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Effectiveness of culturally contextualized 5E+EDP on students' achievement, problem-solving, collaboration, and STEM attitudes

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ABSTRACT

This study examined the effectiveness of a culturally contextualized integrated instructional model that combines the 5E and the engineering design process on ninth-grade students' academic achievement, problem-solving, collaboration, and science, technology, engineering, and mathematics (STEM) attitudes at ethnic-minority boarding schools. Although Vietnam's 2018 General Education Curriculum emphasizes problem-solving and collaboration, ethnic-minority boarding schools continue to lag in these competencies because the curriculum itself seems not to be able to shape these competencies for students, nor is it able to address students' cultural and contextual conditions. A quasi-experimental pretest–posttest control group design was used with 83 ninth-grade students from two boarding schools in a province in Vietnam. The intervention was about "Boarding School Meal 4.0". The research instruments included i) academic tests; ii) students' projects; and iii) surveys on students' STEM attitudes. Data were analyzed using independent- and paired-samples t-tests, with effect sizes (Cohen's d) and 95% confidence intervals reported alongside significance tests. The experimental group achieved significantly higher results on the academic test, with a large effect size. Students in the experimental group also demonstrated problem-solving and collaboration competencies at a proficient level and reported more positive attitudes toward STEM after the intervention. The findings support the potential of the culturally contextualized integrated model as a promising approach for STEM teaching in ethnic-minority boarding schools.

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1. INTRODUCTION

Vietnam has undergone substantial educational reform in recent decades, particularly following Resolution 29-NQ/TW and the introduction of the 2018 General Education Curriculum, which shifted K–12 education from a content-transmission orientation toward competency-based learning. Within this reform agenda, problem solving, critical thinking, creativity, collaboration, and practical application have been positioned as core educational outcomes [1]. Science, technology, engineering, and mathematics (STEM) education has consequently received increasing policy attention because integrated and inquiry-based learning approaches are believed to strengthen students' higher-order thinking, technological competencies, and real-world problem-solving abilities [2]–[5]. International studies have shown that STEM-oriented

pedagogies can improve academic achievement and reasoning skills, particularly when students engage in authentic and contextually meaningful learning activities [2], [4].

Despite these reform efforts, translating policy aspirations into effective classroom practice remains challenging in many Vietnamese schools. The implementation of competency-based STEM education requires substantial changes in instructional methods, assessment practices, classroom organization, and teacher roles. However, many classrooms continue to rely heavily on traditional teacher-centered instruction emphasizing lectures, procedural imitation, and knowledge reproduction. Although professional development programs and teacher training initiatives have been introduced to support educational reform, improvements have often progressed slowly because many teachers were trained within conventional pedagogical traditions and may have limited experience with inquiry-based, project-based, and engineering-oriented teaching approaches. Previous studies also identified infrastructure limitations, shortages of instructional materials, and contextual constraints as persistent barriers to STEM implementation in Vietnamese schools [6], [7].

These challenges are even more significant in mountainous and ethnic-minority regions of Vietnam. Ethnic-minority students in boarding and semi-boarding schools frequently study in environments where the gap between curriculum expectations and classroom realities remains substantial. Geographic isolation contributes to shortages of laboratory facilities and teaching resources, while Vietnamese is often a second language for many learners [7], [8]. As a result, the challenge is not only material but also pedagogical and cultural. Recent studies have suggested that culturally responsive STEM approaches integrating local knowledge, ethnoscience, and culturally meaningful contexts can help reduce the disconnect between school knowledge and students' lived experiences [9], [10]. Such approaches may be particularly important for Tay and Nung students in mountainous boarding schools, where culturally contextualized learning activities can potentially enhance engagement, participation, and competency development.

Within this context, this study investigates the effectiveness of an integrated 5E and engineering design process (EDP) model in teaching the food processing module in Technology 9. Food processing represents a culturally authentic and experience-based domain closely connected to students' daily lives and local food traditions [11], [12]. In addition, the inquiry-oriented structure of the 5E model is pedagogically compatible with the iterative and collaborative nature of EDP [13]. Previous studies have reported the benefits of the 5E model and the EDP on student learning outcomes. However, most studies have examined the two frameworks separately and have primarily been conducted in urban or mainstream settings outside Vietnam. Similarly, although some studies have explored culturally responsive pedagogy or contextualized learning materials, culture has often been incorporated as supplementary content rather than as an authentic driver of engineering design activities. Furthermore, existing studies typically focus on a limited range of outcomes, with relatively few examining academic achievement, problem-solving, collaboration, and learning attitudes simultaneously within a single intervention. These gaps are particularly relevant in Vietnam. The 2018 General Education Curriculum advocates competency-based education and emphasizes the importance of developing students' collaboration, teamwork, and problem-solving competencies. Nevertheless, effective implementation remains challenging in ethnic-minority settings, where instructional practices and learning materials are often insufficiently connected to local cultural contexts and students' lived experiences. As a result, there is a growing need for innovative and culturally responsive STEM pedagogies that can support both academic learning and competency development.

To address these gaps, this study examined the effects of an integrated 5E+EDP model on academic achievement, problem-solving competencies, collaboration skills, and attitudes toward Technology learning among Tay and Nung students in mountainous boarding schools. In doing so, it advances three distinct strands of prior research. First, whereas earlier studies have applied the 5E model and the EDP separately and largely in urban or mainstream settings outside Vietnam, this study is among the first to integrate them within a single culturally contextualized STEM project for ethnic-minority boarding-school students. Second, unlike culturally responsive STEM studies that treat culture as supplementary content or a contextual illustration, this study embeds local food culture and the boarding-school dining context as the authentic engineering challenge that drives the design tasks. Third, whereas prior work has typically evaluated a narrow set of outcomes, this study simultaneously examines academic achievement, problem-solving, collaboration, and STEM attitudes using both achievement tests and rubric-based performance assessment.

2. LITERATURE REVIEW

2.1. The 5E design

The 5E instructional model is one of the most widely applied frameworks in STEM education. The model consists of five sequential phases: engagement, exploration, explanation, elaboration, and evaluation [14]. Furthermore, the model is grounded in constructivist learning theory, which conceptualizes learning as an active process in which learners construct knowledge through inquiry, experience, and reflection [15].

In the engagement phase, teachers stimulate students' curiosity and activate prior knowledge through real-world problems or challenging situations. During the exploration phase, students investigate concepts through hands-on activities, experimentation, and collaborative learning. The explanation phase allows students to discuss findings, construct conceptual understanding, and connect practical experiences with scientific or technological principles. In the elaboration phase, students apply their understanding to new contexts or more complex problems, while the evaluation phase focuses on assessing both learning outcomes and problem-solving processes [14].

In technology education, the 5E model is especially suitable for practical and project-based activities because it enables students to connect technological concepts with real-world applications and engineering practices. Research by Lee *et al.* [16] demonstrated that the 5E model supports experiential learning, collaborative problem-solving, prototyping, and engagement with authentic engineering challenges in technology and engineering education classrooms. Similarly, Ha *et al.* [17] found that 5E-STEM instruction enhanced students' active participation and practical application of STEM knowledge through project-based and inquiry-oriented activities.

2.2. Engineering design process

The EDP is another essential framework in STEM-oriented technology education. EDP refers to a systematic and iterative process through which students identify problems, generate ideas, design solutions, create prototypes, test outcomes, and improve their designs [18], [19]. Unlike linear problem-solving approaches, EDP emphasizes continuous refinement and optimization, reflecting authentic engineering practices [20], [21].

Although different models of EDP have been proposed across engineering and educational contexts, researchers have identified several common stages that consistently appear in the design process. These stages typically include identifying needs or problems, researching and gathering information, brainstorming possible solutions, designing and planning, developing prototypes, testing and evaluating outcomes, communicating solutions, and redesigning or improving the product based on feedback and testing results. Hynes [22] proposed eight major engineering design activities, including problem identification, research, solution development, prototype construction, testing, evaluation, communication, and redesign. Similarly, the National Center for Engineering and Technology Education emphasized activities such as need identification, problem specification, design development, analysis, decision-making, prototype testing, and solution verification [18]. These studies collectively demonstrate that EDP is inherently iterative and multifaceted rather than procedural or linear.

Within STEM education, EDP is particularly valuable because it promotes higher-order thinking and interdisciplinary learning. The EDP serves as an essential pedagogical framework in STEM-oriented technology education because it mirrors authentic engineering practices and supports experiential, inquiry-based learning. By engaging students in iterative cycles of designing, testing, evaluating, and redesigning, EDP enables learners to connect interdisciplinary STEM knowledge with practical problem solving in meaningful real-world contexts [18]. Recent literature highlights that design-based learning and engineering-focused STEM activities are highly effective in promoting STEM literacy, technological competence, and 21st-century skills [3]. In technology education, EDP is particularly valuable because it provides students with opportunities to experience real-world engineering practices through hands-on learning and project development.

2.3. Cultural adaptation of materials

In recent years, cultural adaptation of instructional materials has gained increasing attention in STEM and technology education because culturally responsive learning environments are believed to improve students' engagement, participation, and academic achievement [23]. Cultural adaptation refers to the process of modifying instructional content, examples, learning activities, and teaching strategies to align with students' cultural backgrounds, local contexts, experiences, and community practices. Rather than using standardized materials detached from learners' realities, culturally adapted materials connect academic knowledge with students' everyday lives and sociocultural environments [24]. This approach is particularly important in technology and STEM education, where authentic problem-solving and contextualized learning play essential roles in developing meaningful understanding [25].

Research has shown that culturally adapted STEM instruction can enhance students' motivation and sense of relevance toward learning [26]. Ladson-Billings [27] emphasized that culturally relevant pedagogy enables students to achieve academic success while maintaining cultural identity and developing critical awareness. Building on this perspective, recent STEM education studies have argued that culturally responsive instructional materials help learners connect scientific and technological concepts with local knowledge systems and community practices. For example, study by O'Leary *et al.* [26] found that culturally responsive teaching practices in STEM classrooms improved inclusivity, student engagement, and awareness

of diverse learner identities, particularly among underrepresented student groups. In sum, the cultural adaptation of instructional materials represents an important direction in contemporary STEM and technology education. By incorporating local culture, community knowledge, and students' lived experiences into learning activities, culturally adapted materials can create more inclusive, relevant, and meaningful educational experiences while supporting both STEM competency development and cultural responsiveness.

2.4. Benefits of 5E and EDP in teaching technology

Recent studies have highlighted the effectiveness of the 5E instructions and the EDP approaches in technology education, particularly in enhancing students' problem-solving, collaboration, and academic achievement. Both approaches emphasize inquiry-based learning, hands-on investigation, teamwork, and iterative thinking, enabling students to engage actively in authentic STEM and engineering practices. Research has shown that integrating the 5E model with coding, game design, and STEM projects significantly improves students' ability to analyze problems, generate solutions, evaluate failures, and apply technological knowledge in real-world contexts [28]–[30]. Similarly, STEM inquiry and engineering design activities have been found to strengthen collaboration skills by promoting teamwork, communication, shared reasoning, collective decision-making, and cooperative problem solving throughout the learning process [31]–[33].

Recent evidence also suggests that 5E- and EDP-based STEM instruction can improve students' academic achievement and attitudes toward STEM learning. Studies have reported that students participating in 5E-STEM learning significantly outperformed those receiving conventional instruction because inquiry-oriented and engineering-based activities enhanced conceptual understanding and engagement [17], [34]. Meta-analytic findings further support the positive effects of the 5E model on science, mathematics, and motivational outcomes [15]. In addition, STEM approaches integrating engineering design have been associated with higher motivation, self-efficacy, enjoyment, and perceived relevance of STEM learning, as students actively participate in authentic problem-solving and collaborative design experiences [35]–[37]. Overall, the literature indicates that integrated 5E and EDP approaches provide meaningful and engaging STEM learning experiences that foster both cognitive and affective outcomes in technology education.

2.5. Overview of grade 9 technology education in the 2018 General Education Curriculum in Vietnam

The primary objective of grade 9 technology education is to develop students' core technological competencies, including technological awareness, technological application, engineering design, and technological evaluation. Throughout the learning process, students are encouraged to observe, analyze, design, and create simple technological products or models. In addition, the subject contributes to the development of scientific working habits, discipline, collaboration, and responsibility in both learning and practical work. Another significant objective is to support students in identifying their interests and abilities while providing initial career orientation related to engineering, technology, manufacturing, and other technical fields.

Regarding learning outcomes, the curriculum emphasizes not only theoretical understanding but also the ability to apply knowledge in practical situations. Upon completing the subject, students are expected to understand the role and impact of technology on society and the environment; interpret basic technical diagrams, processes, and technological information; use technological tools and devices safely; and participate in designing, creating, or improving simple technical products. Furthermore, students are expected to develop positive attitudes toward labor, creativity, innovation, and technological advancement within the context of digital transformation and modern economic development.

In this study, the two schools used a textbook series by Knowledge Connection Publisher with the food processing module. The module consists of approximately eight lessons, including review and practical/project-based activities. The module focuses on four major areas: nutrition and health, food selection and preservation, food preparation techniques, and food hygiene and safety. The content is closely connected to daily life and Vietnamese culinary culture. Table 1 summarizes the main topics and content covered in the food processing module.

Table 1. Topics in the food processing module

Topic	Main content
Nutrition and Health	Nutrients and healthy eating
Food Selection and Preservation	Choosing and storing food safely
Food Hygiene and Safety	Causes and prevention of food contamination
Food Preparation	Basic cooking and food processing techniques
Practical Projects	Preparing simple dishes or meal plans

3. METHOD

3.1. Research design

This study used a quasi-experimental pretest–posttest non-equivalent control group design, which is widely accepted in educational research where random assignment of intact classes is not practical [38]. The intervention was implemented in the second semester of the 2024–2025 academic year. The control group (CG) was taught with the conventional method for Technology 9, while the experimental group (EG) received the integrated 5E+EDP instructional model on food processing.

3.2. Participants and setting

A total of 83 ninth-grade students from two ethnic-minority boarding schools in Lang Son Province, Vietnam, participated in the study. The experimental group (n=42) comprised 22 students from one ethnic minority boarding high school and 20 students from another ethnic minority boarding high school. The control group (n=41) comprised two classes from the two schools, one with 20 students and another with 21 students. Purposive sampling criteria were applied: schools served predominantly ethnic-minority populations (Tay and Nung ethnicities accounted for more than 85% of enrolment). The two schools are located in mountainous regions of northern Vietnam, where infrastructure is limited.

Students' ages ranged from 14 to 15 years. Students live at school during the term and return home roughly once a month. For most participants, Vietnamese is a second language. Tay and Nung remain the languages of informal peer interaction. Written consent forms were obtained from all participants and from their parents or guardians.

3.3. The 5E+EDP integrated instructional model vs. conventional instruction

Table 2 presents the phase-by-phase alignment of the 5E+EDP integrated model as implemented in the "Boarding School Meal 4.0: Nutritional Balance and Cost Optimization" for Technology 9. The table also demonstrated how each step in the model reflects the integration of STEM components and indicators of problem-solving competency.

Table 2. Phase-by-phase alignment of the 5E+EDP integrated instructional model

5E phase	EDP phase	Learning activities	STEM integration	Problem-solving competency
Engage (1 session)	Ask	Cafeteria nutrition survey; analysis of current meal data; identification of nutritional gaps and cost constraints	S: nutrition science; M: data analysis	Problem identification
Explore (2 sessions)	Imagine	Investigation of food groups and nutritional requirements; exploration of food safety principles; brainstorming menu solutions	S: food science; T: safety standards; M: nutritional calculation	Idea generation; scientific inquiry
Explain (1 session)	Imagine	Formal instruction on food processing principles; student presentations of initial design concepts; peer feedback	S: food chemistry; T: processing methods	Concept formation; communication
Elaborate (4 sessions)	Plan, create, test	Menu plan development with recipes, nutritional calculations, and cost analysis; Food Festival 4.0 preparation, cooking, and peer tasting evaluation	S+T+E+M: full integration through design–build–evaluate cycle	Solution planning; implementation; collaboration
Evaluate (2 sessions)	Improve	Rubric-based project assessment; structured reflection on design iterations; identification of improvements; final presentation to school community	E: iterative redesign; M: cost optimization	Evaluation, refinement, metacognition

The intervention ran for 10 45-minute sessions across five weeks. Three design principles guided the work. First, cultural relevance was secured by anchoring all problem contexts in the students' boarding-school dining experience: students analyzed the nutritional composition of meals they actually ate, calculated costs using market prices in their home communities, and built solutions from ingredients available in their province. Second, resource feasibility was respected by relying on locally available ingredients and the existing school kitchen, avoiding any need for specialized laboratory equipment or imported materials. Third, 5E+EDP iterative design cycles operated together within each instructional sequence rather than as separate add-ons.

This model was applied in the EG, while the CG were taught with conventional instruction. In the traditional teaching approach for this subject, teachers play the central role and organize lessons according to the linear structure of the textbook. Teachers mainly use lectures, pictures, and charts to explain nutritional components, food selection, and food safety principles, while students listen, take notes, and memorize standardized procedures. In practical lessons, instruction typically follows the model of teacher

demonstration followed by student imitation. Teachers first demonstrate each step of the cooking process, after which students work in fixed groups to reproduce the assigned recipes and measurements. Teachers mainly supervise classroom discipline and evaluate final products based on predetermined criteria such as taste and presentation.

3.4. Training workshop

To conduct this intervention, two teachers attended a four-hour workshop before the intervention so that they could deliver the subject using the model. The workshop was organized by the research team and facilitated by two subject-matter experts from the university. The workshop included one hour of theoretical orientation on the model, followed by three hours of practical training involving model teaching demonstrations, trial instruction using a menu-planning task, and practice in applying the process-based assessment rubrics. To support consistent implementation, the two teachers followed a common set of lesson plans and teaching materials prepared by the research team, and each teacher taught one experimental class and one control class so that teacher-related characteristics were balanced across the two conditions.

3.5. Instruments

Four instruments measured the effects of the intervention. A test comprised 10 multiple-choice items and three short-answer items scored on a 10-point scale, covering food nutrition science, safety principles, and processing technology for Technology 9. Content validity was established through review by three subject specialists. The test assessed both declarative knowledge (identifying macronutrient categories) and applied understanding (calculating the nutritional value of a proposed meal plan).

A problem-solving rubric was developed based on the OECD framework for problem-solving assessment [39] and the dynamic problem-solving perspective of Greiff *et al.* [40]. This rubric was then adapted to the food-processing context, with five criteria: problem identification, idea generation, solution planning, implementation, and evaluation and refinement. Each performance level was defined by specific behavioral descriptors anchored in the project tasks.

The collaboration rubric was developed from the OECD framework for collaborative problem solving [41] and collaborative problem-solving skills proposed by Hesse *et al.* [42], and was further informed by the conceptual synthesis of Graesser *et al.* [43]. The rubric consisted of three criteria: positive communication, peer interaction, and an authentic approach to tasks. It was used to assess students' collaboration while conducting the project.

Both rubrics were reviewed and validated for content by subject-matter experts from the university before use, and each performance level was defined by behavioral descriptors anchored in the project tasks to support consistent scoring. During the preparatory workshop, the two teachers practiced applying the rubrics to sample student work to align their interpretation of the scoring criteria. In the main study, each teacher scored the projects of his or her own experimental class using these shared rubrics. The attitude survey used a five-point Likert scale containing 15 items across five dimensions: interest in technology (3 items), perceived relevance of STEM to daily life (3 items), self-efficacy in STEM tasks (3 items), enjoyment of collaborative learning (3 items), and the necessity of STEM for future careers (3 items). The survey was administered in Vietnamese with simplified language adapted for students whose first language is Tay or Nung.

3.6. Data collection

Table 3 displays information related to the data collection procedures of this study over a period of six weeks. The first week is the preparation week, followed by a five-week treatment. The table demonstrates the intervention, time, and instruments used during the study.

3.7. Data analysis

Quantitative data were analyzed using descriptive and inferential statistics to examine the effects of the intervention on students' academic achievement and attitudes toward Technology 9. Pretest and posttest scores on the food processing achievement test were collected from both groups. Means and standard deviations were calculated, and comparative analyses were conducted to identify differences within and between groups before and after the intervention. For all comparisons, effect sizes were calculated and reported together with significance tests: Cohen's d (with 95% confidence intervals) for between-group differences, and Cohen's dz for within-group pre-to-post changes. Because the experimental and control groups did not differ significantly at pretest, their baseline scores were comparable; analysis of covariance was therefore not used to adjust for initial differences, although the absence of covariate-adjusted modelling is acknowledged as a limitation.

Similarly, pretest and posttest attitude questionnaires were administered to both groups to examine changes in students' attitudes toward Technology 9. Descriptive and comparative analyses were used to

evaluate attitudinal differences following the intervention. In addition, rubric-based assessments were used to evaluate students' problem-solving and collaboration competencies during the project. Descriptive statistics were used to summarize students' competency performance throughout the project activities.

Table 3. Data-collection schedules

No.	Time	Experimental group (n=42)	Control group (n=41)
1	Pre-intervention (1 week before week 1)	Teacher training workshop (4 hours)	
2	Week 1 (start)	Pretest on knowledge (10-point test); pre-test on attitudes (Likert survey)	Pretest on knowledge (10-point test); pre-test on attitudes (Likert survey)
3	Week 1 (Activity 1, 1 session)	Engage phase/Ask: cafeteria nutrition survey; identification of nutritional gaps and cost constraints	Conventional instruction: Lesson 1 on food nutrition (textbook-based delivery)
4	Week 2 (Activities 2–3, 3 sessions)	Explore + Explain phases/Imagine: investigation of food groups; food-safety review; student-led concept presentations with peer feedback	Conventional instruction: Lessons 2–3 on food groups and food safety (textbook-based delivery; teacher-led demonstrations)
5	Week 3 (Activities 4–5, 2 sessions)	Elaborate phase/Plan: menu plan development; recipes; nutritional calculations; cost-effectiveness analysis against school meal budget	Conventional instruction: Lesson 4 on meal planning principles (textbook-based; teacher-assigned worksheet)
6	Week 4 (Activity 6, 3 sessions)	Elaborate phase/Create + Test: "Food Festival 4.0", in which teams cooked their designed dishes; peer tasting evaluation against rubrics for taste, nutrition, cost, and presentation	Conventional instruction: Lessons 5–6 on basic cooking techniques (teacher demonstration; standard practice exercises)
7	Week 5 (Activity 7, 1 session)	Evaluate phase/Improve: rubric-based project assessment; structured reflection on design iterations; final presentation to school community	Conventional instruction: Lesson 7 review and summary (textbook recap; teacher-led Q&A)
8	Week 6 (end)	Posttest on knowledge (10-point test); post-test on attitudes (Likert survey)	Posttest on knowledge (10-point test)

4. RESULTS

4.1. Results on academic tests

Table 4 shows no statistically significant differences between groups in a knowledge test (t=0.15, p=0.881) before the intervention. Students in these classes exhibited similar results on technology knowledge. Table 5 displays the results of the posttest. An independent-samples t-test on posttest scores confirmed that the experimental group scored significantly higher than the control group, t=5.62, p<.001, corresponding to a large effect size (Cohen's d=1.23, 95% CI [0.76, 1.70]). This advantage was consistent across the two schools (d=1.23 and d=1.25).

Table 4. Pretest results of EGs and CGs

Variable	Experimental (*n*=42)	Control (*n*=41)	*t*	*p*	Cohen's d
Test on Technology 9 knowledge	6.82 ±0.95	6.79 ±0.88	0.15	0.881	0.03

Table 5. Post-test results on the Technology 9 test

Classes	*n*	Pre M ± SD	Post M ± SD	*t*	Cohen's d
EG1	22	6.86 ± 0.94	7.95 ± 1.05	3.99**	1.23
CG1	20	6.80 ± 0.89	6.75 ± 0.91	—	—
EG2	20	6.78 ± 0.97	8.30 ± 1.22	3.98**	1.25
CG2	21	6.78 ± 0.86	6.95 ± 0.92	—	—
Combined EG	42	6.82 ± 0.95	8.12 ± 1.13	5.62**	1.23
Combined CG	41	6.79 ± 0.88	6.85 ± 0.91	—	—

Note: *t*-values from paired-samples *t*-tests. ** $p < .01$.

4.2. Problem-solving

Table 6 reports the scores for each problem-solving criterion. The results show that EG students achieved the proficient level for all criteria. The highest score was for improvement-oriented thinking (M=3.67). The lowest scores were in presentation and argumentation (M=3.11).

4.3. Collaboration

Table 7 reports the scores for each collaboration criterion. The results show that EG students achieved the proficient level for the three criteria. The highest score was for positive communication (M=3.67), while peer interaction and an authentic approach to tasks were also achieved with similar results (M=3.56).

Table 6. Problem-solving by criterion (experimental groups, n=9 teams, 42 students)

Criterion (max. 4.0)	Mean ± SD	Level
Problem analysis and knowledge application	3.56 ± 0.53	Proficient
Solution design and optimization	3.56 ± 0.53	Proficient
Product creation (food and poster)	3.22 ± 0.44	Proficient
Presentation and argumentation	3.11 ± 0.33	Proficient
Improvement-oriented thinking	3.67 ± 0.50	Proficient
Overall (max. 20)	17.11 ± 0.60	Proficient

Table 7. Collaboration by criterion (experimental groups, n=9 teams, 42 students)

Criterion (max. 4.0)	Mean ± SD	Level
Positive communication	3.67 ± 0.50	Proficient
Peer interaction	3.56 ± 0.53	Proficient
Authentic approach to tasks	3.56 ± 0.53	Proficient
Overall (max. 12)	10.78 ± 0.94	Proficient

4.4. Attitudes towards STEM

Table 8 displays the results on students' attitudes towards STEM before and after the intervention for the experimental group. The results show that students exposed to the 5E+EDP instruction reported more positive attitudes towards Technology 9 across all aspects surveyed. All pre-to-post changes corresponded to large effect sizes (Cohen's d ranging from 1.35 to 1.75; overall dz=1.75).

Table 8. Pre/post results on attitudes towards STEM of the EGs

Attitudes towards STEM	Pre M ± SD	Post M ± SD	Δ	*t*	*p*	Cohen's d
Interests in STEM	3.12 ± 0.68	4.09 ± 0.52	+0.97	9.82	< 0.001	1.52
Relevance of STEM to daily life	3.25 ± 0.71	4.18 ± 0.55	+0.93	9.15	< 0.001	1.41
Self-efficacy in STEM tasks	2.95 ± 0.75	3.88 ± 0.62	+0.93	8.76	< 0.001	1.35
Enjoyment of collaborative learning	3.42 ± 0.65	4.32 ± 0.49	+0.90	10.21	< 0.001	1.58
Perceived necessity of STEM	3.15 ± 0.73	4.15 ± 0.58	+1.00	9.45	< 0.001	1.46
Overall	3.18 ± 0.58	4.12 ± 0.48	+0.94	11.34	< 0.001	1.75

5. DISCUSSION

This study was conducted with two purposes: to train teachers with a different method to teach Technology 9 and to examine the effects of a culturally contextualized 5E+EDP integrated instructional model on students' academic achievement, problem-solving, collaboration competencies, as well as their attitudes towards the STEM approach. The findings demonstrated that the culturally contextualized 5E+EDP model was associated with significantly higher students' academic achievement in the food processing module. This result is consistent with previous studies showing that inquiry-based STEM learning and engineering design activities positively influence students' learning outcomes and conceptual understanding [15], [34]. Similar to earlier research, the integration of the 5E+EDP provided active and experiential learning environments in which students engaged in problem solving, collaborative inquiry, and iterative design processes. However, this study extends previous literature by incorporating cultural contextualization, particularly within the context of ethnic minority boarding schools in Vietnam. Unlike many previous STEM studies conducted in urban or mainstream educational contexts, this intervention integrated local food traditions, familiar ingredients, and culturally meaningful meal-planning activities into the learning process. Students were required to design nutritionally balanced boarding-school meals closely connected to their daily experiences, cultural eating practices, and local community contexts. This culturally relevant learning environment may have enhanced students' engagement and perceived relevance of the learning tasks.

The findings also provide further support for previous research highlighting the importance of connecting STEM learning to students' cultural and everyday experiences [27], [44]. In this study, the integration of local cultural contexts into the 5E+EDP learning process appeared to increase students' participation, ownership, and motivation during learning activities. The use of culturally familiar food-processing tasks likely enabled students to connect technological and nutritional knowledge with everyday practices more meaningfully. Consequently, the positive academic outcomes observed in this study may reflect not only the effectiveness of the 5E+EDP model itself but also the important role of culturally adapted instructional materials in supporting meaningful STEM learning among ethnic minority students. Because the design did not include a condition that isolated cultural contextualization from the 5E+EDP model itself, this study's findings suggest possible direct effects of contextualized materials, which can be reinforced by more

controlled studies. These findings extend previous research by demonstrating the potential value of such contextualization within ethnic-minority boarding schools in Vietnam.

The findings also revealed that Tay and Nung students demonstrated proficient problem-solving and collaboration competencies while participating in the project. The improvements in collaboration and problem-solving may be attributable to the structure of the learning activities themselves. Through the inquiry and iterative design processes emphasized in the 5E model and EDP [31], [33], students were required to negotiate ideas, evaluate alternative solutions, justify decisions, and respond to practical constraints encountered during food processing. As a result, collaboration emerged as a necessary component of task completion rather than a separate instructional objective, requiring students to communicate, coordinate responsibilities, and make collective decisions throughout the design process [33].

In contrast, such competencies were less visible in conventional classes, where students mainly listened to lectures, took notes, or followed predetermined procedures demonstrated by teachers during menu-design activities. Traditional instruction often emphasized procedural replication and product completion rather than student-centered inquiry, discussion, or collaborative decision-making. The findings of this study also indicated that EG students' attitudes toward the model were more positive after the intervention. This result is consistent with previous studies showing that STEM approaches can enhance students' interest, motivation, enjoyment, and perceived relevance of STEM learning [36], [37]. Because attitudes were measured only within the experimental group, this change cannot be attributed solely to the model and may also reflect the novelty of the instructional approach. Future studies can address this limitation and the long-term effects of the 5E+EDP model.

One possible explanation for this improvement is that the 5E+EDP model may have created a more active and meaningful learning environment compared with traditional teacher-centered instruction. Through collaborative menu-design projects, food-processing experiments, and iterative problem-solving activities, students were encouraged to participate actively in designing solutions rather than passively memorizing knowledge or reproducing procedures. Such authentic and hands-on learning experiences have been shown to positively influence students' attitudes toward STEM learning because students perceive the activities as more relevant, engaging, and practical [35].

6. IMPLICATIONS

The findings suggest several implications for technology education and STEM teaching practices, particularly in ethnic-minority and boarding-school contexts. First, the results indicate that curriculum materials alone may not be sufficient to support the development of the full range of competencies targeted by the grade 9 technology curriculum. In the participating schools, students who experienced the integrated 5E+EDP approach achieved higher academic results than those receiving conventional instruction and demonstrated proficient problem-solving, collaboration, and more positive learning attitudes. These findings suggest that pedagogical approaches incorporating inquiry, engineering design, and authentic problem-solving activities may complement existing curriculum materials and provide additional opportunities for competency development. Consistent with previous research, curriculum reform is unlikely to achieve its intended outcomes without corresponding changes in classroom pedagogy [45], [46].

Second, the study highlights the decisive role of teachers and instructional approaches in the successful implementation of competency-based STEM education. The positive changes observed in students' academic achievement, collaboration, problem-solving competencies, and STEM attitudes were associated more closely with inquiry-based and culturally contextualized teaching practices than with curriculum materials themselves. However, expecting teachers who have been trained and familiar with traditional instructional systems for generations to independently adopt innovative STEM pedagogies may be unrealistic. Research has shown that teachers often require substantial pedagogical support, professional learning opportunities, and sustained guidance before they can effectively implement inquiry-based and culturally responsive STEM instruction [45], [47].

Third, the findings demonstrate that targeted teacher professional development can create meaningful educational change. In this study, teachers received training on the 5E+EDP model to facilitate more active, student-centered, and culturally responsive learning environments. This finding is consistent with studies showing that professional development programs focusing on inquiry-based STEM teaching and culturally responsive pedagogy can significantly improve teachers' instructional capacity and curriculum implementation practices [47], [48]. The study therefore suggests that sustainable improvement in technology education requires not only curriculum innovation but also long-term investment in teacher training, pedagogical support, and culturally adapted instructional resources.

7. LIMITATIONS AND FUTURE RESEARCH DIRECTIONS

This study has several limitations to be addressed in further research. First, the study employed a quasi-experimental design in which two teachers each taught one experimental and one control class. Although this arrangement balanced teacher characteristics across the two conditions, and implementation was standardized through teacher training and a shared set of lesson plans, it was not possible to fully control teacher-related variables such as teaching experience, classroom-management style, and interaction with students. These uncontrolled factors may have influenced students' learning outcomes and attitudes in ways beyond the intervention itself.

Second, the novelty and complexity of the culturally contextualized 5E+EDP approach may also have affected the study results. Since both teachers and students were relatively unfamiliar with inquiry-based STEM learning, collaborative engineering design activities, and formative assessment practices, variations in the implementation quality and adaptation to the new instructional model may have occurred across classrooms. Consequently, some observed improvements may partly reflect the motivational effects of participating in a new and engaging learning experience rather than the instructional model alone.

Third, the study relied primarily on quantitative outcome measures and did not include classroom observations or qualitative interview data. As a result, the research was unable to capture detailed classroom interactions, student engagement processes, or teachers' pedagogical adaptations during the implementation of the 5E+EDP model. In addition, the absence of student interviews limited a deeper understanding of how ethnic minority students perceived the culturally contextualized STEM activities and how these experiences influenced their attitudes and collaborative behaviors.

Future research could address these limitations by employing mixed-methods designs or action research studies incorporating classroom observations, teacher reflections, and student interviews to provide richer insights into the implementation process and learning experiences. Further studies with larger sample sizes, longer intervention periods, and more controlled experimental conditions would also help strengthen the generalizability of the findings. In addition, future research could explore how culturally contextualized STEM approaches influence different ethnic minority groups across diverse educational settings and technology learning modules.

8. CONCLUSION

Implemented in Technology 9 through the project "Boarding School Meal 4.0," this study provides empirical evidence that a culturally contextualized 5E+EDP instructional model can support learning in ethnic-minority boarding schools. Students taught with the model achieved significantly higher academic results than their peers in conventional classes, with a large effect. The findings suggest that curriculum materials alone may be insufficient to develop these competencies in ethnic-minority boarding schools. Teacher preparation, inquiry-based pedagogy, and culturally adapted learning resources appear to play important roles in translating curriculum intentions into meaningful classroom experiences. These factors may be particularly relevant for schools serving students from ethnic-minority and under-resourced communities, where learning is often strengthened when classroom activities are connected to local contexts and students' lived experiences.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
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R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest regarding the work reported in this paper.

INFORMED CONSENT

Informed consent or assent was obtained from all participating ninth-grade students and from their parents or guardians, in accordance with the procedures of the participating schools.

ETHICAL APPROVAL

The research involving human participants complied with the relevant national regulations, the institutional policies of Hung Yen University of Technology and Education, and the policies of the participating boarding schools, in accordance with the principles of the Declaration of Helsinki.

DATA AVAILABILITY

The data that support the findings of this study are available upon reasonable request from the corresponding author.

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