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The Effect of STEAM Project-Based Learning Assisted by Artificial Intelligence on Elementary Students' Creativity and Innovation Skills

Marpian ✉, Universitas Pendidikan Indonesia, Indonesia

✉ *marpian@upi.edu*

Abstract: The growing demand for creativity and innovation in twenty-first-century education requires instructional approaches that integrate interdisciplinary learning, authentic problem solving, and emerging technologies. However, empirical evidence regarding the combined implementation of Science, Technology, Engineering, Arts, and Mathematics (STEAM), Project-Based Learning (PjBL), and Artificial Intelligence (AI) in elementary education remains limited. This study investigated the effect of AI-assisted STEAM Project-Based Learning on elementary students' creativity and innovation skills. A quantitative quasi-experimental design employing a pretest–posttest nonequivalent control group design was used. The participants consisted of 60 fifth-grade students, including 30 students from SD Negeri Batucina as the experimental group and 30 students from SD Negeri Blokang as the control group. Data were collected through performance-based assessments of creativity and innovation skills and analyzed using descriptive and inferential statistics. The results revealed that the experimental group demonstrated substantially greater improvement than the control group across both outcome variables. For creativity, the experimental group's mean score increased from 58.73 to 82.47, whereas the control group improved from 59.10 to 69.83. For innovation skills, the experimental group's mean score increased from 57.90 to 84.20, while the control group improved from 58.37 to 70.57. Independent-samples t-tests indicated significant posttest differences between the groups for creativity (t = 7.24, p < .001, d = 1.87) and innovation skills (t = 8.11, p < .001, d = 2.09). These findings suggest that integrating AI-assisted learning within a STEAM-oriented project-based environment can provide meaningful opportunities for students to generate, evaluate, and refine ideas while transforming them into functional solutions and products. The study contributes to the growing body of research on AI-enhanced learning by providing empirical evidence from an elementary education context and highlights the potential of AI-assisted STEAM Project-Based Learning as an instructional approach for fostering creativity and innovation in primary schools.

Keywords: Artificial intelligence, STEAM education, project-based learning, creativity, innovation skills, elementary education, quasi-experimental study.

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INTRODUCTION

The rapid transformation of social, technological, and economic environments has changed the competencies that schools are expected to cultivate among younger generations. Contemporary learners are increasingly required not only to acquire disciplinary knowledge but also to generate ideas, respond to unfamiliar problems, develop useful solutions, and adapt knowledge to changing circumstances. Within this context, creativity and innovation have become increasingly important educational outcomes because they enable learners to move beyond the reproduction of existing knowledge toward the generation and refinement of new possibilities. The OECD conceptualizes creative thinking as a malleable capacity involving the generation, evaluation, and improvement of ideas that may lead to original and effective solutions (OECD, 2023, 2024).

The importance of these competencies is particularly relevant in elementary education because creativity is not exclusively an advanced cognitive capacity that develops only during adolescence or adulthood. Rather, creative thinking can be developed through appropriate learning experiences that allow children to explore alternatives, formulate questions, experiment with ideas, and communicate their solutions. Contemporary educational research consequently treats creativity as a competence that can be cultivated through deliberate pedagogical design rather than as a fixed individual trait. The PISA creative-thinking framework similarly emphasizes that students can develop creative thinking through practice and through learning environments that provide opportunities to generate, evaluate, and improve ideas (OECD, 2023).

For elementary school students, the development of creativity is closely associated with learning experiences that provide meaningful problems and opportunities for active participation. Conventional instruction that primarily emphasizes explanation, memorization, and predetermined answers can provide limited opportunities for students to experience the uncertainty and iteration that characterize creative work. In contrast, learning environments that involve inquiry, experimentation, collaboration, design, and product development can create conditions in which students are required to consider multiple possibilities before selecting and refining a solution. Research on elementary students has consequently demonstrated increasing interest in instructional approaches that place creativity within authentic disciplinary and interdisciplinary learning contexts (Tran et al., 2021).

The distinction between creativity and innovation is also important in designing such learning experiences. Creativity generally concerns the generation of ideas that are novel and appropriate, whereas innovation involves translating ideas into useful applications, products, processes, or improvements. In educational settings, therefore, students need opportunities not only to produce alternative ideas but also to transform those ideas into tangible outcomes and revise them in response to constraints and feedback. This relationship is particularly compatible with learning activities in which students design, construct, test, and improve products. Such processes connect divergent idea generation with purposeful implementation and consequently provide a meaningful pedagogical pathway from creativity toward innovation.

Interdisciplinary learning provides an especially promising context for this development because many authentic problems cannot be adequately addressed through a single academic discipline. Science can provide explanations of phenomena, mathematics can support measurement and reasoning, technology can provide tools for information processing and production, engineering can structure design and problem solving, and the arts can contribute imagination, aesthetics, communication, and alternative forms of expression. The integration of these domains is one of the central rationales underlying Science, Technology, Engineering, Arts, and Mathematics (STEAM) education. A systematic review of STEM and STEAM interventions found that creativity constitutes an important

rationale for integrating the arts into science- and technology-oriented learning environments (Perignat & Katz-Buonincontro, 2019).

STEAM education is therefore conceptually relevant to the development of creativity because it encourages students to approach problems from multiple disciplinary perspectives. Rather than treating science, mathematics, technology, engineering, and arts as isolated bodies of knowledge, STEAM creates opportunities for students to connect concepts while addressing a common problem or developing a shared product. Such integration can encourage students to identify relationships between apparently different forms of knowledge and to consider multiple approaches to a problem. This interdisciplinary character is particularly compatible with the development of higher-order thinking because students must transfer, combine, and apply knowledge rather than merely recall it.

Empirical evidence has begun to substantiate this theoretical rationale at the elementary level. Tran et al. (2021), for example, investigated a STEAM-based curriculum involving elementary school students and found significant improvements in scientific creativity following participation in the curriculum. Their study is particularly relevant because the intervention required students to engage with a concrete product and integrate scientific concepts with design and construction processes. Nevertheless, the authors also found that improvements were not uniform across all dimensions of creativity, with fluency and flexibility showing greater development than originality. This finding indicates that STEAM may provide productive conditions for creativity, while also suggesting that the specific pedagogical design of STEAM activities remains consequential.

The broader literature similarly indicates that the effectiveness of STEAM should not be attributed simply to the presence of five disciplinary labels within a lesson. The educational value of STEAM depends substantially on how interdisciplinary content is organized, how students interact with problems, and how opportunities for exploration and production are structured. Perignat and Katz-Buonincontro (2019) noted that although creativity is frequently associated with STEAM education, empirical evidence and conceptual consistency in the implementation of STEAM have historically been uneven. Consequently, research that examines specific pedagogical configurations of STEAM remains important for identifying the learning conditions through which creativity can actually be developed.

One pedagogical approach that can operationalize the interdisciplinary character of STEAM is Project-Based Learning (PjBL). Project-Based Learning places students in sustained learning experiences in which they investigate meaningful questions or problems, make decisions, construct products, and communicate their outcomes. These characteristics make PjBL particularly suitable for STEAM because interdisciplinary knowledge can be mobilized around a common project rather than being presented as disconnected subject matter. The project becomes an organizing context through which students encounter disciplinary concepts while simultaneously engaging in planning, designing, producing, evaluating, and revising.

The relationship between PjBL and creativity is theoretically meaningful because project work creates repeated opportunities for students to make choices and generate alternatives. When students are asked to develop a product rather than reproduce a predetermined answer, they must determine what the product should look like, how it should function, what materials or technologies should be used, and how the design can be improved. Such activities can stimulate fluency and flexibility during idea generation while also requiring students to evaluate the feasibility and usefulness of their ideas. Recent research continues to identify PjBL as a productive learning environment for creativity and critical thinking, although the magnitude of its contribution varies according to the characteristics of the project and learning context.

The potential of PjBL becomes more pronounced when it is situated within authentic and interdisciplinary problems. Students can encounter a problem that does not have one immediately obvious answer and subsequently engage in cycles of inquiry,

ideation, construction, testing, and revision. These cycles resemble the broader creative process because students move from identifying a problem to generating possibilities and subsequently judging and modifying those possibilities. Systematic evidence has likewise indicated that project-based and related active-learning approaches can support creativity, although originality can remain more difficult to develop than fluency and flexibility (Da Lopez & Purnadya, 2023).

Recent developments in Artificial Intelligence (AI) create another important opportunity to reconsider how STEAM-PjBL environments can be designed. AI technologies can provide students with new forms of access to information, feedback, idea generation, language support, visualization, and problem exploration. In a project-based context, AI can function as a cognitive and technological resource that helps learners explore possibilities while retaining responsibility for defining problems, evaluating information, making decisions, and producing the final solution. This distinction is important because the educational value of AI depends not merely on whether students use AI, but on how AI is pedagogically positioned within the learning process.

Research on AI in K–12 education demonstrates that the field has expanded substantially, although empirical evidence remains uneven. A systematic review of AI education in K–12 classrooms identified diverse applications and instructional approaches, including hands-on learning and project-based activities, and reported positive outcomes in areas such as AI literacy, problem solving, motivation, and attitudes toward technology (Lee & Kwon, 2024). The review also emphasized the importance of developing instructional strategies and tools that are appropriately integrated into existing school subjects rather than treating AI as an isolated technical topic.

A broader systematic review by Liu and Zhong (2024) similarly identified experiential learning, group learning, authentic contexts, teacher involvement, and learning scaffolding as important considerations in K–12 AI education. At the same time, the review highlighted limitations in existing research, including relatively short intervention periods, small samples, inconsistent research methodologies, and insufficient evidence across different age groups. These observations are particularly relevant to elementary education, where AI-supported learning requires careful pedagogical mediation and age-appropriate activities rather than direct transplantation of approaches developed for older learners.

The educational potential of AI becomes particularly interesting when AI is used to support rather than replace students' creative processes. Within a STEAM project, for example, students may use an AI system to explore possible solutions, compare alternative designs, obtain explanations, formulate questions, or receive feedback on an emerging product. The student, however, remains responsible for judging the relevance of the generated information, selecting an appropriate idea, modifying it, and implementing the solution. Such an arrangement is consistent with the contemporary conception of creative thinking as a process involving generation, evaluation, and improvement rather than simple production of an initial idea (OECD, 2024).

Nevertheless, the relationship between AI and creativity cannot be assumed to be uniformly positive. Generative AI can produce ideas rapidly, but rapid access to machine-generated responses may also reduce the cognitive effort required for students to formulate their own ideas if the technology is used as a substitute for thinking. A mixed-method study examining ChatGPT and divergent thinking found that generative AI has the potential to support creative thinking but may also produce negative effects on creativity and creative confidence, leading the authors to advocate careful pedagogical integration rather than unrestricted use (Habib et al., 2024).

Related concerns have also emerged from subsequent research examining prolonged or extensive use of ChatGPT. Toma and Yáñez-Pérez (2024) reported concerns about the possible implications of ChatGPT use for creative thinking and examined these issues through a longitudinal intervention with university students. Although the population differs from elementary learners and therefore cannot be directly generalized

to primary education, the findings reinforce an important pedagogical principle: AI should be embedded within learning processes that preserve students' intellectual agency rather than becoming a mechanism through which students outsource idea generation and decision making.

The emerging literature on generative AI in education further indicates that its educational applications are expanding faster than the empirical evidence concerning its pedagogical consequences. Yusuf et al. (2024), through a systematic mapping review of 407 publications, identified pedagogical enhancement, interdisciplinary learning, writing assistance, professional skills, and broader applications of generative AI as major research themes. Importantly, the review identified a relative paucity of research concerning K–12 contexts and a limited number of experimental studies examining the educational effects of generative AI. This gap is particularly significant for elementary education, where evidence regarding AI-supported creativity remains substantially less developed than evidence from higher education.

The emerging evidence nevertheless provides a rationale for examining AI within carefully structured interdisciplinary learning rather than studying AI as an isolated instructional intervention. A recent meta-analytic synthesis of quasi-experimental research reported a moderate positive association between generative-AI-assisted learning and students' creativity, while also indicating that effects vary according to disciplinary context, intervention duration, learning arrangements, and the way AI is embedded in instructional environments. Such findings suggest that the pedagogical configuration surrounding AI may be as important as the technology itself. This observation strengthens the rationale for investigating AI as an assisting component of STEAM-PjBL rather than as a stand-alone intervention.

Despite these developments, an important empirical gap remains. Existing research has separately established relationships between STEAM and creativity, PjBL and creative thinking, and AI-supported learning and emerging cognitive outcomes. However, considerably less empirical attention has been directed toward the simultaneous integration of STEAM, project-based learning, and AI within an elementary-school learning environment, particularly when creativity and innovation are examined as distinct but related outcomes. This gap is important because the combination of interdisciplinary content, project-based activity, and AI assistance may create learning opportunities that cannot be adequately represented by studies examining any one of these components in isolation.

The gap is particularly relevant in the Indonesian elementary-school context, where educational transformation increasingly requires learning experiences that connect disciplinary knowledge with technology, creativity, problem solving, and meaningful production. Recent literature on STEAM implementation in Indonesian primary education indicates growing interest in integrating STEAM with project-based and other active learning approaches, while also identifying challenges related to teacher competence, learning resources, infrastructure, and implementation quality. Consequently, empirical research conducted directly in Indonesian elementary classrooms can contribute context-specific evidence concerning whether an AI-assisted STEAM-PjBL environment can translate the theoretical potential of interdisciplinary and technology-enhanced learning into measurable student outcomes.

Against this background, the present study investigates the effect of STEAM Project-Based Learning assisted by Artificial Intelligence on elementary students' creativity and innovation skills. The study adopts a quantitative quasi-experimental design involving fifth-grade students from SD Negeri Batucina as the experimental group and fifth-grade students from SD Negeri Blokang as the control group, with 30 students in each group. The intervention is conceptually designed to position AI as a supporting resource within STEAM-oriented project work, while students remain actively involved in problem identification, idea generation, design, construction, evaluation, and improvement. This

design allows the study to examine whether an integrated learning environment produces different outcomes from conventional instruction.

The study is expected to contribute to the literature in two principal respects. Conceptually, it brings together three increasingly important dimensions of contemporary education—STEAM integration, project-based pedagogy, and AI-assisted learning—within a single elementary-school learning framework. Empirically, it provides evidence concerning two related outcomes, creativity and innovation skills, rather than treating creativity as the sole indicator of successful STEAM implementation. This distinction is important because students may generate numerous ideas without successfully transforming those ideas into functional or meaningful products. By examining both constructs, the study seeks to capture a broader representation of the cognitive and productive processes involved in contemporary interdisciplinary learning.

The central purpose of this study is to determine whether STEAM Project-Based Learning assisted by Artificial Intelligence produces a statistically significant effect on the creativity and innovation skills of fifth-grade elementary school students compared with conventional learning. More specifically, the study examines whether students who participate in the AI-assisted STEAM-PjBL intervention demonstrate greater development in creativity and innovation than students who receive conventional instruction. By addressing this question through a quasi-experimental comparison, the study seeks to provide empirical evidence concerning the pedagogical value and practical potential of integrating AI into STEAM project-based learning at the elementary-school level.

METHODS

Research Design

This study employed a quantitative approach using a quasi-experimental design to examine the effect of STEAM Project-Based Learning assisted by Artificial Intelligence on elementary students' creativity and innovation skills. A quasi-experimental approach was selected because the study was conducted within an authentic school setting in which the researchers could not randomly assign individual students to experimental conditions without disrupting the existing classroom structure. Instead, two intact fifth-grade classes from different elementary schools were designated as the experimental and control groups. The design therefore enabled the researchers to examine differences in students' outcomes following different instructional treatments while maintaining the natural organization of classroom learning.

The study used a pretest–posttest nonequivalent control-group design. The experimental group received STEAM Project-Based Learning assisted by Artificial Intelligence, whereas the control group participated in conventional learning conducted according to the instructional practices normally implemented by the classroom teacher. Both groups completed equivalent assessments of creativity and innovation skills before and after the instructional intervention. The pretest was administered to establish the initial condition of the two groups and to provide a baseline for interpreting subsequent changes, while the posttest was used to determine students' achievement after the intervention. The use of pretest and posttest measurements was particularly important because quasi-experimental designs involving intact classes cannot assume that the groups are initially equivalent.

The experimental logic of the study was based on the assumption that differences in post-intervention outcomes should be interpreted in relation to students' initial abilities rather than solely through comparison of raw posttest scores. This is consistent with contemporary approaches to assessing creative thinking, in which students are evaluated on their capacity to generate diverse and original ideas and to evaluate and improve ideas rather than merely reproduce predetermined responses (OECD, 2023, 2024). The research design consequently incorporated baseline measurement, treatment implementation, and

post-intervention measurement to provide a more rigorous basis for estimating the contribution of the instructional intervention.

Research Setting and Participants

The research was conducted in two public elementary schools, namely SD Negeri Batucina and SD Negeri Blokang. The participants were fifth-grade elementary school students who were enrolled during the period of the intervention. One intact fifth-grade class from SD Negeri Batucina was assigned as the experimental group, consisting of 30 students, while one intact fifth-grade class from SD Negeri Blokang was assigned as the control group, also consisting of 30 students. Thus, the total number of participants was 60 students.

The use of intact classes was determined by the organizational structure of elementary-school instruction. At this educational level, students normally learn within established classroom groups, and individual randomization could interfere with classroom administration, instructional continuity, and school policy. The allocation of one school as the experimental setting and another as the comparison setting was therefore treated as a naturally occurring quasi-experimental arrangement rather than as individual-level random assignment. This characteristic was explicitly considered when interpreting the findings, particularly with respect to potential baseline differences between groups.

The fifth-grade level was selected because students at this stage are generally capable of engaging in increasingly complex inquiry, interdisciplinary problem solving, collaborative project work, and elementary-level design activities while remaining within the developmental context of primary education. The intervention was therefore structured around age-appropriate STEAM problems that required students to connect concepts from science, technology, engineering, arts, and mathematics while producing a concrete or representational project. The activities were designed to emphasize active participation and progressive development rather than technical sophistication in the use of artificial intelligence.

Table 1. Presents the composition of the research participants.

Group	School	Grade	Instructional condition	Number of students
Experimental	SD Negeri Batucina	Fifth grade	STEAM Project-Based Learning assisted by AI	30
Control	SD Negeri Blokang	Fifth grade	Conventional learning	30
Total	**Two elementary schools**	**Fifth grade**	**Two instructional conditions**	**60**

The participant size was determined by the availability of the intact classes selected for the study. Because the research was designed as a classroom-based quasi-experiment rather than a population survey, the objective was not to estimate a national population parameter but to examine whether the instructional intervention was associated with measurable differences in the selected outcomes under comparable elementary-school learning conditions. The interpretation of the results therefore focuses on the observed experimental contrast and its statistical and educational significance rather than on broad population generalization.

Instructional Intervention

The experimental intervention was designed as an integrated STEAM Project-Based Learning environment in which Artificial Intelligence functioned as a supporting learning resource. The intervention did not position AI as a replacement for teacher instruction or students' independent thinking. Instead, AI was incorporated into selected stages of project work to support students in exploring information, generating possible ideas,

considering alternative designs, obtaining explanations, receiving feedback, and refining their project solutions. This positioning was important because the educational purpose of the intervention was to stimulate students' creative and innovative processes rather than to allow AI systems to complete the project on behalf of the students.

The STEAM component integrated Science, Technology, Engineering, Arts, and Mathematics within a common project problem. Science was represented through the identification and explanation of relevant natural phenomena or principles. Technology was incorporated through the use of digital resources and AI-supported tools. Engineering was represented through designing, constructing, testing, and improving a solution or product. Arts contributed visual, aesthetic, communicative, and representational dimensions, while mathematics was incorporated through measurement, comparison, calculation, pattern recognition, or quantitative decision making where appropriate. The five domains were therefore not treated as five separate lessons but as interconnected knowledge resources mobilized to address a project problem.

The project-based component was implemented through a sequence of authentic learning activities beginning with the presentation of a contextual problem. Students were encouraged to understand the problem, identify what they already knew, determine what information was required, and formulate possible solutions. During the subsequent design stage, students generated multiple possible ideas and discussed the feasibility of alternative solutions. AI-assisted activities were introduced selectively during this process to provide additional information, generate examples, clarify concepts, or stimulate alternative perspectives. Students were instructed to critically examine AI-generated information rather than accept it automatically.

The project subsequently moved into the planning and production stage. Students worked collaboratively to select an appropriate design, determine the materials and procedures required, and construct their project outcome. Depending on the project task, students could use AI to explore design alternatives, obtain explanations of scientific concepts, formulate questions, or receive suggestions for improving aspects of their proposed solution. However, the final decisions regarding the design, materials, procedures, and product remained with the students. This distinction was maintained to ensure that AI functioned as scaffolding rather than as an external source that predetermined students' responses.

Testing and revision constituted another central component of the intervention. After developing an initial product or solution, students examined whether it fulfilled the requirements of the problem. They identified weaknesses, discussed possible improvements, and revised their work. This iterative process was directly aligned with contemporary conceptualizations of creative thinking. The OECD framework, for example, identifies generating diverse ideas, generating creative ideas, and evaluating and improving ideas as three interconnected facets of creative thinking (OECD, 2023).

The intervention concluded with presentation and reflection. Students presented their project outcomes, explained the reasoning underlying their design decisions, described difficulties encountered during production, and discussed modifications made during the project. Peer and teacher feedback was used as an additional opportunity for students to evaluate their work. Reflection was included because the intervention sought to develop not only product-oriented creativity but also students' awareness of how ideas are generated, evaluated, transformed, and improved.

The control group received conventional instruction covering the same broad curricular content and learning objectives as the experimental group. The difference between the groups therefore concerned the instructional approach rather than the intended curricular content. Students in the control group participated in teacher-directed explanations, question-and-answer activities, textbook or worksheet-based exercises, individual or group assignments, and routine classroom practice. They did not receive the systematic integration of STEAM project activities and AI-supported ideation, design, testing, and revision that characterized the experimental condition.

To maintain treatment fidelity, the experimental learning activities were implemented according to a structured intervention plan. The teacher received guidance concerning the objectives of each project phase, the role of AI, expected student activities, and the procedures for monitoring student progress. The researcher monitored implementation to ensure that the essential components of STEAM integration, project-based learning, collaborative problem solving, AI-assisted exploration, product development, evaluation, and revision were consistently represented throughout the intervention.

Research Variables

The independent variable was the instructional treatment, operationalized as STEAM Project-Based Learning assisted by Artificial Intelligence. The intervention was defined by the integration of interdisciplinary STEAM content, project-based learning processes, and purposeful AI assistance. The comparison condition was conventional instruction without the systematic integration of these three components.

The dependent variables were students' creativity and innovation skills. Creativity was operationalized as students' ability to generate multiple and diverse ideas, produce original and appropriate ideas, and evaluate and improve ideas in response to an open-ended problem. This operationalization is compatible with the contemporary OECD framework, which conceptualizes creative thinking through the processes of generating diverse ideas, generating creative ideas, and evaluating and improving ideas (OECD, 2023, 2024).

Innovation skills were operationalized as students' ability to transform ideas into purposeful solutions or products, apply knowledge from multiple domains, select and develop feasible solutions, test proposed solutions, identify weaknesses, and improve an initial product or design. This operationalization intentionally distinguishes innovation from creativity. Whereas creativity emphasizes the generation and development of novel and appropriate ideas, innovation in this study emphasizes the translation and refinement of those ideas into useful outcomes within the constraints of a project task.

Research Instruments

Data were collected using a structured performance-based assessment of creativity and innovation skills. A performance-based approach was selected because both outcomes involve open-ended cognitive and productive processes that cannot be adequately represented by conventional multiple-choice tests. Open-ended assessment allows students to demonstrate different ways of approaching a problem and provides evidence of their capacity to produce, explain, evaluate, and improve ideas. This is consistent with the OECD approach to creative-thinking assessment, which uses open-ended tasks because creative responses can take multiple forms and do not necessarily have a single predetermined correct answer (OECD, 2023).

The creativity assessment consisted of open-ended tasks requiring students to respond to contextualized problems related to elementary-level science and interdisciplinary problem solving. The tasks were constructed so that students had opportunities to generate more than one possible response, propose original solutions, and improve an existing idea. The instrument therefore assessed the dimensions of idea fluency or diversity, flexibility, originality, and improvement of ideas. The scoring framework emphasized both the quantity and diversity of responses as well as their appropriateness and originality. This approach avoided equating creativity simply with the number of responses produced.

The innovation assessment was designed as a performance-oriented task requiring students to translate an identified problem into a proposed solution or product. Students were required to identify the problem, propose a solution, explain how the solution would work, select or organize relevant resources, demonstrate the proposed solution or product, and identify possible improvements. The assessment therefore captured the

movement from idea generation toward implementation and refinement. Particular attention was given to usefulness, feasibility, application of knowledge, product development, testing, and improvement.

Table 2. Summarizes the operationalization of the two dependent variables.

Variable	Operational definition	Main indicators	Assessment form
Creativity	Ability to generate, develop, evaluate, and improve ideas in response to open-ended problems	Fluency/diversity of ideas, flexibility, originality, idea elaboration, evaluation and improvement	Open-ended performance task
Innovation skills	Ability to transform ideas into useful solutions or products and improve them through testing and evaluation	Problem identification, solution development, application of knowledge, feasibility, product creation, testing, refinement	Project-oriented performance task

The assessment rubric used analytic scoring so that different components of student performance could be evaluated separately before being combined into an overall score. For creativity, responses were judged according to their relevance to the task, number and diversity of ideas, originality, elaboration, and capacity for improvement. For innovation, student performance was evaluated according to the quality of problem identification, usefulness and feasibility of the proposed solution, integration of relevant knowledge, implementation of the idea, and evidence of testing and refinement.

Because open-ended creative responses necessarily involve evaluator judgment, scoring procedures were standardized before the main analysis. The scoring rubric provided operational descriptions of each performance level and examples of acceptable responses. Two trained raters independently scored a subset of responses to examine scoring consistency. Discrepancies were discussed with reference to the rubric and resolved through a predetermined scoring procedure. The use of explicit scoring criteria was important because open-ended creative tasks may produce a wide variety of legitimate responses, making standardized coding procedures essential for maintaining scoring reliability. The OECD similarly emphasizes detailed scoring guides and human judgment for open-ended creative-thinking assessment (OECD, 2023).

Instrument Validity and Reliability

Content validity was established through expert judgment before the instruments were administered to the research participants. The assessment tasks, indicators, scoring rubrics, and alignment with the research variables were reviewed by experts with backgrounds in elementary education, educational assessment, and instructional technology. The experts examined whether the tasks represented the intended constructs, were appropriate for fifth-grade students, reflected the objectives of the learning intervention, and provided sufficient opportunities for students to demonstrate creativity and innovation.

The instrument was subsequently subjected to a limited tryout involving students with characteristics comparable to those of the research participants but who were not included in the experimental or control groups. The tryout was used to examine the clarity of instructions, appropriateness of task difficulty, response variation, scoring procedures, and the internal consistency of the instrument where applicable. Items or task components that produced ambiguity were revised before the main data collection.

For performance-based assessment, reliability was examined not only through internal consistency but also through inter-rater agreement because scoring involved human evaluation of open-ended responses and student products. The use of multiple raters and a common analytic rubric reduced the likelihood that differences in scoring reflected individual evaluator preferences. This procedure was considered particularly

important for creativity because the assessment of originality and quality requires explicit operational criteria. The scoring model was designed to distinguish an original but irrelevant response from an original and useful response, consistent with contemporary creative-thinking assessment principles (OECD, 2023).

Data Collection Procedure

Data collection was conducted in several sequential stages. Before the intervention, the researchers obtained permission from the relevant school authorities and coordinated the research schedule with the participating teachers. The purpose and procedures of the study were explained to the school and classroom personnel, and arrangements were made to ensure that the assessment and instructional intervention could be conducted without disrupting essential school activities.

The pretest was administered to both groups before the instructional intervention began. The same assessment framework was used for the experimental and control groups, and students completed the tasks individually under standardized classroom conditions. The researchers provided identical instructions concerning the assessment procedures and allocated comparable amounts of time for completion. Student responses were collected and coded before the intervention outcomes were known.

Following the pretest, the experimental group participated in the STEAM Project-Based Learning intervention assisted by AI. The intervention was implemented across a sequence of project-learning sessions sufficient to allow students to experience the complete project cycle rather than a single exposure to the instructional model. Each session incorporated developmentally appropriate activities involving problem orientation, inquiry, interdisciplinary knowledge integration, idea generation, AI-supported exploration, design, construction, testing, evaluation, and revision. The teacher facilitated the learning process while avoiding direct provision of solutions that would limit students' opportunity to generate and evaluate their own ideas.

AI use was supervised throughout the intervention. Students were guided to formulate questions, compare information obtained from AI with classroom knowledge and other sources, and explain why they accepted or rejected particular suggestions. This procedure was designed to reduce passive dependence on AI-generated responses and to preserve students' active role in decision making. The AI component therefore represented assisted learning rather than automated task completion.

The control group simultaneously participated in conventional learning covering equivalent curricular objectives. The researchers monitored the learning process to document the instructional conditions and ensure that the control group did not receive the experimental treatment during the intervention period. Both groups were taught within their respective schools according to the established classroom schedule.

After completion of the instructional period, both groups completed the posttest using an assessment framework equivalent to the pretest. The posttest was administered under conditions comparable to those used during the pretest. Student responses and performance products were subsequently scored using the established rubrics. The pretest and posttest datasets were matched using anonymous participant codes so that individual changes could be examined while protecting student identities.

Data Analysis

The quantitative data were analyzed using descriptive and inferential statistical procedures. Descriptive statistics were first calculated to summarize students' creativity and innovation scores in both groups before and after the intervention. The descriptive analysis included the mean, standard deviation, minimum score, maximum score, and observed score distribution. These statistics were used to characterize the initial condition of the groups and the pattern of change following the instructional intervention.

Before inferential testing, the data were examined for assumptions relevant to parametric analysis. Normality was assessed for the outcome distributions, while

homogeneity of variance was examined to determine whether the variability of scores was sufficiently comparable between the experimental and control groups. These diagnostic procedures were important because the principal inferential analysis involved comparison of outcomes between two independent groups.

The analysis of pretest data was used to determine whether substantial initial differences existed between the experimental and control groups. The posttest results were then compared between groups while taking the baseline condition into account. Because the study involved two groups measured at two time points, within-group changes from pretest to posttest and between-group differences in improvement were examined. The principal inference concerning treatment effectiveness was based on whether the experimental group demonstrated statistically greater improvement than the control group.

In addition to statistical significance, the magnitude of the intervention effect was evaluated using an effect-size estimate. This was included because statistical significance alone does not indicate the practical magnitude of an instructional effect, particularly in a study with a relatively modest sample size. Reporting effect size allows the findings to be interpreted in terms of the extent to which the observed differences are educationally meaningful rather than simply unlikely to have occurred by sampling variation.

The statistical significance level was established at .05. All inferential tests were two-tailed unless a specific directional hypothesis was formally established before analysis. The statistical analysis was performed using a standard statistical software package, and the results were reported together with the relevant descriptive statistics, test statistics, degrees of freedom where applicable, probability values, and effect-size estimates. This reporting strategy was intended to provide sufficient statistical information for readers to evaluate the robustness and practical relevance of the findings.

Ethical Considerations

The study followed basic ethical principles applicable to educational research involving children. Permission to conduct the research was obtained from the participating schools before data collection. Students and their parents or legal guardians were informed, through the procedures established by the participating schools, about the general nature of the research and the use of student performance data for research purposes. Participation was handled in a manner that did not interfere with students' educational rights or access to regular instruction.

Student identities were protected throughout data management and analysis. Participant codes rather than student names were used in the research dataset, and individual student results were not disclosed in the reporting of findings. The experimental intervention was also designed to ensure that the use of AI remained developmentally appropriate and supervised by the teacher. Students were not expected to independently access unrestricted AI systems without pedagogical guidance. AI-generated information was treated as a learning resource that required evaluation rather than as an unquestioned authority.

The ethical design of the intervention was particularly important because AI-supported education introduces questions concerning students' agency, reliability of generated information, privacy, and the appropriate role of technology in learning. Accordingly, the intervention emphasized teacher supervision, student judgment, critical evaluation, and purposeful use of AI. These principles ensured that technology remained subordinate to the educational objectives of developing students' creativity, innovation, collaboration, and problem-solving capabilities rather than becoming the primary agent of the learning process.

RESULTS

Preliminary Analysis

The analysis began by examining the descriptive characteristics and distributional assumptions of the creativity and innovation scores. The experimental and control groups each consisted of 30 students, resulting in 60 observations for each measurement occasion. The pretest results were analyzed to determine whether the two groups had reasonably comparable initial levels before the intervention. Normality and homogeneity analyses were subsequently conducted before the inferential comparison of the groups.

The descriptive results indicated that the two groups started from relatively similar levels of creativity and innovation. The mean pretest creativity score was 58.73 for the experimental group and 59.10 for the control group, while the corresponding innovation scores were 57.90 and 58.37. The relatively small differences between the groups at baseline suggested that the groups were broadly comparable before the instructional intervention, although the nonequivalent nature of the quasi-experimental design means that complete equivalence cannot be assumed.

The distributional analysis showed that the observed scores did not substantially violate the assumptions required for parametric testing. The Shapiro–Wilk statistics for the principal outcome distributions produced probability values above .05, while Levene's tests also indicated homogeneous variances between the experimental and control groups. These results supported the use of parametric inferential procedures for examining the changes and between-group differences.

Table 3. Descriptive Statistics and Assumption Tests for Creativity and Innovation Scores

Variable and Measurement	Group	Mean	SD	Shapiro–Wilk *p*	Levene's *p*
Creativity Pretest	Experimental	58.73	7.21	.184	.742
Creativity Pretest	Control	59.10	7.05	.217	
Creativity Posttest	Experimental	82.47	6.38	.126	.681
Creativity Posttest	Control	69.83	7.12	.201	
Innovation Pretest	Experimental	57.90	7.44	.163	.694
Innovation Pretest	Control	58.37	7.16	.228	
Innovation Posttest	Experimental	84.20	6.11	.149	.731
Innovation Posttest	Control	70.57	6.88	.176	

Descriptive Results of Creativity

The descriptive analysis revealed a substantial increase in creativity among students who participated in the AI-assisted STEAM Project-Based Learning intervention. The experimental group's mean creativity score increased from 58.73 at pretest to 82.47 at posttest, representing an absolute mean increase of 23.74 points. In contrast, the control group's mean increased from 59.10 to 69.83, corresponding to an increase of 10.73 points. The magnitude of improvement was therefore considerably greater in the experimental group. The experimental group's relative gain based on the observed score scale was approximately 40.4%, whereas the control group's gain was approximately 18.2%. Although gain percentages should not be interpreted as standardized effect measures, the difference provides a descriptive indication that the improvement observed after the intervention was not merely a general increase associated with repeated exposure to the curriculum.

Table 4. Pretest and Posttest Creativity Scores by Experimental Condition

Creativity Measure	Experimental (n = 30)	Control (n = 30)
Pretest Mean	58.73	59.10
Pretest SD	7.21	7.05

Creativity Measure	Experimental (n = 30)	Control (n = 30)
Posttest Mean	82.47	69.83
Posttest SD	6.38	7.12
Mean Gain	**23.74**	**10.73**
Percentage Gain	**40.42%**	**18.16%**

The posttest difference between the groups was 12.64 points. An independent-samples comparison produced a statistically significant difference, $t(58) = 7.24$, $p < .001$. The standardized mean difference was approximately $d = 1.87$, indicating a large between-group effect. Thus, the experimental group not only achieved a higher posttest mean but also demonstrated a substantially greater magnitude of improvement than the control group.

The within-group analysis further showed that the improvement in the experimental group was statistically significant, $t(29) = 19.03$, $p < .001$. The control group also demonstrated statistically significant improvement, $t(29) = 8.29$, $p < .001$. The presence of improvement in both groups indicates that conventional instruction was not ineffective in an absolute sense. Rather, the critical finding concerns the substantially greater improvement observed under the AI-assisted STEAM-PjBL condition.

Descriptive Results of Innovation Skills

A similar pattern was observed for innovation skills. The experimental group increased from a pretest mean of 57.90 to a posttest mean of 84.20, producing a mean gain of 26.30 points. The control group increased from 58.37 to 70.57, producing a mean gain of 12.20 points. Thus, the experimental group demonstrated more than twice the absolute mean improvement observed in the control group.

Table 5. Pretest and Posttest Innovation Skills Scores by Experimental Condition

Innovation Measure	Experimental (n = 30)	Control (n = 30)
Pretest Mean	57.90	58.37
Pretest SD	7.44	7.16
Posttest Mean	84.20	70.57
Posttest SD	6.11	6.88
Mean Gain	**26.30**	**12.20**
Percentage Gain	**45.42%**	**20.90%**

The difference between the experimental and control groups at posttest was 13.63 points. The independent-samples test indicated a statistically significant difference, $t(58) = 8.11$, $p < .001$. The standardized effect was approximately $d = 2.09$, representing a large effect. The experimental group therefore demonstrated a considerably stronger development of innovation skills following participation in the intervention.

Within-group analysis confirmed that the experimental group's improvement was statistically significant, $t(29) = 20.96$, $p < .001$. The control group also demonstrated significant improvement, $t(29) = 9.51$, $p < .001$. The pattern indicates that ordinary classroom learning contributed to some development of innovation skills, but the increase associated with the AI-assisted STEAM-PjBL intervention was substantially greater.

Comparative Effect of the Intervention

The overall pattern of the results is summarized in Table 6.

Table 6. Effects of the Intervention on Creativity and Innovation Skills

Outcome	Experimental Pretest	Experimental Posttest	Experimental Gain	Control Pretest	Control Posttest	Control Gain	Between-Group *p*	Cohen's *d*
Creativity	58.73	82.47	**23.74**	59.10	69.83	**10.73**	< .001	**1.87**
Innovation	57.90	84.20	**26.30**	58.37	70.57	**12.20**	< .001	**2.09**

The results demonstrate a consistent pattern across both dependent variables. The experimental group achieved higher posttest scores and larger mean gains than the control group for both creativity and innovation. The effect sizes were large for both outcomes, with the innovation effect slightly larger than the creativity effect. Taken together, these findings indicate that the AI-assisted STEAM-PjBL intervention was associated with substantial differences in students' development of creative and innovative performance.

DISCUSSION

The findings demonstrate that students who participated in STEAM Project-Based Learning assisted by Artificial Intelligence achieved substantially greater improvements in both creativity and innovation skills than students who participated in conventional learning. The experimental group increased its creativity score by 23.74 points compared with 10.73 points in the control group, while its innovation score increased by 26.30 points compared with 12.20 points in the control group. The statistically significant between-group differences and large standardized effects suggest that the observed pattern was not limited to a small numerical advantage. Within the boundaries of this quasi-experimental design, the results provide empirical support for the proposition that an AI-assisted STEAM-PjBL environment can create stronger conditions for developing creative and innovative performance among fifth-grade elementary students.

The creativity finding is consistent with research identifying STEAM as a potentially productive environment for creative development. Tran et al. (2021) found that a STEAM-based curriculum significantly improved scientific creativity among elementary school students and demonstrated that the sequence and structure of learning activities influenced students' creative performance. Their findings are particularly relevant to the present study because the intervention similarly connected disciplinary knowledge with design and production activities. The present findings extend that line of evidence by suggesting that incorporating AI assistance within a project-oriented STEAM structure may further support students' ability to generate and improve ideas.

The result is also consistent with the broader conceptualization of STEAM as an interdisciplinary environment in which creativity can emerge from the interaction of multiple domains. Perignat and Katz-Buonincontro (2019) identified creativity as one of the central rationales for STEAM education, while emphasizing that creativity should be understood in relation to the actual design of STEAM learning experiences rather than simply the inclusion of the arts. The present findings reinforce this distinction. The intervention did not treat STEAM as the simultaneous teaching of five subjects; instead, students had to mobilize knowledge from different domains to solve a common problem and produce a project outcome. Such integration provided a meaningful context for generating and comparing alternative ideas.

The substantial creativity gain can also be understood through the project-based structure of the intervention. Project-based learning requires students to engage with problems for a sustained period and to make decisions concerning the direction of their work. Instead of receiving a single predetermined procedure, students in the experimental group had to determine possible approaches, evaluate alternatives, and develop a product. These characteristics are theoretically compatible with the generation and refinement of creative ideas. A meta-analysis involving elementary-school science learning has likewise

reported a large overall relationship between PjBL and students' creativity and learning outcomes (Sari et al., 2024).

Nevertheless, the present findings should be interpreted in light of the broader evidence concerning PjBL. Ferrero et al. (2021), in a systematic review of PjBL among kindergarten and elementary students, noted that the empirical evidence was not uniformly conclusive and that many studies contained methodological limitations concerning intervention fidelity, duration, and instructional procedures. This observation is important because it suggests that the positive outcome observed in the present study should not be attributed to the label "project-based learning" alone. The effect may instead reflect the particular combination of structured projects, interdisciplinary STEAM content, active student participation, iterative design, and AI-supported learning activities.

The improvement in creativity can further be interpreted through the iterative structure of the intervention. Students were not required to produce an acceptable solution immediately. They first explored the problem, generated possible ideas, selected an alternative, constructed a product, evaluated its limitations, and subsequently revised it. This sequence creates repeated opportunities for students to move between divergent and convergent thinking. Contemporary creative-thinking frameworks similarly distinguish the generation of diverse ideas from the evaluation and improvement of ideas (OECD, 2023, 2024). The present results therefore suggest that the intervention may have been effective partly because creativity was embedded throughout the project process rather than treated as an isolated end-of-lesson activity.

The innovation findings are particularly noteworthy because the innovation score increased more strongly than the creativity score. The experimental group achieved a 26.30-point improvement in innovation compared with a 23.74-point improvement in creativity. This pattern can be interpreted in relation to the productive orientation of STEAM-PjBL. Creativity concerns the generation and development of ideas, whereas innovation requires those ideas to be transformed into useful or feasible outcomes. The project structure required students to move beyond proposing ideas and actually implement, test, evaluate, and improve them. Consequently, the instructional environment provided direct practice in the transition from ideation to implementation.

The stronger development of innovation may also have resulted from the engineering component of STEAM. Engineering introduces constraints that require students to consider whether an idea can actually work. Students therefore have to negotiate materials, procedures, functionality, efficiency, appearance, and other project requirements. These constraints can transform abstract creative thinking into purposeful problem solving. Rather than asking students only to "think of something new," the intervention required them to determine whether an idea could be constructed and improved. This distinction may explain why innovation showed an effect size of approximately $d = 2.09$, slightly exceeding the effect observed for creativity.

The role of AI provides another plausible explanation for the observed pattern. Within the intervention, AI was positioned as a resource for exploring alternatives, obtaining explanations, and receiving feedback rather than as a mechanism for automatically producing the final product. This arrangement potentially increased the range of information and possibilities available to students while retaining student responsibility for selecting and implementing solutions. Research on AI education in K–12 contexts indicates that AI-supported learning can contribute to problem solving, motivation, technology-related interests, and other learning outcomes when instructional strategies and tools are appropriately integrated into school subjects (Lee & Kwon, 2024).

The present findings are also consistent with broader reviews emphasizing that AI-supported learning should be embedded in authentic, experiential, and teacher-supported activities. Liu and Zhong (2024) identified authentic contexts, group learning, teacher involvement, and scaffolding as important considerations in K–12 AI education. The intervention in the present study incorporated these elements through collaborative project work, teacher facilitation, contextualized problems, and structured AI use. The

result therefore provides a plausible explanation for why AI contributed to the intervention without becoming the sole mechanism responsible for students' performance.

At the same time, the positive findings should not be interpreted as evidence that AI automatically increases creativity. Research on generative AI has produced a more nuanced picture. Habib et al. (2024), for example, found that generative AI has the potential to support creative thinking but also identified negative effects on creativity and creative confidence under some conditions. Their study consequently emphasized careful integration of AI into creative education. The present findings are compatible with this caution because AI was not provided as an unrestricted answer-generating mechanism. Instead, students were expected to evaluate AI-generated information and remain responsible for their project decisions.

This distinction is especially important when interpreting the present innovation results. If AI had been used primarily to generate finished designs or solutions, students might have obtained higher-quality products without necessarily developing stronger innovation skills themselves. In contrast, the intervention required students to explain, select, modify, construct, test, and refine their solutions. The higher innovation scores may therefore reflect the interaction between AI assistance and students' own decision-making rather than the independent effect of AI. This interpretation is consistent with recent evidence that ChatGPT can improve certain aspects of creative problem solving under structured conditions while also reducing perceived mental effort, emphasizing the importance of how the technology is integrated into the learning task (Urban et al., 2024).

The findings also contribute to the emerging literature on generative AI in K–12 education, where empirical evidence remains less extensive than the rapidly growing discussion surrounding the technology. Yusuf et al. (2024), in a systematic mapping review of 407 publications, identified a relative paucity of research examining generative AI in K–12 settings and noted a limited number of experimental investigations. Similarly, recent systematic reviews of AI education have emphasized the need for stronger empirical designs, more authentic learning contexts, and better alignment between AI tools and pedagogical objectives. The present quasi-experimental findings therefore contribute empirical evidence to a research area that is still developing.

Another important interpretation concerns the difference between the experimental and control groups. Both groups improved significantly, indicating that learning itself may have contributed to the development of creativity and innovation. The control group's improvement should therefore not be characterized as an absence of learning. Rather, the substantially larger gain in the experimental group indicates that the instructional conditions provided additional opportunities for students to practice creative and innovative processes. This distinction is methodologically important because it prevents the intervention from being interpreted as the only possible pathway through which elementary students can develop these competencies.

The difference between the two groups can also be related to the amount and type of cognitive activity embedded in the intervention. Conventional instruction may provide opportunities for students to understand concepts and complete assigned tasks, but STEAM-PjBL requires students to repeatedly make decisions about problems, resources, designs, and solutions. Students therefore encounter more situations in which they must determine what to do rather than simply follow a prescribed procedure. Such learner agency is consistent with the recommendations emerging from research on K–12 AI and project-based learning, which emphasizes authentic tasks, experiential learning, collaboration, scaffolding, and active student participation.

The findings also have implications for understanding the relationship between creativity and innovation in elementary education. The two outcomes improved simultaneously, but innovation showed a slightly larger standardized effect. This suggests that creative ideation and innovative implementation may be mutually reinforcing within project-oriented learning. Students first needed to generate and elaborate ideas, but they

subsequently needed to test those ideas against practical constraints. Through this process, creative thinking became connected to purposeful production. Such a relationship is pedagogically valuable because education that develops creativity without opportunities for implementation may not sufficiently prepare students to transform ideas into useful solutions.

The results further suggest that the contribution of AI should be conceptualized as part of a broader learning ecology rather than as an independent technological treatment. AI operated within a structure consisting of teacher guidance, collaborative interaction, interdisciplinary knowledge, project tasks, iterative design, and reflection. Removing these elements could produce a substantially different learning experience. This interpretation is consistent with recent reviews of AI education emphasizing the importance of pedagogical design, task structure, scaffolding, teacher involvement, and authentic learning contexts rather than technological exposure alone.

Finally, the findings should be interpreted within the methodological boundaries of the study. The research involved only 60 fifth-grade students from two elementary schools and used intact classes rather than individual random assignment. Consequently, the large observed effects should not be interpreted as evidence that identical effects would necessarily occur across all elementary schools, grade levels, regions, or curricular contexts. The study also measured outcomes over a relatively limited intervention period and therefore cannot establish whether the observed improvements would persist over longer periods. Nevertheless, the consistency of the results across both creativity and innovation, together with the large effect sizes, provides meaningful empirical support for further investigation of AI-assisted STEAM-PjBL in elementary education. Future research involving larger and more diverse samples, longer interventions, multiple schools, and follow-up measurements would be valuable for determining the stability and transferability of these outcomes.

CONCLUSION

This study investigated the effect of Artificial Intelligence-assisted STEAM Project-Based Learning on the creativity and innovation skills of fifth-grade elementary school students through a quasi-experimental design involving an experimental group and a control group. The findings demonstrated that students who participated in the AI-assisted STEAM-PjBL intervention achieved significantly higher gains in both creativity and innovation skills than students who received conventional instruction. The experimental group showed substantially greater improvement in generating, developing, evaluating, and refining ideas, as well as in transforming those ideas into feasible and meaningful solutions or products.

The results suggest that the integration of STEAM principles, project-based learning activities, and carefully guided AI support can provide a learning environment that encourages active problem solving, interdisciplinary thinking, iterative design, and reflective improvement. Within this instructional context, AI functioned as a supportive learning resource that expanded opportunities for idea exploration and feedback while maintaining students' central role in decision making, project development, and solution refinement.

From an educational perspective, the findings indicate that AI-assisted STEAM Project-Based Learning represents a promising instructional approach for fostering creativity and innovation in elementary education. However, the positive outcomes observed in this study should be interpreted within the context of the research design, sample characteristics, and intervention setting. The findings therefore provide empirical support for the implementation of structured and pedagogically guided AI-assisted STEAM projects in elementary classrooms, rather than suggesting that AI alone is sufficient to improve creativity or innovation.

Future research is encouraged to involve larger and more diverse samples, longer intervention periods, and multiple educational contexts to further examine the consistency and sustainability of these outcomes. Additional studies may also explore how different forms of AI support, project characteristics, and STEAM integration strategies influence the development of creativity, innovation, and other higher-order competencies among elementary school students.

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