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ENHANCING THE APPLICATION COMPETENCY THROUGH A STEAM-BASED CHEMISTRY UNIT ON PRODUCING CARBONATED FRUIT DRINKS IN GRADE 11

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Abstract. Application competency is demonstrated through students' ability to utilize subject-specific knowledge and skills to explain common phenomena in nature and daily life. This is an essential component that should be emphasized in Chemistry education at the high school. The present study aimed to design and implement STEAM-based instructional topics in Grade 11 Chemistry to foster students' ability to enhance their application competency. The research involved a survey of 112 students from two high schools and 15 Chemistry teachers to investigate the status of STEAM teaching. The effectiveness of the intervention was assessed through a pre-test and post-test quasi-experimental design with a random sample of 77 students. During the implementation of the STEAM-based instructional content, students applied the knowledge and skills they had acquired and explored within the topic to create STEAM-related products. The findings indicate that teaching STEAM-based topics is a feasible and effective approach to developing students' application competency.

Keywords: STEAM teaching, Application Competency, grade 11 Chemistry, Chemistry instruction.

1. Introduction

Developing students' qualities and competencies is one of the key objectives of the new general education curriculum. The reformed curriculum emphasizes comprehensive education, aiming to help students develop cognitive abilities, knowledge, and practical skills [1]. Moreover, the Education Law enacted in 2019 clearly states that the goal of education is the holistic development of ethics, knowledge, and culture, while equipping learners with essential qualities and competencies to meet societal demands.

According to the 2018 General Education Curriculum for Chemistry issued by the Ministry of Education and Training, the application competency is expressed through students' ability to use their Chemistry knowledge and skills to explain common natural and everyday phenomena; address issues related to environmental protection and sustainable development; and appropriately respond to and solve basic problems concerning themselves, their families, and communities [2]. This is considered a crucial component of competence for students, as it links learned knowledge with real life, allowing them to recognize the relevance and significance of chemistry in practice. To foster this competence, a variety of teaching methods and models should be integrated.

STEM stands for Science, Technology, Engineering, and Mathematics [3]. In education, STEM is not taught as separate disciplines but rather as an integrated curriculum, equipping students with knowledge and skills across these fields through an interdisciplinary approach. This allows students to apply their learning to solve real-world problems. STEM education can enhance learners' interest and motivation in related subjects, while also developing their problem-solving abilities and capacity to apply knowledge [4]. Nowadays, STEM has evolved into STEAM with the integration of Art, encompassing aesthetics and humanistic values, contributing to a more holistic development of learners. STEAM is considered a highly effective educational approach that promotes the all-round development of students.

Numerous international studies have examined STEM and STEAM education, such as the study by Park HyunJu and colleagues on the perceptions and practices of teachers in implementing STEAM education in schools [5]; Liudmila V. Shukshina and associates (2021) on a conceptual framework for STEM and STEAM teaching in the Russian Federation. The authors emphasize the role of STEAM education in fostering creative thinking, collaboration skills, and digital competencies to meet the demands of the modern digital economy. With approximately 20.2% of Russian university students enrolled in STEAM-related fields, the article proposes expanding teacher training, developing integrated curricula from general to higher education, and strengthening partnerships with industry to enhance the quality of human resources. [6]; and the 2023 study by Alexey A. Chistykov and co-authors on integrating project-based learning with STEAM education [7]. In Vietnam, Thai Hoai Minh et al. (2023) conducted an experimental STEM-integrated Chemistry lesson to promote students' problem-solving and career orientation [8]. Hoang Thi Tuyet (2023) reviewed the evolution from STEM to STEAM and STREAM, emphasizing the integration of arts and literacy for holistic student development [9]. The Vietnam Ministry of Education and Training (MOET) has paid special attention to promoting STEM education. The MOET emphasizes the importance of STEM education in developing students' competencies, particularly *the Application Competency*. The MOET also guides educational institutions to implement STEM education through three main forms: (1) STEM-integrated lessons within subject areas, (2) experiential STEM activities, and (3) scientific and technical research projects [10].

Chemistry is a natural science that tightly integrates theory and practice. The subject focuses on the study of substances, their transformations, and real-world applications in daily life and material/product production processes. Through Chemistry, students not only master fundamental knowledge but also learn to apply it in everyday contexts. Chemistry is also closely connected with many other educational fields. Alongside subjects such as Mathematics, Physics, Biology, Informatics, and Technology, Chemistry plays an important role in delivering STEM/STEAM education, a growing global educational trend [2].

The application competency, which refers to students' ability to apply acquired knowledge and skills to real-life situations, plays a critical role in teaching and serves as an important indicator for assessing students' capacity to transfer academic learning into practical contexts. Meanwhile, STEAM education is an interdisciplinary approach that emphasizes the integration of knowledge across different fields, fostering students' creativity, problem-solving abilities, and their capacity to apply what they have learned in the creation of STEAM products. These characteristics demonstrate a close connection between STEAM teaching and the development of application competency. Building upon this correlation, the present study aims to enhance students' Application Competency through the design and implementation of a STEAM-based Chemistry unit on "Producing carbonated fruit drinks".

2. Content

2.1. STEAM-based instruction in Chemistry

**** The concept of STEM/STEAM education***

STEAM education is an integrated model that combines Science, Technology, Engineering, the Arts, and Mathematics into a unified framework: "Science and Technology are analyzed through Engineering and the Arts, grounded in Mathematics" [11]. It promotes interdisciplinary learning by enabling students to apply scientific and technical knowledge alongside artistic and social elements to solve real-world problems. The arts component fosters creative thinking, helping learners adapt to rapid scientific and technological changes [4]. Effective STEAM education requires close integration of the arts with other disciplines [4]. Mpofu (2019) proposed the five-level integration model of STEM education begins with Level 1, where S-T-E-M represents a segregated approach with minimal integration among disciplines. Level 2, referred to as STEM, involves connections between two or more subject areas. Level 3, denoted as E/T S-T/E-M, includes the integration of technology or engineering into one of the remaining STEM domains. At Level 4, STEM becomes an interdisciplinary model that fully integrates all four areas of science, technology, engineering, and mathematics into a cohesive teaching and learning framework. Finally, Level 5, known as SMATE, extends this integration by incorporating the arts, forming a comprehensive educational approach that combines mathematics, science, arts, technology, and engineering (MSATE) [12]. As a leading educational trend of the 21st century, STEAM emphasizes that creativity, enabled through the arts, is essential alongside knowledge and skills [13].

* ***Structure*** **of a STEM/STEAM lesson**

According to Official Dispatch No. 3089 issued by the Ministry of Education and Training, each STEM/STEAM lesson consists of five main activities and follows an eight-step engineering design process as shown in QR1 [10].

QR1

**** The importance of STEM/STEAM and the role of Art in STEAM***

Ta Thi Kim Chi (2020) researched the organization of STEM-ART (STEAM) experiential learning within competency-based education under the new curriculum, showing that STEAM not only equips students with practical knowledge but also supports personal and life skills development [14]. In 2023, Hoang Thi Tuyet provided a comprehensive analysis of STEM, STEAM, and STREAM education from global and Vietnamese perspectives, emphasizing their potential in developing learners' competencies [15]. The integration of the arts in STEAM plays a key role in fostering creativity [16], promoting visual thinking, communication, and collaboration, and developing learners' aesthetic orientation and sensibility [17].

2.2. The application competency

2.2.1. Definition of the application competency

The application competency skills are defined by the Quebec Ministry of Education (Canada) as "the ability to propose, carry out, and resolve tasks and demands posed by human life based on experience, knowledge, and skills" [18]. In Vietnam, Nguyen Thi Thu Hang and Phan Thi Thanh Hoi (2018) define the application competency as "the ability of individuals to identify real-life problems, to mobilize relevant knowledge, or to explore and discover knowledge to effectively solve practical issues". This definition emphasizes both the cognitive process of problem recognition and the proactive engagement in knowledge application [19]. Similarly, Dong Thanh Lam and Tran Trung Ninh (2020) conceptualize the application competency as "the learner's ability to independently and efficiently solve emerging problems by applying the knowledge and skills they have acquired to practical situations and activities". According to the authors, this competency reflects not only intellectual capacity but also the learner's personal qualities and characteristics in the process of acquiring and utilizing knowledge to meet real-world demands [20]. The Ministry of Education and Training defines this component competency as "the learner's ability to apply and synthesize knowledge, experience, skills, and attitudes to effectively address practical issues related to the content they have studied" [2].

2.2.2. Structure of the application competency

Based on the 2018 General Education Curriculum for Chemistry, the structure of the Application Competency is divided into three main components [2]. In addition, several researchers have also proposed frameworks for the Application competency, most of which align with the structure suggested by the Ministry of Education and Training.

Table 1. Correlation of application competency structures proposed by various authors

Ho Thi Hoai Thuong and Trinh Le Hong Phuong (2024) [21]	Pham Thi Binh and Do Xuan Hoa (2023) [22]	The Ministry of Education and Training (2018) [2]
1. Identifying and orienting relevant knowledge and skills to solve problems.	1. Investigating the problem, collecting related knowledge.	1. Identifying problems and posing guiding questions to mobilize knowledge and skills.
2. Planning to solve problems in learning and real-life contexts.	2. Planning and implementing the plan.	2. Planning and solving problems.
3. Implementing problem-solving plans in learning and real life.		
4. Evaluation and adjustment.	3. Evaluation and reflection.	3. Self-assessment and self-adjustment.

In this study, we chose to adopt the competency structure proposed by Ho Thi Hoai Thuong and Trinh Le Hong Phuong. This structure provides a detailed description of the components of the Application Competency, aligning well with the framework outlined in the Chemistry General Education Curriculum. It effectively captures the essential elements required for developing students' ability to apply acquired knowledge and skills in practical and learning contexts.

2.2.3. Indicators of the application competency

Based on the structure of the competency framework developed by Hoai Thuong and Hong Phuong (2024), and the identified components of the Application Competency in the 2018 General Education Curriculum for Chemistry, we propose a framework for developing the Application Competency of high school students in the context of Chemistry education [2], [21]. The framework for the application competency in chemistry for high school students is shown in QR2.

QR2

2.3. Correlation between STEM/STEAM-based teaching and the application competency in Chemistry

Based on the structure of STEM/STEAM lessons and instructional procedures, as well as the indicators of the competency to apply knowledge and skills in Chemistry specified by the Ministry of Education and Training, we observe that the teaching process under the STEM/STEAM model is highly compatible with the indicators of this competency (see QR3).

QR3

2.4. The Organic Chemistry content strand in Grade 11 Chemistry

The Grade 11 Organic Chemistry curriculum includes key topics such as hydrocarbons, hydrocarbon derivatives, carbonyl compounds, and carboxylic acids, each allocated a specific portion of instructional time [2]. These topics aim to help students understand the properties and real-life applications of organic compounds, enabling them to apply this knowledge in everyday contexts. In this study, several STEAM-based lesson topics were designed in alignment with the Organic Chemistry strand to support the development of students' competency in applying acquired knowledge and skills.

QR4

Allocation of instructional time for the organic chemistry content strand in Grade 11 Chemistry is shown in QR4.

2.5. Current situation of implementing formative assessment to develop the application competency among high school students

Objectives: To investigate the current status. For teachers: To examine the current implementation of STEM/STEAM education in Chemistry teaching, including the teaching methods and techniques employed, as well as the difficulties and challenges encountered.

For students: To assess the level of interest and engagement when participating in STEM/STEAM-based topics in Chemistry.

Research method: Cross-sectional survey research.

Instruments: Survey questionnaires for both teachers and students (see QR5).

Based on the results collected from 100 students and 15 teachers at Ly Thai To High School, Trinh Hoai Duc High School, and Binh Phu High School in Bình Dương Province in April 2025, the following findings were obtained:

QR5

The findings indicate that while the majority of teachers (75%) demonstrated a moderate understanding of STEM/STEAM education, and all were familiar with the "A" component Art—in STEAM, the actual implementation of STEAM-based instruction remains limited. Only 37.5% of teachers organized STEAM activities through interdisciplinary extracurricular sessions, and 31.3% integrated them into regular classroom or project-based learning. Despite these limitations, all teachers (100%) recognized the significant role of STEAM education in fostering key competencies in Chemistry, especially the application competency. Moreover, 81.3% believed that STEAM integration contributes positively to increasing students' engagement and interest in Chemistry.

However, several challenges were reported, including insufficient instructional time, difficulty in selecting appropriate themes, limited facilities and teaching aids, and disparities in student academic abilities within a single class. These factors align with limitations identified in previous studies and are directly associated with the practical difficulties that hinder the development of students' ability to apply the application competency effectively through STEAM-oriented instruction.

From the student perspective, although 54.2% of respondents expressed moderate to high interest in Chemistry, more than half (51.4%) indicated that they rarely participated in STEAM-related activities during Chemistry lessons. Nonetheless, the survey results reveal that students showed genuine curiosity and motivation to explore interdisciplinary knowledge, real-world applications, and creative tasks, suggesting a strong potential for nurturing the Application Competency through well-designed STEAM experiences. Additionally, students acknowledged that many Chemistry teachers made deliberate efforts to create opportunities for STEAM-based learning and actively promoted the development of their ability to apply knowledge and skills.

These results highlight the mismatch between the recognized importance of STEAM-oriented teaching and the actual conditions of its implementation. While teacher awareness is relatively high, structural and contextual barriers still limit the effectiveness of this approach. To realize the full potential of STEAM in developing students' Application Competency in Chemistry, targeted solutions addressing time constraints, resource availability, and teacher professional development are needed.

2.6. Developing students' application competency through STEAM-based instruction

Illustrative STEAM Lesson Plan: "Producing Carbonated Soft Drinks from Fruit", following the 5-step STEM teaching model.

** Lesson Objectives*

Chemistry Cognitive Competency (NT): NT1: Define alcohol; state the general formula for saturated, monohydric, open-chain alcohol; classify the degrees of alcohol; describe the bonding and molecular structure of methanol and ethanol. NT2: Write structural formulas and name simple alcohols (C1–C5) using IUPAC and common naming conventions. NT3: Describe the physical properties of alcohol (state, boiling point trends, solubility in water); explain how hydrogen bonding influences boiling points and solubility. NT4: Describe the chemical properties of alcohols: substitution reactions at the –OH group (common to all alcohols and specific to polyalcohols); dehydration reactions forming alkenes or ethers; oxidation of primary and secondary alcohols to aldehydes and ketones using CuO; combustion reactions. NT5: Explain methods of ethanol preparation via ethylene hydration and starch fermentation; explain glycerol production from propylene.

Scientific Inquiry Competency in Chemistry (TN): TN1: Conduct experiments such as ethanol combustion, and glycerol reaction with copper(II) hydroxide; describe and explain the observed chemical phenomena.

Application competency (VD): VD1: Describe the applications of alcohols, the negative effects of alcohol abuse, and demonstrate responsible attitudes regarding personal and community health. VD2: Apply knowledge of alcoholic fermentation (sugar breakdown) to produce carbonated beverages. VD3: Plan and select appropriate methods for soft drink production; carry out the plan and evaluate its effectiveness. VD4: Explore further knowledge to improve the STEAM product development process.

General Competencies: Collaboration and Communication (HT): Collaborate effectively in groups to plan, propose, and implement production methods and processes. Work together on product development according to the group design. Problem Solving and Creativity (GQ): Propose feasible solutions and develop plans for producing carbonated soft drinks from fruit in line with product goals and real-world constraints.

Qualities (Values): Diligence (CC): Demonstrated through timely and complete execution of assigned tasks. Responsibility (TN): Shown through active participation and accountability in group tasks. Integrity (TT): Reflected in honest reporting of experimental results and product outcomes.

STEAM Integration:

Science (S): Understanding ethanol production through fermentation of starch- or sugar-rich raw materials (e.g., fruits). Raise awareness about the dangers of alcohol abuse and counterfeit alcohol. Investigate fermentation using natural enzymes or microbial starters (e.g., scoby, kefir fungi).

Technology (T): Design the production process (steps, materials, packaging, logos). Use tools such as Microsoft PowerPoint to present research and product designs. Compare household vs. industrial fermentation technologies.

Engineering (E): Select appropriate fruits (e.g., grapes, pineapples, apples, strawberries). Apply fermentation techniques, including fruit preprocessing, sugar concentration adjustment, use of suitable containers, and temperature regulation. Perform product quality control, followed by filtration, bottling, and storage to ensure optimal preservation.

Art (A): The product packaging is aesthetically appealing and includes complete information regarding the product's ingredients, production process, and health benefits. It incorporates messages related to environmental protection, green living, and eco-friendliness. The packaging also includes reminders to dispose of empty bottles in designated areas after use, aligning with the principles of sustainable development. Sensory evaluation of the product considers aspects such as color (clear, visually appealing, free of sediment), fragrance, and overall palatability. The design reflects a balance and harmony between production processes and marketing strategies. Environmentally friendly materials and ingredients are utilized, contributing to the promotion of sustainable development education among students.

Math (M): Calculate production costs, time, raw material quantities, output volume, and optional additives. Ensure precise formulation and optimize production efficiency.

* *Learning materials:* Learner support worksheets, checklists 1, 2, and 3, rubrics 1, 2, 3, 4, and 5, product/solution evaluation criteria, guiding questions, step-by-step product development guide, product poster

* *Instructional equipment:* Laptop, television, projector, materials for product development

* *Duration:* 5 class periods (in-class instruction) and 20 days (at-home implementation)

* *Teaching process*

- *Activity 1: Introduction and Problem Posing (30 minutes)*

Objective: Students identify the requirements and tasks of the project "Producing carbonated fruit drinks". (Aligned with competencies: Collaboration and Communication – HT, Responsibility – TN).

Implementation:

Contextualizing the Problem: Beverage consumption is a basic daily need, especially during periods of extreme heat. Carbonated soft drinks and bottled beverages are among the most common choices to quench thirst. However, these commercially produced beverages often contain high levels of sugar, artificial flavors, and food colorings, which, over time, may have adverse health effects, such as obesity, hyperglycemia, diabetes, cirrhosis, and kidney failure.

- The teacher prompts students to discuss and propose possible solutions to address the problems raised. Through discussion, students are guided to the idea of producing a healthier alternative: carbonated soft drinks made through natural fermentation. Based on student input, the teacher introduces the project theme: *"Producing carbonated fruit drinks"*.

- The teacher presents criteria for evaluating the final product, such as taste, carbonation level, clarity, safety, natural ingredients, and environmentally friendly packaging. These criteria help guide students in product design and quality assurance.

- Group Formation and Project Planning: Students are instructed to form production groups (each consisting of 6 - 7 members), acting as "startup companies" for soft drink manufacturing. Each group nominates members and reports the team roster to the teacher. Groups propose preliminary plans, including a project timeline and general implementation strategy. The teacher facilitates and moderates discussion to ensure a consistent understanding of the project's goals and structure.

From activity 2 to 4 are shown in QR6.

QR6

- *Activity 5: Sharing, Discussion, and Refinement (45 minutes)*

- Objectives: VD3, VD4, TT, TN, CC, HT, GQ.

- Implementation:

+ The teacher invites each group to introduce their final product, presenting the ingredients, production process, benefits, and instructions for use of their fruit-based carbonated beverage.

+ Each student group presents the results of the product they have developed, accompanied by a promotional poster that includes the following content: the process of producing the carbonated fruit beverage, the results of various trials, the finalized production procedure, instructions for using the product, its benefits, and usage guidelines.

+ The group presents the products they have developed (each team has 5 minutes for their presentation). After the presentation, they invite the teacher and the other groups to taste the product and experience its flavor. Following the tasting and presentation, the teacher and other groups provide feedback and suggestions to help improve the product.

+ The teacher and students score the teams based on evaluation criteria outlined in the assessment rubric. The teacher then summarizes and gives an overall evaluation of the project, focusing on: knowledge and skills related to alcohol content, the issue of alcohol use in society and daily life, the process of designing and producing the product, teamwork skills, presentation and persuasion skills, problem-solving abilities, as well as practical and experimental skills.

Assessment methods: Observation checklist No. 2, product evaluation rubric, review of student production journals, and documenting the entire process.

Through the STEAM teaching plan on the topic “Producing carbonated fruit drinks,” the elements of the application competency have been continuously integrated throughout the sequence of activities and assessed through instructional tools, allowing timely feedback to learners.

Figure 1. Students presenting foundational knowledge

Figure 2. Student’s carbonated soft drinks from fruit product

The STEAM teaching plan on the topic “Producing carbonated fruit drinks” is shown in QR7.

A pedagogical experiment was conducted using the pre-test and post-test experimental research method on randomly assigned groups during the 2024–2025 academic year. The experimental groups included 43 students from Ly Thai To High School and 34 students from Trinh Hoai Duc High School, both located in Thuan An City, Binh Duong Province. The STEAM-based Chemistry teaching plan was designed to develop the component of *Application Competency*, which focuses on students’ ability to apply acquired knowledge and skills. Evaluation criteria and rubrics were developed based on the topic-specific requirements, learning outcomes, and indicators of the Application Competency component.

QR7

QR8

Based on the data collected from Checklist 1, Checklist 2, Checklist 3, and Rubric 4 (for teachers) and Rubric 5 (for students), along with students’ pre-test and post-test results, the research team constructed visual charts to illustrate the findings of the study (see QR8).

Table 2. Results of students' self-assessment on the application competency through Rubric 5 before and after the experiment

Indicators of competency component	Criteria	Average before intervention	Average after intervention
Apply chemical knowledge to identify and explain some natural phenomena and applications of chemistry in life (VD1)	1.1. Identify problems within the STEAM topic	2.34	3.64
	1.2. Collect information and determine relevant knowledge and skills related to the STEAM topic	2.77	3.92
Apply integrated knowledge to evaluate the impact of a real-world issue and propose some methods, solutions, models, or plans (VD2)	2.1. Collect information and determine relevant knowledge and skills related to the STEAM topic	2.55	4.00
	2.2. Choose suitable options aligned to produce carbonated soft drinks from fruit	2.56	3.78
	2.3. Implement the STEAM product creation plan and pay attention to the Art elements	2.55	4.00
	2.4. Conclude and evaluate the STEAM product	2.44	4.08
Respond appropriately in situations related to oneself, family, and community through sustainable social development and environmental protection (VD3)	3.1. Respond appropriately in situations related to oneself, family, and community in line with sustainable social development	2.62	4.05
	3.2. Propose improvements to the recently created STEAM product, both in content and Art aspects	2.55	4.00

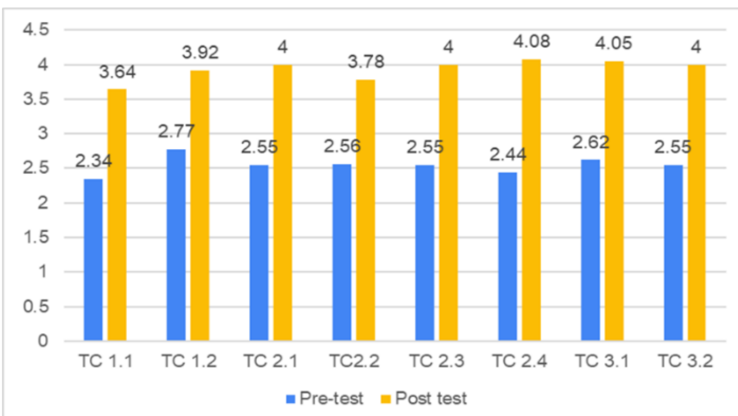

Figure 3. Chart illustrating the results of students' self-assessment on the application competency through rubric 5 before and after the experiment

Table 3. Summary of test result parameters between pre-test and post-test

Test group	Mean score ($\bar{X}$)	Variance (s_i^2)	Standard Deviation (S)	Dependent t-test	Effect Size (ES)
Pre-test	6,47	2,39	1,55	$3,59.10^{-7}$	0,86
Post-test	7,80	2,31	1,14		

The experimental results and Rubric 5 indicate that before intervention, most students scored at lower competency levels (1 and 2), while post-intervention data showed a significant shift toward higher levels (4 and 5). The Pre-test outperformed the Post-test, with a statistically significant t-test result ($p < 0.05$) and a large effect size (0.86). These findings confirm the effectiveness of STEAM teaching in developing the competency of applying knowledge and skills in Chemistry. Furthermore, assessments using Checklists 1–3 also revealed improvements in students' general competencies and qualities, such as diligence, responsibility, collaboration, self-regulation, and creative problem-solving. The data collected during the experimental phase of the study are shown in QR 9.

QR9

3. Conclusions

This study developed and implemented a STEAM-based instructional plan for the topic "Producing carbonated fruit drinks" to evaluate students' Application Competency in Chemistry. Results indicated that students effectively applied their acquired knowledge and skills to solve real-life problems, demonstrating the potential of STEAM education to foster this competency. The findings suggest that STEAM-based approaches are well-aligned with the goals of general education reform. However, the study was limited to 77 students and one instructional topic. The relationship between STEAM teaching and the development of Application Competency remains insufficiently explored. To validate the findings, future research should involve larger samples, multiple topics across grade levels, and employ additional methods such as surveys and interviews to clarify this correlation. Instructional design should prioritize real-life content to support the development of diverse student competencies.

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