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Effectiveness of an instructional model to enhance digital skills, creative problem-solving, critical thinking and achievement motivation for higher vocational certificate students

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ABSTRACT

The main objective of this research is to investigate the effectiveness of a learning management model for enhancing digital skills, creative problem-solving, analytical thinking, and achievement motivation among higher vocational certificate students. This is an analytic-descriptive study. A sample group of 30 second-year higher vocational certificate students was chosen via cluster random sampling. Classrooms were used as the sampling units. The research instruments included the learning management model, a digital skills assessment scale, a creative problem-solving assessment scale, an analytical thinking ability assessment scale, and an academic achievement motivation assessment scale. The statistics used for data analysis were percentages, means, standard deviations, and t-tests (dependent samples) to test for differences in means. The research findings revealed the following: the students' digital skills after receiving instruction using the model were significantly higher than before receiving instruction, at the .05 level; the students' creative problem-solving scores after receiving instruction using the model were significantly higher than before receiving instruction, at the .05 level; the students' critical thinking ability after receiving instruction using the model was significantly higher than before receiving instruction, at the .05 level; the students who received instruction using the model demonstrated achievement motivation that was overall at a high level.

Keywords: Instructional model, digital skills, creative problem-solving, critical thinking, achievement motivation.

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INTRODUCTION

The accelerating transition to a digital society has reshaped the entire skills landscape. UNESCO (2022) emphasizes that vocational education, traditionally focused on providing mid-level technical labor, must now cultivate professionals who are "digitally-augmented" and capable of continuous learning, solving complex, unstructured problems, and self-regulating their motivation. The World Economic Forum (2020) similarly identifies creative problem-solving, critical analysis, and self-directed learning as the top competencies most relevant to emerging job sectors. However, large-scale audits of Thai vocational colleges highlight a persistent reliance on teacher-centered methods, such as demonstrations, note-taking, and algorithmic replication (Thongpanit, 2021). This mismatch between the curriculum and the demands of Industry 4.0 has contributed to a significant "competency gap," which this study seeks to address.

Conceptualizing the core competencies

In today's digital landscape, digital skills go beyond basic ICT operations. They now involve the strategic ability to access, curate, and create knowledge artifacts while navigating concerns such as privacy, security, and algorithmic bias (Audrin, Audrin and Salamin, 2024). Creative problem-solving (CPS) is defined as the process of generating and refining novel ideas within real-world constraints (Treffinger, Isaksen and Dorval, 2003), and it is critical for navigating complex, ever-changing environments. Critical thinking (CT) involves the careful evaluation of evidence, identifying underlying assumptions, and constructing reasoned arguments (Thayer, 2006). Finally, achievement motivation, framed within self-determination theory (SDT), reflects the intensity and persistence of mastery-oriented behavior, predicting both academic success and workplace adaptability (Deci and Ryan, 2020; Vansteenkiste and Ryan, 2023). The interaction of these constructs forms the foundation of this study.

Pedagogical threads: From constructivism to phenomenon-based learning

At the heart of this study lies a pedagogical shift from traditional, content-driven education to more dynamic, learner-centered approaches. Constructivist epistemology posits that knowledge is actively constructed through the manipulation of artifacts and social negotiation (Khammani, 2002). In vocational settings, this translates into authentic project-based learning, peer-driven debugging, and reflective journaling. The model evolves further through phenomenon-based learning, an approach institutionalized in Finland since 2016 that organizes curricula around interdisciplinary, real-world phenomena rather than subject silos (Silander, 2015; Schaffar, 2024). Students engage in an iterative cycle: (i) framing a shared question, (ii) searching for relevant digital resources, (iii) prototyping solutions, and (iv) presenting their findings publicly. This method fosters integrated development of digital literacy, CPS, and critical thinking, creating a holistic learning experience. Research indicates significant improvements in problem-solving skills when compared to traditional subject-based instruction (Schaffar, 2024).

Importantly, these active learning environments also function as motivational affordances. Tasks that support autonomy, promote collaboration, and provide competence-relevant feedback satisfy fundamental psychological needs, thus enhancing intrinsic achievement motivation (Deci and Ryan, 2020). Thayer's (2006) quasi-experimental study supports this claim, showing that media analysis projects resulted in higher critical-thinking gains than traditional lecture-based formats ($d = 0.81$).

Empirical gaps specific to Thai vocational education

While constructivist learning theory posits that understanding and transferable skills develop when learners engage with authentic problems, negotiate meaning with more knowledgeable others, and reflect on their mental models (Khammani, 2002), there is a gap in its implementation within Thai vocational education. Phenomenon-based learning has shown promise in enhancing students' interdisciplinary problem-solving skills (Schaffar, 2024) but often lacks formal validation using standardized skill assessments. Studies by Thayer (2006) and Chaiyarat (2024) highlight successful interventions in critical thinking and creative problem-solving but lack a robust integration of digital competence, which remains under-addressed. Moreover, while gamified cooperative learning (Chaiyarat, 2024) demonstrated improvements in motivation, the digital component was neither explicitly taught nor assessed, leaving an essential gap in vocational curricula. These findings indicate the need for a unified model that not only enhances digital skills, creative problem-solving, and critical thinking but also addresses achievement motivation in the Thai vocational context.

Purpose and research questions

This study integrates constructivist learning theory and phenomenon-based design to develop, implement, and validate a six-phase instructional model that targets the four core competencies: digital skills, creative problem-solving, critical thinking, and achievement motivation. The study adopts a cluster-randomized,one-group pretest-posttest design to investigate the following research questions:

1. To what extent does participation in the instructional model increase students'digital skills?
2. To what extent does it enhance students'creative problem-solving ability?
3. To what extent does it improve students'critical thinking?
4. What level of achievement motivation do students report after completing the intervention?

We hypothesize that statistically significant gains will be observed in the first three domains($\alpha = .05$), while the fourth domain will show high achievement motivation, thereby providing an empirical rebuttal to the"pedagogical status quo" in Thai vocational colleges.

METHOD

This study aimed to enhance digital skills, creative problem-solving, critical thinking, and achievement motivation for higher vocational diploma students through a newly developed learning management model. After expert review, the model was implemented in a trial with a student sample. The results of the model trial were analyzed using a one-group pretest-posttest experimental design. Data from pre- and post-model testing were analyzed using descriptive statistics to calculate means and standard deviations, along with inferential statistics (e.g., t-tests) to identify statistically significant differences in scores.

Participants and setting

The study took place at That Phanom College, part of Nakhon Phanom University, located in northeastern Thailand. The college offers four two-year higher vocational certificate programs. The study focused on the Electrical and Automation Engineering program, as its graduates are expected to handle tasks such as the installation, programming, and maintenance of Industry 4.0 equipment—skills aligned with the study's goals.

The target population consisted of 85 second-year students enrolled in the first semester of the academic year 2024. To select participants, cluster sampling was used, where entire classes (rather than individual students) were randomly assigned to participate. One section of 30 students (18 males, 12 females) was selected. Ages ranged from 18 to 21 years (M = 19.3, SD = 0.7). Inclusion criteria for participation were:

- Enrollment in the required course "Life Skills for Health and Society."
- No prior exposure to phenomenon-based learning.
- Access to a personal Gmail account for Google Classroom use.

Students with color vision deficiency were not excluded, as the digital platforms used in the study provided alternative visual cues.

Power analysis and sample size

The 30 participants were recruited after receiving institutional ethical approval (NPU-EDU-2024-07). The researcher visited the class, explained the study's objectives, and secured written consent from all students. Participation was voluntary, with no inducements offered. The study took place in the college's innovation studio, a flexible learning space equipped with Chromebooks, Wi-Fi, a laser cutter, and a 3D printer. The sessions were scheduled during regular class hours (08:30–11:30, Mondays) over eight consecutive weeks.

Research design

A one-group pretest-posttest quasi-experimental design was employed. This design was deemed appropriate for evaluating the proof-of-concept of the newly developed instructional model (Cook and Campbell, 1979). Cluster sampling was used to assign participants to the study, but there was no random assignment of conditions, which limits the generalization of findings. The study adhered to the APA Ethics Code and was approved by the Nakhon Phanom University Institutional Review Board (NPU-EDU-2024-07).

Intervention: Instructional model architecture

The intervention was structured using a six-component model delivered through an eight-week module titled "Energy-Smart Automation for Community Rice Mills." Each weekly session lasted 180 minutes (08:30–11:30, Mondays).

Principles and Rationale

The instructional model was grounded in two complementary theories:

- Constructivist learning theory, which emphasizes that learners actively construct knowledge by interacting with authentic problems (Khammani, 2002).
- Phenomenon-based learning, which integrates real-world phenomena into the curriculum, fostering interdisciplinary problem-solving (Silander, 2015).

The instructional model emphasized three key principles:

P1: Learning must be anchored in a relevant, complex, and community-based phenomenon.
P2: Digital tools are integral and serve as epistemic mediators, reshaping how students access, analyze, and represent information.
P3: Reflection and peer feedback loops are essential for the iterative refinement of both products and mental models.

Learning objectives

By the end of the module, students were expected to:

O1: Perform advanced searches in IEEE Xplore and the Thai Science Database.
O2: Evaluate the credibility, bias, and copyright status of online sources.
O3: Create a sensor-based prototype that reduces energy consumption by at least 10%in a simulated rice-mill line.
O4: Generate at least five distinct solution pathways (fluency) and combine unrelated concepts (flexibility) as

assessed by the Treffinger CPS rubric.
O5: Construct sound arguments that integrate evidence from multiple sources.
O6: Report a minimum score of 3.5 on the Achievement Motivation Scale.

Theoretical synergy

The instructional model integrates constructivist scaffolding (e.g., advance organizers, dialogue prompts, cognitive apprenticeships) throughout each phase of the phenomenon-based inquiry cycle (engage → investigate → analyze → act → reflect). For instance, during the investigation phase, students used a jigsaw technique to become “mini-experts” on subtopics such as variable-frequency drives, Arduino energy-logging shields, and rice-husk moisture sensors, which were then synthesized into a collaborative cross-disciplinary solution.

Instructional process

Each 180-minute weekly session was divided into the following phases:

1. Phenomenon Framing (10 minutes): Introduction of a local rice mill's time-lapse footage showing a rising energy bill, prompting students to ask guiding questions.
2. Collaborative Planning (20 minutes): Students formed teams and assigned roles(e.g., project manager, data engineer, documentation lead)while updating Gantt charts in Google Sheets.
3. Digital Inquiry and Skill Micro-Lessons (60 minutes): Just-in-time micro-lessons (e.g., Boolean search operators, energy-audit spreadsheets) were followed by immediate application to the students' projects.
4. Solution Prototyping (70 minutes): Students created prototypes using Tinkercad simulations and ESP32 microcontrollers. The teacher facilitated with Socratic questioning to encourage evidence-based decisions.
5. Public Exposition and Reflection (20 minutes): Students shared their prototypes via Padlet and reflected using prompts in Google Forms.

Support factors

Technological supports included Chromebooks, high-speed Wi-Fi, and access to a Creative Corner stocked with materials for low-fidelity prototyping. Human supports involved the first author as facilitator, a laboratory technician for safety, and two alumni acting as near-peer mentors. Institutional support included endorsement from the college director and flexibility in scheduling.

Assessment and feedback

Formative assessments included auto-graded quizzes on digital skills, peer critique sessions for creativity, and targeted feedback from the facilitator on critical thinking. Summative assessments were administered using identical pre- and post-test batteries.

Measures

All instruments were developed or adapted according to DeVellis’s (2017) framework:

Digital skills assessment (DSA): A 30-item assessment, based on UNESCO (2022) digital-competence descriptors, measured tasks like conducting refined Google searches and creating CC-BY licensed infographics. Content validity was reviewed by a panel of ICT educators (I-CVI = .88), and pilot testing showed internal consistency (α = .84) and test-retest reliability (r = .79).

Creative problem-solving assessment (CPSA): Adapted from Treffinger et al. (2003), this tool presented ill-structured scenarios related to rice-mill automation. Inter-rater reliability was ICC = .92.

Critical Thinking Ability Test (CTAT): A 25-item multiple-choice test, based on the Cornell Critical Thinking Test Level Z.

Achievement motivation scale (AMS): A 20-item Likert scale, adapted from Vallerand et al. (1992), with confirmatory factor analysis supporting unidimensionality (CFI = .94, RMSEA = .05, 90% CI [.03, .07]).

Procedure

Week 1 was dedicated to orientation and pre-testing. Weeks 2–7 implemented the instructional model, with post-testing and debriefing in Week 8. Assessments were staggered across sessions to minimize fatigue.

Intervention fidelity

Fidelity was monitored using a 20-item checklist aligned to the five instructional phases. External raters attended 25% of sessions, ensuring an adherence rate of 93% (range: 85 to 100%).

Data analysis

Data were tested for normality (Shapiro-Wilk) and univariate outliers (z > ±3.29). Hypotheses H1–H3 were tested using dependent-samples t-tests (with effect sizes calculated using Cohen's d), and H4 was evaluated using a one-sample t-test. SDs and confidence intervals for effect sizes were reported for paired designs.

RESULTS

Recruitment and participant flow

Of 85 eligible second-year Electrical and Automation Engineering students, one intact class of 30 was randomly selected. All 30 attended the orientation session, provided informed consent, and completed the full pre-test battery (100% inclusion). During the eight-week intervention, two students missed one session each because of mild illness; both were offered make-up laboratories within 48 h and continued in the study. No student crossed over to another condition or withdrew. Consequently, the intent-to-treat analysis retains all 30 participants (96% attendance per session).

Baseline descriptive and diagnostic statistics

Table 1 presents pre-test means, standard deviations, skewness, and kurtosis for the four outcome measures. Neither Kolmogorov–Smirnov nor Shapiro-Wilk tests were significant (p > .11), supporting the use of parametric procedures. Levene's test for equality of variances across weekly cohorts was non-significant (F < 1.86, p > .17), indicating homogeneity. No floor or ceiling effects were detected: the lowest mean was 57% of the maximum possible score, and the highest was 67%.

Table 1. The overall Achievement Motivation score was x̄ = 4.02 (S.D. = 0.13), which corresponds to a high level.

Domain measured	Mean post-test (post)	Mean pre-test (pre)	t-value	Statistical significance
Digital skills	24.43	17.23	14.357	p < .05
Creative problem-solving	39.00	26.90	30.751	p < .05
Critical thinking	33.26	24.63	24.621	p < .05
Achievement motivation	x̄ = 4.02 (S.D. = 0.13)	N/A	N/A	High Level

Manipulation checks and fidelity metrics

The external fidelity observer recorded 24 instructional episodes (25% randomly sampled). Mean adherence to the five-phase protocol was 93.4% (SD = 4.1). Specific element compliance ranged from 88 % (timely transition from prototyping to exposition) to 100 % (use of real-world phenomenon as anchor). Students' electronic artefacts—Google Drive logs, Tinkercad circuits, and Padlet videos—were time-stamped; 97% were submitted within the allocated window, corroborating procedural fidelity.

Primary outcomes: Cognitive skill gains

Hypotheses 1–3 were examined with dependent-samples t-tests. Table 2 displays pre- and post-test means, mean gain scores, 95% confidence intervals, t-values, p-values, and Cohen's d effect sizes. The mean gain of 7.20 points corresponds to a 42 % improvement and a very large effect size (d = 2.62, 95% CI [2.11, 3.13]). Every individual student improved; the smallest gain was 4 points and the largest was 11 points. The mean gain of 12.10 points represents a 45% increase relative to the pre-test baseline. The effect size was extremely large (d = 5.61, 95% CI [4.50, 6.72]). Inspection of sub-scores revealed balanced growth across fluency (Δ = 4.3), flexibility (Δ = 3.9), and elaboration (Δ = 3.7). The mean gain of 8.63 points equates to a 35 % rise. Cohen's d was 4.49 (95 % CI [3.60, 5.38]). Item-level analysis showed the greatest improvement on inference items (Δ = +0.35 per item), followed by evaluation items (Δ = +0.31).

Table 2. Cognitive skill gains.

Variable	Pre-test mean	Post-test mean	Mean Gain	t-value	p-value	Cohen's d	95% CI for d
Digital skills	17.23	24.43	7.20	14.357	< .05	2.62	[2.11, 3.13]
Creative problem-solving	26.90	39.00	12.10	30.751	< .05	5.61	[4.50, 6.72]
Critical thinking	24.63	33.26	8.63	24.621	< .05	4.49	[3.60, 5.38]

Secondary outcome: Achievement motivation

Hypothesis 4 was evaluated by comparing the post-test AMS mean against the scale midpoint (3.0). The obtained mean of 4.02 (SD = 0.13) was significantly higher than the midpoint, $t(29) = 42.91$, $p < .001$, $d = 7.83$, indicating a "high" level of motivation. Eighty-seven percent of students scored ≥ 4.0, and no participant scored below the neutral point.

Correlational and exploratory analyses

Pearson correlations among post-test scores are shown in Table 3. Achievement motivation correlated most strongly with creative problem-solving ($r = .68$, $p < .001$), followed by critical thinking ($r = .61$, $p = .001$) and digital skills ($r = .56$, $p = .002$). Multiple regression was employed to explore whether baseline variables (GPA, gender, prior Arduino experience) predicted gain scores. The model was non-significant ($F < 1.3$, $p > .28$), suggesting that the intervention was equally beneficial across demographic and academic subgroups.

Table 3. Pearson correlations among post-test scores.

Variable	1	2	3	4
1. Achievement motivation	-			
2. Creative problem-solving	.68***	-		
3. Critical thinking	.61**	.45**	-	
4. Digital skills	.56**	.52**	.48**	-

Robustness checks

To ensure that findings were not driven by the two students with partial absences, we re-ran analyses with their data removed. Effect sizes remained virtually identical ($\Delta d < 0.05$), confirming robustness. Additionally, we applied the Bonferroni correction for three primary comparisons ($\alpha_{adj} = .0167$); all t-values remained significant ($p < .001$).

DISCUSSION

This study demonstrates that a purposefully scaffolded,phenomenon-driven instructional model can significantly enhance digital skills, creative problem-solving, critical thinking, and achievement motivation among Thai vocational students. The magnitude of improvement, with Cohen's d>4 for all cognitive outcomes, far exceeds the typical effects of technology integration reported in meta-analyses ($d \approx 0.30$–0.50) and is comparable to intensive creative-thinking interventions delivered over longer periods. However, it is crucial to interpret these improvements cautiously in light of potential threats to internal validity—particularly testing, maturation, and history effects.

Theoretical mechanisms for improvement

Three plausible mechanisms appear to explain the observed gains:

Authentic problem context

The rice-mill energy challenge served as a"boundary object" that connected classroom activities to real-world vocational practices. This increased the perceived utility of the skills being learned, which aligns with self-determination theory (SDT) and the idea that mastery goals are more likely to be pursued when students see the practical relevance of their learning (Deci and Ryan, 2020). This aspect supports the notion that authentic, problem-based learning enhances motivation and engagement (Kivunja, 2020).

Iterative inquiry and feedback loops

The model's iterative cycle of inquiry, prototyping, and public exposition externalized cognitive processes that are typically invisible to both students and instructors. This allowed for targeted feedback at critical moments when conceptual restructuring was most likely, a process consistent with constructivist learning principles (Khammani, 2002). These feedback loops likely supported students'competence and autonomy, fostering intrinsic motivation (Deci and Ryan,2020).

Micro-lessons and autonomy support

Embedded micro-lessons fulfilled students'need for competence while supporting autonomy. The flexibility for students to choose which tutorials to access and when to apply new skills allowed them to take ownership of their learning, which is a core tenet of SDT (Deci and Ryan, 2020). This autonomy support likely contributed to the observed gains in both achievement motivation and critical thinking.

Practical implications

The six-component model demonstrated notable flexibility and scalability. Notably, it requires no proprietary software and can be replicated in colleges with basic resources such as Chromebooks and free CAD tools. Since the model is adaptable to different contexts, the phenomenon (e.g., energy-smart automation) can be substituted with regionally relevant challenges such as smart agriculture or eco-tourism, enhancing its ecological validity across various vocational disciplines. Instructors shifting from a traditional lecture-based approach could start by replacing two conventional periods with a condensed three-phase cycle (frame, prototype, reflect) and expand as they gain confidence.

However, the study's limitations must be considered when interpreting the findings. The absence of a control group and the use of a one-group pretest-posttest design mean we cannot definitively rule out alternative explanations such as maturation or history effects. The eight-week intervention may have introduced testing effects, as students could have been more motivated simply due to repeated exposure to assessments. Thus, while the observed gains are compelling, these potential confounds necessitate cautious interpretation.

Limitations and future research

The study's design also imposes constraints on the generalizability and robustness of the findings. The sample size (n = 30) and the study's single-site context limit the external validity. Future research should include multi-site replication across various vocational programs—such as those in hospitality, business, and healthcare—to determine whether the model is similarly effective across different fields.

Additionally, the reliance on researcher-developed instruments, although validated through pilot testing, raises concerns about researcher bias. Incorporating standardized measures, such as the Cornell Critical Thinking Test or the IC3 Digital Literacy Certification, would strengthen the credibility of the findings and help mitigate biases associated with custom-developed assessments.

Another limitation is that the intervention bundled multiple active ingredients, such as the phenomenon-based learning approach, peer collaboration, and micro-lessons. Future research could benefit from factorial designs that isolate and evaluate the relative impact of each component, identifying which aspects of the intervention are most cost-effective and impactful.

Longitudinal mixed-methods studies are also necessary to explore how peer interaction influences skill acquisition. Anecdotal evidence from chat logs suggests that students who provided more detailed explanatory comments gained more on critical thinking assessments. Micro-analytic coding of these interactions could provide valuable insights into the causal pathways through which peer collaboration supports learning.

Finally, a cost-effectiveness analysis is needed to assess the practical value of this model. While the intervention utilized free software and digital tools, the costs associated with facilitator training and extended contact time(e.g., the 180-minute sessions) may be significant. Comparing learning gains relative to cost would help inform policy decisions regarding broader implementation at institutional and national levels.

The findings of this study contribute to constructivist and self-determination theories by showing that when vocational learners engage in authentic, digitally augmented problem-solving tasks, they not only acquire the technical competencies necessary for Industry 4.0 but also develop the motivational resilience needed for lifelong learning. The large, consistent gains observed in this study provide strong support for the broader implementation of this instructional model, though further longitudinal evaluation and control-group studies are warranted to fully assess its long-term impact and effectiveness across diverse contexts.

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