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INTEGRATION OF THE STEAM APPROACH IN DEEP LEARNING TO STIMULATE STUDENTS' CRITICAL THINKING

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Abstract: This quantitative study examines the impact of integrating STEAM (Science, Technology, Engineering, Arts, and Mathematics) approaches into deep learning models to enhance students' critical thinking skills. A quasi-experimental design was employed with 120 high school students (60 experimental, 60 control) using pre-test/post-test measures based on the Cornell Critical Thinking Test (CCTT). Results indicated a statistically significant improvement in critical thinking scores ($p < 0.05$, Cohen’s $d = 0.89$) among students exposed to STEAM-deep learning modules. Qualitative analysis of project artifacts further revealed enhanced problem-solving and creativity. The study underscores the efficacy of interdisciplinary STEAM pedagogy in fostering 21st-century skills.

Keywords: STEAM education, deep learning, critical thinking, quantitative research, pedagogy.

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INTRODUCTION

The Industrial Revolution 4.0 demands critical thinking skills as students' core competencies. Deep learning and the STEAM approach have the potential to answer this challenge through the integration of disciplines and inquiry-based learning (Becker & Park, 2011). Preliminary studies show low critical thinking scores of students in Indonesia (PISA 2022), driving the need for pedagogical innovation. The development of the 21st century requires students to master critical thinking skills as an essential competency in facing the complexity of global problems. Data from the Programme for International Student Assessment (PISA) 2022 shows that Indonesian students' critical thinking skills are still ranked low (ranked 74 out of 81 countries), with an average score of 370, far below the OECD average (478). This indicates the urgency to develop innovative learning models that can stimulate higher-order thinking skills (HOTS).

In this context, the STEAM (Science, Technology, Engineering, Arts, and Mathematics) approach emerges as a promising pedagogical framework. STEAM not only integrates STEM disciplines with the arts but also emphasizes project-based learning (PjBL) and inquiry (Quigley et al., 2017). The integration of arts in STEM has been shown to increase students' creativity, motivation, and problem-solving abilities (Liao, 2016). However, the effectiveness of STEAM is not optimal if it is not combined

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with deep learning strategies, which focus on conceptual understanding, knowledge transfer, and active cognitive engagement (Hattie, 2017).

Previous research on STEAM tends to be fragmented, some exploring STEM aspects (Becker & Park, 2011), others examining art separately (Eisner, 2002). In fact, the holistic integration of STEAM in deep learning can create authentic learning experiences, where students not only master content but also develop metacognition and analytical-synthesis skills (Perignat & Katz-Buonincontro, 2019). A preliminary study in 5 Indonesian schools showed that 72% of teachers had difficulty designing STEAM activities that combined conceptual depth and critical thinking skills (PPG Survey, 2023). The concept of deep learning in this study refers to Hattie's (2017) framework which includes: (1) mastery of concepts, (2) transfer of knowledge to new contexts, and (3) metacognition. Meanwhile, STEAM is understood as an extension of STEM with the addition of an art dimension to stimulate creativity and multidisciplinary understanding (Liao, 2016). The synthesis of these two approaches is expected to produce a synergistic effect, where art acts as a "catalyst" to overcome the rigidity of traditional STEM (Guyotte et al., 2014).

METHOD

The research design used in this study is Quasi-experimental with pretest-posttest control group design. The research variables are: Independent variables, namely STEAM-deep learning (project integrated module), and dependent variables, namely critical thinking scores (measured by CCTT Level X).

The participants were 120 high school students (grade XI) selected through purposive sampling (60 experiments, 60 controls). The criteria for schools with project-based curriculum, basic technology access. Data collection instruments and techniques are in the form of Tests: CCTT (40 items, α-Cronbach = 0.82). Questionnaire: Likert scale to measure student engagement. Observation: STEAM project assessment rubric (criteria: originality, data analysis, collaboration).

Data analysis used in the form of paired sample t-test (pretest-posttest), independent sample t-test (group comparison), and regression analysis to identify predictors of success. The hypotheses are:

H_1: Students exposed to STEAM-deep learning show a more significant increase in critical thinking scores compared to the control group (conventional learning).

H_2: Arts integration in STEAM projects is the strongest predictor of increased student analytical skills ($\beta > 0.40$).

RESULT AND DISCUSSION

The results of the study on the problems that have been formulated previously. In the results of this study, it describes the characteristics of the research informants, as well as the data that has been obtained from the informants. Then the results of this study the researcher obtained from in-depth interviews with informants. The observations carried out in this study are a form of observation by directly observing the research object to then record the symptoms found in the field in order to complete the data needed as a

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reference which is related to the problems being studied. This in-depth observation aims to find out how the integration of the STEAM approach in in-depth learning stimulates students' critical thinking. Furthermore, the informants who have been determined are expected to be things that meet the information desired by the researcher. So that through the answers from the informants will help researchers in obtaining the information that researchers need in the study. In addition, researchers also use documentation techniques. This aims to obtain information that supports the analysis and description of data that will be presented by researchers descriptively. Then the results of this research will be explained descriptively using relevant theories.

1. Data Description

Table 1. Distribution of critical thinking pretest scores

Class Group-Test	**Average**	**min-max score**
Exsperiment	52.3 (SD = 6.1)	minimum = 40, maximum = 65
Control	51.8 (SD = 5.9)	Skor minimum = 42, maximum = 64
Normality test (Shapiro-Wilk)	-	Eksperimen: $p = 0.12$ (> 0.05, normality data)

2. Pretest-Posttest Comparison

a. Exsperimen (STEAM-Deep Learning)

1) Posttest average: 78.5 (SD = 7.3).
2) Improve Score : +26.2 poin.
3) Paired Sample t-test: $t(59) = 15.67$, $p < 0.001$ (signifikan). Effect Size (Cohen's d): 0.89 (efek besar).

b. Control (Konvensional Learning)

1) Posttest average: 61.2 (SD = 6.8).
2) Improve Score: +9.4 poin.
3) Paired Sample t-test: $t(59) = 5.32$, $p = 0.02$ (significant, but the effect small).

3. Significant differences between groups

1) Independent Sample t-test (Posttest)**:**
   a. $t(118) = 4.85$, $p = 0.003$ (significant).
   b. Mean difference= 17.3 (CI 95%: 12.1–22.5).

4. Predicotr factor prediktor (Regresi Linear)

Table 2. Analysis Factor Prediktor (Regresi Linear)

Variabel Prediktor	**B**	***p*-value**	**Kontribusi**
Arts integration	0.45	0.01	Significant
Use of Technology	0.32	0.04	Significant
Group Collaboration	0.28	0.06	No significant

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Average 0.67 (The model explains 67% of the variance in critical thinking improvement).

Furthermore, the research results obtained were also as follows:

- Correlation Between Student Engagement and Posttest Scores: $r = 0.53$ ($p < 0.01$), shows a positive relationship.
- Comparison of Critical Thinking Sub-Dimensions (CCTT):
    - Analysis: Highest improvement (+35%).
    - Evaluation: improvement +28%.
    - Inferentiation: Peningkatan +22%.
- Increase in critical thinking scores of the experimental group
    - (posttest average= 78.5 vs. pretest = 52.3; p < 0.001).
    - Significant differences between experimental and control groups (posttest: 78.5 vs. 61.2; p = 0.003).
    - Strongest predictor: Arts integration in STEAM project (β = 0.45, p = 0.01).

DISCUSSION

1. The Effectiveness of STEAM-Deep Learning Integration in Improving Critical Thinking

The results of the paired sample t-test analysis showed a significant increase (p < 0.001) in the critical thinking scores of the experimental group (mean posttest = 78.5 vs. pretest = 52.3). This finding is in line with Vygotsky's (1978) theory of scaffolding in collaborative learning, where the STEAM-deep learning approach provides an interdisciplinary framework for independent knowledge construction. Projects such as "Designing Renewable Energy Solutions" (a combination of physics, visual arts, and mathematics) force students to analyze problems from a multidimensional perspective, thus training analytical and evaluation skills, two key indicators of critical thinking (Facione, 1990). The results of the paired sample t-test analysis showed a significant increase (p < 0.001, Cohen's d = 0.89) in the critical thinking scores of the experimental group after the STEAM-deep learning intervention (pretest: 52.3 → posttest: 78.5). This finding is in line with the cognitive integration theory (Perkins, 2017) which states that the interdisciplinary approach (STEAM) facilitates the formation of complex mental models through: 1) Contextual problem solving (e.g., art-based robotic design projects) that train systemic analysis; 2) Cross-disciplinary connections (e.g., the use of mathematical principles in art data visualization) to strengthen conceptual understanding.

Comparison with the control group (independent t-test, p = 0.003) confirmed that the STEAM-deep learning model was superior to conventional learning (mean posttest: 78.5 vs. 61.2). This is supported by the observation that 85% of students in the experimental group were able to solve open-ended problems on the CCTT with evidence-based arguments, while only 45% of the control group. A study by Conradty & Bogner (2020) found that arts integration in STEM enhances creativity, but this study strengthens the evidence that arts also act as a catalyst for critical thinking through data visualization and design. The effect size (Cohen's d = 0.89) is higher than Sanders' (2009) meta-analysis (d = 0.65), indicating that the combination of STEAM with deep

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learning (e.g., project-based problem-based learning) is superior to conventional STEM approaches.

2. The Role of Arts Components in STEAM as the Main Predictor

Regression analysis revealed that arts integration was the strongest predictor of increased critical thinking (β = 0.45, p = 0.01). Qualitative data from the project rubric showed that: 1) Data visualization (e.g., pollution impact infographics) helped students identify patterns and causal relationships; 2) Creative design (e.g., eco-friendly product prototypes) triggered divergent thinking (Guilford, 1967).

These findings support Yakman's (2008) argument that art is not just a decorative element, but a tool to connect STEM abstractions with human contexts. A concrete example in this study is the "Soundwave Art" project where students used the principles of wave physics to create an art installation, while analyzing the impact of sound frequencies on health. The findings support the theory of cognitive load reduction through a multidisciplinary approach (Sweller, 2010).

Regression analysis revealed that arts integration was the strongest predictor of improved critical thinking (β = 0.45, p = 0.01). Students who used arts techniques (e.g. infographics or digital storytelling) to present scientific solutions showed better synthesis skills. This supports Root-Bernstein's (2003) hypothesis that "thinking with images" expands cognitive capacity. A concrete example is seen in the "Ecosystem Simulation with 3D Animation" project, where students had to transform ecological data into a visual narrative, practicing abstraction and scientific communication skills.

CONCLUSION

STEAM integration in deep learning has been shown to be effective in enhancing students' critical thinking. Interdisciplinary approaches facilitate the transfer of knowledge to real-world contexts. Policy: Curriculum should allocate hours for structured STEAM projects. Practice: Teachers need training in STEAM-deep learning instructional design. Further Research: Exploration of long-term impacts and contexts of inclusive education.

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