented in Table VI.

TABLE VI RELIABILITY ANALYSIS RESULTS

Construct	Cronbach's Alpha
Networking Knowledge Confidence	0.84
Collaborative Troubleshooting	0.87
Vocational Relevance	0.82
Learning Design Effectiveness	0.89
Overall Instrument	0.91

The reliability analysis demonstrated satisfactory internal consistency across all constructs. Cronbach's alpha values ranged from 0.82 to 0.89, exceeding the commonly accepted threshold of 0.70. The overall reliability coefficient of 0.91 indicates excellent internal consistency of the instrument.

Following the reliability assessment, descriptive statistics were calculated to examine students' perceptions of the proposed socio-technical activity ecology framework. Mean scores and standard deviations were computed for each construct to determine the overall level of agreement among participants. The results are presented in Table VII.

Descriptive Findings

TABLE VII DESCRIPTIVE STATISTICS OF STUDENT PERCEPTIONS

Construct	Mean	SD
Networking Knowledge Confidence	4.08	0.61
Collaborative Troubleshooting	4.21	0.58
Vocational Relevance	4.33	0.54
Learning Design Effectiveness	4.18	0.57

Overall, the descriptive findings indicate positive student perceptions of the proposed framework. Vocational Relevance recorded the highest mean score (M = 4.33, SD = 0.54), suggesting that students recognised the importance of networking knowledge within games development and related technical domains. Similarly, Collaborative Troubleshooting (M = 4.21, SD = 0.58) and Learning Design Effectiveness (M = 4.18, SD = 0.57) achieved high ratings, indicating positive perceptions of the socio-technical and collaborative learning environment created through the proposed framework.

THEORETICAL CONTRIBUTION

This paper makes three theoretical contributions.

First, it extends Activity Theory from a primarily analytical framework toward a design-sensitive framework for TVET networking education. Activity Theory is often used to explain technology-mediated learning after it has occurred. By integrating it with ACAD, this paper positions the activity system as both an analytical and design object.

Second, it extends ACAD into vocationally intensive and hardware-software integrated learning environments. ACAD's epistemic, set, and social design dimensions are especially useful for examining networking laboratories, but they require enrichment through a systemic account of rules, community, division of labor, and contradictions.

Third, it contributes to networking education research by shifting attention from tool effectiveness to activity ecology. More fundamentally, the framework repositions networking education from a predominantly technical subject domain toward a socio-material and vocationally situated learning practice. Simulation tools are important, but the framework argues that their value depends on their alignment with tasks, social participation, assessment, and vocational relevance.

The key theoretical claim is that networking competence should be understood not only as an individual cognitive outcome but as a socio-technical accomplishment. It emerges through participation in mediated, collaborative, institutionally structured activity. Viewed in this way, networking competence becomes less an individual possession than a collectively enacted socio-technical capability.

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VI June 2026

IMPLICATIONS FOR TVET PRACTICE

The proposed socio-technical activity ecology is intended not only as an analytical and design framework but also as a guide for educational practice. If networking competence is understood as a socio-technical accomplishment emerging through mediated and collaborative activity, then curriculum, laboratory environments, assessment strategies, and educator practices should be designed to support such forms of learning. The following implications outline how the proposed framework may inform the development of networking education for non-specialist learners in TVET.

Curriculum Design

TVET networking curricula should be organized around authentic vocational objects rather than abstract topic sequences alone. For non-specialist learners, networking should be connected to systems they recognize, such as networked technical systems, smart devices, building technologies, and digitally connected workplaces.

Laboratory Design

Laboratories should move beyond isolated configuration exercises. Tasks should require learners to interpret failures, document decisions, justify configurations, and collaborate on troubleshooting. Simulation tools and physical devices should be used as mediating artifacts within meaningful scenarios.

Assessment Reform

Assessment should evaluate systems reasoning, diagnostic explanation, and collaborative problem solving. Written tests and configuration accuracy remain useful, but they should be complemented by performance-based assessment, troubleshooting logs, reflective explanations, and scenario-based tasks.

Professional Development

Educators require support in designing socio-technical learning environments. Professional development should include activity-system analysis, ACAD-based learning design, facilitation of collaborative troubleshooting, and recognition of contradictions as learning opportunities.

The broader significance of this framework becomes clearer when viewed against global workforce projections. The World Economic Forum estimates that technological transformation will continue to reshape occupational structures through 2030, with digital and network-related competencies becoming increasingly important across industries [25]. Rather than preparing a small group of networking specialists, TVET institutions are therefore increasingly responsible for cultivating networking literacy across diverse technical disciplines. The proposed socio-technical activity ecology provides one possible theoretical foundation for designing such interdisciplinary learning environments.

FUTURE DIRECTIONS

While the present study provides preliminary empirical validation, further large-scale validation across multiple TVET disciplines and institutional contexts remains necessary. Future research may adopt design-based research approaches to iteratively design, implement, and refine networking learning environments [2], [23], [1]. Mixed-method studies could combine learning analytics, classroom observation, interviews, and performance assessment to examine how learners develop networking competence over time.

Longitudinal research is especially important because object transformation may not be visible in short interventions. Researchers should investigate how students move from command-based understanding toward systems-based reasoning. Comparative studies across TVET disciplines may also identify how vocational identity influences engagement with networking.

CONCLUSIONS

This conceptual paper has proposed a socio-technical activity ecology for networking education in TVET. The framework integrates Activity Theory and Activity-Centered Analysis and Design to explain how networking competence develops through interactions among learners, tools, tasks, social arrangements, institutional rules, and vocational objectives.

The paper argues that networking education for non-specialist learners should not be treated merely as simplified computing instruction. Instead, it should be designed as a situated, mediated, collaborative, and vocationally meaningful activity system. By foregrounding mediation, contradiction, object transformation, and design alignment, the proposed framework provides a theoretical foundation for curriculum innovation, laboratory redesign, assessment reform, and future empirical research.

The preliminary empirical validation conducted with Bachelor of Information Technology (Games Development) students provides initial empirical evidence supporting the practical applicability of the proposed framework. While broader validation across multiple TVET disciplines remains necessary, the findings suggest that the integration of Activity Theory and ACAD offers a promising foundation for networking education in socio-technical learning environments. The results further indicate that the framework can support networking learning through meaningful interactions among learners, technological tools, collaborative activities, and vocationally relevant tasks.

More broadly, the proposed socio-technical activity ecology offers a theoretically coherent foundation for reconceptualizing networking education as a vocationally situated and collaboratively enacted learning practice, rather than merely the acquisition of isolated technical procedures. This view aligns with recent findings suggesting that technology-enhanced environments shape both technical and social dimensions of user experience and learning [32]. By integrating analytical and design-oriented perspectives, the framework contributes to a more holistic understanding of how networking competence can be developed within contemporary TVET environments.

ACKNOWLEDGMENT

The authors are grateful to Center for Research and Innovation Management (CRIM), Universiti Teknikal Malaysia Melaka (UTeM) for the financial support and to Advanced Interaction Technology (AdViT), Centre for Advanced Computing Technology (C-ACT), Fakulti Teknologi Maklumat dan Komunikasi (FTMK) for the support of equipment and facilities throughout this research.

REFERENCES

1. T. Anderson and J. Shattuck, "Design-based research: A decade of progress in education research?," Educational Researcher, vol. 41, no. 1, pp. 16–25, 2012, doi: 10.3102/0013189X11428813.
2. S. Barab and K. Squire, "Design-based research: Putting a stake in the ground," Journal of the Learning Sciences, vol. 13, no. 1, pp. 1–14, 2004, doi: 10.1207/S15327809JLS1301_1.
3. M. S. K. Batiibwe, "Using Cultural Historical Activity Theory to understand how emerging technologies can mediate teaching and learning in a mathematics classroom: A review of literature," Smart Learning Environments, vol. 6, Art. no. 22, 2019, doi: 10.1186/s40561-019-0110-7.
4. L. Carvalho, P. Yeoman, and N. B. Dohn, "Exploring how the ACAD toolkit supports design for learning," Journal of New Approaches in Educational Research, vol. 12, no. 2, pp. 289–305, 2023, doi: 10.7821/naer.2023.7.1494.
5. L. Castañeda, F. M. Esteve-Mon, and J. Adell, "Thinking through ACAD: Learning to see theory in action," Networked Learning Conference Proceedings, vol. 13, 2022, doi: 10.54337/nlc.v13.8565.
6. M. T. H. Chi and R. Wylie, "The ICAP framework: Linking cognitive engagement to active learning outcomes," Educational Psychologist, vol. 49, no. 4, pp. 219–243, 2014, doi: 10.1080/00461520.2014.965823.

7. Cisco, Cisco Annual Internet Report (2018–2023) White Paper. San Jose, CA, USA: Cisco Systems, 2020.
8. M. Cole and Y. Engeström, "A cultural-historical approach to distributed cognition," in Distributed Cognitions: Psychological and Educational Considerations, G. Salomon, Ed. Cambridge, U.K.: Cambridge University Press, 1993, pp. 1–46.
9. B. Collis and A. Margaryan, "Applying Activity Theory to computer-supported collaborative learning and work-based activities in corporate settings," Educational Technology Research and Development, vol. 52, no. 4, pp. 38–52, 2004, doi: 10.1007/BF02504717.
10. Y. Engeström, Learning by Expanding: An Activity-Theoretical Approach to Developmental Research. Helsinki, Finland: Orienta-Konsultit, 1987.
11. Y. Engeström, "Expansive learning at work: Toward an activity-theoretical reconceptualization," Journal of Education and Work, vol. 14, no. 1, pp. 133–156, 2001, doi: 10.1080/13639080020028747.
12. P. Goodyear, L. Carvalho, and P. Yeoman, "Activity-Centred Analysis and Design (ACAD): Core purposes, distinctive qualities and current developments," Educational Technology Research and Development, vol. 69, no. 2, pp. 445–464, 2021, doi: 10.1007/s11423-020-09926-7.
13. C. Grimalt-Álvaro and J. Ametller, "A Cultural-Historical Activity Theory approach for the design of a qualitative methodology in science educational research," International Journal of Qualitative Methods, vol. 20, pp. 1–12, 2021, doi: 10.1177/16094069211060664.
14. D. Lazarou, R. Sutherland, and S. Erduran, "Using Cultural-Historical Activity Theory to design and evaluate an educational game in science education," Journal of Computer Assisted Learning, vol. 27, no. 1, pp. 1–14, 2011, doi: 10.1111/j.1365-2729.2011.00410.x.
15. C. P. Lim and D. Hang, "An activity theory approach to research of ICT integration in Singapore schools," Computers & Education, vol. 41, no. 1, pp. 49–63, 2003, doi: 10.1016/S0360-1315(03)00015-0.
16. J. Q. Liu, M. K. Noordin, M. A. Azmi, A. N. M. Nasir, and M. Arsat, "Digital competencies for TVET educators: A framework for professional development," Akademika, vol. 94, no. 3, pp. 144–160, 2024, doi: 10.17576/akad-2024-9403-09.
17. G. Mwansa, M. R. Ngandu, and Z. S. Dasi, "Enhancing practical skills in computer networking: Evaluating the unique impact of simulation tools, particularly Cisco Packet Tracer, in resource-constrained higher education settings," Education Sciences, vol. 14, no. 10, Art. no. 1099, 2024, doi: 10.3390/educsci14101099.
18. D. Nussbaumer, "An overview of Cultural Historical Activity Theory (CHAT) use in classroom research 2000 to 2009," Educational Review, vol. 64, no. 1, pp. 37–55, 2012, doi: 10.1080/00131911.2011.553947.
19. R. K. Parua, "The driving logic of digital transformation in TVET," Vocational Technology Education, vol. 1, no. 2, Art. no. e12, 2024, doi: 10.54844/vte.2024.0590.
20. S. Rahmawati, S. Prestridge, A. G. Abdullah, and I. Widiaty, "Unpacking the digital competence challenge in vocational education: A case from Indonesia," Social Sciences & Humanities Open, vol. 12, Art. no. 101803, 2025, doi: 10.1016/j.ssaho.2025.101803.
21. M. Sailer, R. Maier, S. Berger, T. Kastorff, and K. Stegmann, "Learning activities in technology-enhanced learning: A systematic review of meta-analyses and second-order meta-analysis in higher education," Educational Research Review, vol. 43, Art. no. 100610, 2024, doi: 10.1016/j.edurev.2024.100610.
22. L. S. Vygotsky, Mind in Society: The Development of Higher Psychological Processes. Cambridge, MA, USA: Harvard University Press, 1978.
23. F. Wang and M. J. Hannafin, "Design-based research and technology-enhanced learning environments," Educational Technology Research and Development, vol. 53, no. 4, pp. 5–23, 2005, doi: 10.1007/BF02504682.
24. P. Warmington, H. Daniels, A. Edwards, S. Brown, J. Leadbetter, D. Martin, D. Middleton, V. Popov, and A. Apostolov, "Divisions of labour: Activity Theory, multi-professional working and intervention research," Journal of Vocational Education and Training, vol. 63, no. 2, pp. 143–159, 2011, doi: 10.1080/13636820.2011.561930.
25. World Economic Forum, The Future of Jobs Report 2025. Geneva, Switzerland: World Economic Forum, 2025.
26. J. Wu, H. Husnin, and M. Mohamad, "Teachers' digital competency in vocational education: A systematic review," Multidisciplinary Reviews, vol. 8, no. 10, Art. no. 2025313, 2025, doi:

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VI June 2026

10.31893/multirev.2025313.

27. P. Yeoman and L. Carvalho, "Moving between material and conceptual structure: Developing a card-based method to support design for learning," Design Studies, vol. 64, pp. 64–89, 2019, doi: 10.1016/j.destud.2019.05.003.
28. P. Yeoman and S. Wilson, "Designing for situated learning: Understanding the relations between material properties, designed form and emergent learning activity," British Journal of Educational Technology, vol. 50, no. 5, pp. 2090–2108, 2019, doi: 10.1111/bjet.12856.
29. Z. Zhong and S. Juwaheer, "Digital competence development in TVET with a competency-based whole-institution approach," Vocational Technology Education, vol. 1, no. 2, Art. no. e13, 2024, doi: 10.54844/vte.2024.0591.
30. G. Zurita and M. Nussbaum, "A conceptual framework based on Activity Theory for mobile CSCL," British Journal of Educational Technology, vol. 38, no. 2, pp. 211–235, 2007, doi: 10.1111/j.1467-8535.2006.00580.x.
31. A. Bandura, Guide for Constructing Self-Efficacy Scales. Greenwich, CT, USA: Information Age Publishing, 2006, pp. 307–337.
32. E. Hamid, G. Wan, N. Bahaman, N. Harum, N. A. Zakaria, and A. A. Malek, "Enhancing Social Experience in Home Network Assisted Tools," International Journal of Research and Innovation in Social Science, vol. 10, no. 2, pp. 6023–6034, 2026, doi: 10.47772/IJRISS.2026.10200444.