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Teaching for Creativity through an AI-Assisted C-R-E-A-T-E Model in Chemistry Project-Based Learning: A TCOF-Based Feasibility Evaluation

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Abstract

Creativity-oriented chemistry learning requires instructional designs that enable students to generate, refine, transform, and evaluate ideas through meaningful scientific inquiry. However, the success of such learning depends not only on the availability of innovative models and digital tools but also on teachers' ability to facilitate creativity-supportive classroom practices. This study aimed to evaluate the pedagogical feasibility of an Artificial Intelligence-assisted C-R-E-A-T-E learning model in a chemistry project-based learning activity on natural paint production. The study employed a descriptive-evaluative design with a design-based research orientation. Participants included 16 Grade XI students, three trained observers, three chemistry teachers as validators, and two expert lecturers. Data were collected using the Teaching for Creativity Observation Form (TCOF), which evaluates four dimensions of creativity-supportive teaching: questioning techniques, teacher responses to students' ideas, classroom activities that foster creativity, and whole-lesson methods that support creative learning. The data were analyzed using descriptive percentages and interpretive categories. The results showed that questioning techniques and creativity-oriented classroom activities reached full implementation, each scoring 100%. Teacher responses to students' ideas reached a high level of implementation at 82%, whereas whole-lesson implementation of the creative learning model remained moderate at 50%. These findings indicate that the AI-assisted C-R-E-A-T-E model is pedagogically feasible for supporting creativity-oriented chemistry instruction, particularly in strengthening questioning strategies and project-based creative activities. However, deeper scaffolding is still required in imagination-building, reflective evaluation, and metacognitive guidance. The study contributes to chemistry education by demonstrating how AI can be positioned as a cognitive support tool within a structured creative learning model, while emphasizing that teacher mediation remains central to meaningful and responsible AI integration.

Keywords: Artificial Intelligence; Chemistry Learning; C-R-E-A-T-E Model; Teaching for Creativity; TCOF

INTRODUCTION

Creativity has become one of the most essential competencies in contemporary education because it enables learners to respond productively to complex problems, uncertain situations, and rapidly changing social and technological environments (OECD, 2013, 2019; UNESCO, 2018). In the context of twenty-first-century learning, creativity is no longer viewed merely as an artistic capacity, but as a multidimensional cognitive and practical competence that supports innovation, problem-solving, scientific reasoning, collaboration, and adaptive thinking (BFK, 2015; OECD, 2024; Thornhill-Miller et al., 2023). Within educational settings, creativity involves the ability to generate multiple ideas, approach problems from different perspectives, produce original responses, elaborate ideas into meaningful outcomes, and evaluate the relevance and feasibility of those ideas (Dumont & Willis, 2008; Guilford, 1967; OECD, 2024). Classic theories of creativity have emphasized core dimensions such as fluency, flexibility, originality, and elaboration, while more recent educational perspectives highlight the importance of reflective evaluation and contextual usefulness in determining whether an idea can be considered creative (Kaufman & Beghetto, 2009; Runco & Jaeger, 2012; van Broekhoven, 2025; Yuan, 2023). Therefore, creativity-oriented learning should not only encourage students to produce novel ideas but also guide them to refine, justify, and apply those ideas in meaningful learning contexts (Heard et al., 2023; Lloyd-Cox et al., 2022; van Broekhoven, 2025).

In science education, creativity plays a particularly significant role because scientific learning requires students to observe phenomena, formulate questions, construct explanations, design investigations, interpret evidence, and propose solutions (Barata et al., 2024; Pahrudin et al., 2025; Pinar et al., 2025). Chemistry, as one of the central domains of science education, provides rich opportunities for cultivating creativity because it connects abstract concepts with observable materials and real-life applications (Jamal et al., 2025; Johnstone, 2010; Moju et al., 2025; Qian et al., 2023). Understanding chemistry requires students to move between macroscopic phenomena, submicroscopic explanations, and symbolic representations (Kapici, 2023; Talanquer, 2011; L. Wang et al., 2022). This representational complexity demands flexible thinking, conceptual integration, and the ability to transform abstract knowledge into practical understanding (Ripsam & Nerdel, 2024; Sim & Daniel, 2014; Treagust et al., 2003). Consequently, chemistry learning should not be limited to memorizing definitions, formulas, and classifications; it should also provide opportunities for students to investigate materials, design procedures, test ideas, and evaluate scientific products (Byusa et al., 2022; Rahmawan et al., 2025).

One chemistry topic that can be meaningfully connected with creativity-oriented learning is colloid (Al-Idrus et al., 2019; Awaliyah & Rusmini, 2023; Azumi et al., 2024). Colloid concepts are closely related to everyday phenomena, including paint, milk, fog, cosmetics, food products, and pharmaceutical materials (Guo et al., 2025; Matchett, 2020; Tadros, 2013; B. Wang et al., 2024). Learning colloids through project-based activities allows students to understand not only theoretical definitions but also the practical characteristics of dispersed systems, dispersion media, particle stability, and product formulation (Desiana et al., 2022; Ginting et al., 2023; Jacob et al., 2022). The activity of making natural paints, for example, offers an authentic context in which students can explore natural pigment sources, extraction techniques, mixture stability, and the quality of the resulting product. Through this activity, students are expected to connect chemistry concepts with environmental awareness, local resources, and creative product development. Such learning experiences can support students in developing scientific understanding while also encouraging creative exploration.

However, the development of creativity in chemistry classrooms does not occur automatically simply because students are involved in projects. Creativity-oriented project-based learning requires intentional pedagogical design and strong teacher facilitation (Aisyah & Novita, 2025; Hmelo-Silver, 2004). Teachers need to create learning environments that allow students to ask questions, explore alternatives, express ideas, make decisions, test procedures, and reflect on outcomes. In this sense, teachers play a central role in transforming project-based activities into meaningful creative learning experiences. Without appropriate teacher guidance, project activities may become procedural tasks that emphasize product completion rather than creative thinking, conceptual understanding, and reflective learning. Therefore, the success of creativity-oriented chemistry instruction depends significantly on teachers' ability to facilitate creativity-supportive practices.

Teaching for creativity involves several important pedagogical behaviors (Rios-Atehortua et al., 2024). Teachers must be able to use open-ended and probing questions that stimulate students' thinking, respond constructively to diverse ideas, encourage students to elaborate their responses, and provide opportunities for students to revise and refine their work (Al-Abdali & Al-Balushi, 2016; Sowden et al., 2025; Su & Yang, 2023). In addition, teachers should design classroom activities that support exploration, collaboration, experimentation, and reflection

(Markula & Aksela, 2022; Scott-Barrett et al., 2023; Strat et al., 2024). A creativity-supportive classroom also requires psychological safety, where students feel confident to express unusual ideas, take intellectual risks, and learn from mistakes (Han et al., 2022; Hansen et al., 2025). These conditions are especially important in science learning because students often hesitate to propose alternative explanations or experimental procedures when they fear being judged as incorrect. Therefore, teacher practices are a critical component in fostering creativity-oriented learning.

The C-R-E-A-T-E learning model provides a structured framework that can be used to support creativity-oriented instruction (Volosa et al., 2025; Wahyu & Kusrijadi, 2022, 2024). In this study, C-R-E-A-T-E refers to six learning stages: Constructing, Reflecting, Exploring, Analyzing, Transforming, and Evaluating (Volosa et al., 2025; Wahyu & Kusrijadi, 2024). These stages are designed to guide students from initial understanding to reflective product development. In the Constructing stage, students build foundational knowledge and identify the learning problem (Brod, 2021; Bryce & Blown, 2024; Rodger Bybee, 2018). In the Reflecting stage, students activate prior knowledge and examine their initial assumptions (Brod, 2021; Pedaste et al., 2015; Wahyu & Kusrijadi, 2024). In the Exploring stage, students investigate possible ideas, materials, and procedures (Volosa et al., 2025; Wahyu & Kusrijadi, 2024). In the Analyzing stage, students compare alternatives and connect their ideas with scientific principles (Markula & Aksela, 2022; Pedaste et al., 2015; Wahyu & Kusrijadi, 2022). In the Transforming stage, students convert ideas into concrete products or solutions. Finally, in the Evaluating stage, students assess the process, product, and scientific reasoning underlying their decisions (Markula & Aksela, 2022; Wahyu & Kusrijadi, 2022, 2024). This structure is relevant for chemistry project-based learning because it allows students to move systematically from conceptual understanding to creative application.

The integration of Artificial Intelligence into the C-R-E-A-T-E model can further enrich creativity-oriented learning when used appropriately. AI-based tools can support students in generating initial ideas, accessing information, comparing possible procedures, and refining project plans (Cooper, 2023; Kasneci et al., 2023; Ng et al., 2021). In the context of natural paint production, AI can assist students in identifying potential natural pigment sources, suggesting extraction procedures, comparing material properties, and providing prompts for reflection. However, the use of AI in education must be approached critically. AI should not be positioned as a substitute for student reasoning or teacher guidance. Instead, it should function as a cognitive support tool that helps students explore possibilities while still requiring them to verify information, apply scientific concepts, and make responsible decisions. Without adequate teacher mediation, AI use may lead to superficial learning, overreliance on machine-generated responses, or uncritical acceptance of inaccurate information (Kasneci et al., 2023; Ng et al., 2021).

For this reason, AI integration in chemistry learning requires not only digital access but also pedagogical and ethical readiness. Teachers need to guide students in formulating effective prompts, evaluating AI-generated information, connecting suggestions with chemistry concepts, and distinguishing between useful support and unsupported claims. In addition, students need to develop AI literacy, which includes understanding how AI works, how to use it responsibly, how to evaluate its outputs, and how to maintain academic integrity. When integrated within a structured model such as C-R-E-A-T-E, AI has the potential to support exploration and creativity. However, its educational value depends largely on how teachers facilitate its use in the classroom. Thus, evaluating teacher practices becomes essential for understanding the feasibility of AI-assisted creative learning.

To examine teacher practices in creativity-oriented classrooms, a valid observational framework is required. The Teaching for Creativity Observation Form (TCOF) provides such a framework because it focuses on observable teacher behaviors that support creativity in science classrooms. The TCOF consists of four main categories: questioning techniques, teacher responses to students' ideas, classroom activities that foster creativity, and whole-lesson methods that support creative learning (Beghetto & Kaufman, 2014; Valle-Muñoz et al., 2025). These categories are relevant to the implementation of the AI-assisted C-R-E-A-T-E model because they capture how teachers stimulate students' thinking, respond to ideas, organize learning activities, and maintain a coherent creativity-oriented instructional process. Therefore, the TCOF is appropriate for evaluating the pedagogical feasibility of teacher practices in implementing an AI-assisted creative learning model.

Although creativity, project-based learning, and AI integration have been widely discussed in educational research, studies that specifically examine teacher practices in implementing AI-assisted creative learning models in chemistry classrooms remain limited. Much of the existing literature focuses either on students' creativity outcomes, the general potential of AI in education, or the effectiveness of project-based learning. Less attention has been given to how teachers enact creativity-supportive pedagogy when AI is integrated into a structured learning model. This gap is important because the success of AI-assisted learning does not depend solely on the technology itself, but also on teachers' instructional decisions, questioning strategies, feedback practices, scaffolding, and ability to maintain students' autonomy and critical thinking.

The novelty of this study lies in the integration of three components: the C-R-E-A-T-E model as a structured creativity-oriented learning syntax, AI as a supervised cognitive support tool, and TCOF as an observational framework for evaluating teacher practices. Rather than claiming direct improvement in students' creativity without outcome-based evidence, this study focuses on the pedagogical feasibility of the model as reflected in observable creativity-supportive teaching practices. This focus is important because feasibility evaluation provides an initial basis for determining whether a learning model can be implemented meaningfully before further studies examine its effects on student creativity, conceptual understanding, or product quality.

Therefore, this study aims to evaluate the pedagogical feasibility of an AI-assisted C-R-E-A-T-E learning model in chemistry project-based learning through the Teaching for Creativity Observation Form. Specifically, the study analyzes the extent to which teachers implement creativity-supportive practices in questioning, responding to students' ideas, designing creative classroom activities, and conducting whole-lesson creativity-oriented instruction. The findings are expected to contribute to chemistry education by providing evidence on how AI-assisted project-based learning can be pedagogically structured and observed, while also identifying areas that require refinement, particularly in imagination-building, reflective evaluation, AI literacy, and metacognitive scaffolding.

METHODS

This study employed a descriptive-evaluative research design with a design-based research orientation (Dharmayana & Herawati, 2021; F. Wang & Hannafin, 2005). This design was selected because the study did not aim to test the causal effectiveness of the AI-assisted C-R-E-A-T-E model through an experimental comparison, but rather to evaluate the pedagogical feasibility of its classroom implementation based on observable teacher practices. The focus of the study was therefore directed toward how teachers implemented creativity-supportive teaching behaviors during chemistry project-based learning, as measured through the Teaching for Creativity Observation Form (TCOF). This methodological focus is consistent with the available data in the manuscript, which emphasize teacher practices and implementation quality rather than direct measurement of students' creativity outcomes.

The design-based research orientation was used to guide the development, implementation, evaluation, and refinement of the learning model in an authentic classroom context. In this study, design-based research was not applied as a long-term multi-cycle intervention, but as an instructional development framework consisting of four stages: preliminary analysis, instructional design, classroom implementation, and evaluation-refinement. The preliminary analysis stage focused on identifying the need for creativity-oriented chemistry learning and the potential role of AI as a cognitive support tool. The instructional design stage involved aligning the C-R-E-A-T-E learning syntax with a project-based chemistry activity on natural paint production. The implementation stage was conducted in a Grade XI chemistry classroom during the colloid topic. The evaluation-refinement stage was carried out by observing teacher practices using the TCOF framework and identifying strengths and areas requiring improvement.

The study was conducted in a senior high school chemistry classroom in Bandung, Indonesia. The learning activity involved 16 Grade XI students who participated in a project-based chemistry lesson on making natural paints. The topic was selected because it provides an authentic context for connecting colloid concepts with real-life applications. Through the natural paint project, students were expected to explore natural pigment sources, examine mixture formation, consider colloidal stability, and evaluate the quality of the resulting product.

The classroom implementation was observed by three trained observers from a Chemistry Education Study Program. These observers were responsible for independently completing the TCOF during the learning process. In addition, three chemistry teachers and two expert lecturers were involved as validators. The validators reviewed the relevance, clarity, and alignment of the learning design and observation instrument with the objectives of creativity-oriented chemistry instruction.

The learning intervention was designed using the AI-assisted C-R-E-A-T-E model. In this study, C-R-E-A-T-E refers to six instructional stages: Constructing, Reflecting, Exploring, Analyzing, Transforming, and Evaluating. The model was implemented in the context of a chemistry project on natural paint production, with AI positioned as a supervised cognitive support tool rather than an independent source of answers.

In the Constructing stage, the teacher introduced the problem of producing natural paints and guided students to connect the project with prior knowledge about mixtures, pigments, and colloids. In the Reflecting stage, students discussed their initial understanding, assumptions, and possible materials that could be used as natural pigment sources. In the Exploring stage, students used AI-supported inquiry to search for alternative natural materials, preparation methods, and potential procedures. In this stage, the teacher guided students to formulate appropriate prompts and compare AI-generated suggestions with available resources.

In the Analyzing stage, students examined the relevance of AI-generated information by connecting it with chemistry concepts, particularly dispersed phase, dispersion medium, colloidal stability, and the role of binding or dispersing agents. The teacher emphasized that AI-generated information should not be accepted automatically, but should be evaluated through scientific reasoning. In the Transforming stage, students developed procedures and produced natural paint samples based on their analysis. Finally, in the Evaluating stage, students reflected on the learning process, evaluated the quality of the product, and discussed the scientific validity of their decisions. The integration of AI was intended to support idea generation, information exploration, and procedural refinement. However, teacher mediation remained central throughout the learning process to ensure that AI use supported students' reasoning, creativity, and conceptual understanding rather than replacing them.

In this study, multi-creativity was defined as an integrated creative capacity consisting of five dimensions: fluency, flexibility, originality, elaboration, and evaluative reflection (Dumont & Willis, 2008; Guilford, 1967). Fluency refers to the ability to generate multiple ideas or alternative solutions. Flexibility refers to the ability to view a problem from different perspectives or shift between different approaches. Originality refers to the production of uncommon or novel ideas. Elaboration refers to the ability to develop ideas into detailed procedures, explanations, or products. Evaluative reflection refers to the ability to assess ideas, procedures, and products based on scientific reasoning and contextual relevance. However, this study did not directly measure students' multi-creativity as an outcome variable. Instead, the study evaluated teacher practices that were expected to support the development of multi-creativity. Therefore, the findings should be interpreted as evidence of pedagogical feasibility and creativity-supportive teaching implementation, not as evidence of direct improvement in students' creativity.

The primary instrument used in this study was the Teaching for Creativity Observation Form (TCOF), adapted from Al-Abdali and Al-Balushi (Al-Abdali & Al-Balushi, 2016). The TCOF was selected because it provides a structured framework for observing teacher behaviors that support creativity in science classrooms. The instrument consists of four categories with a total of 23 observable elements. The first category, Questioning Techniques, consists of six elements related to the use of open-ended, probing, divergent, and problem-solving questions. This category evaluates whether the teacher asks questions that stimulate students' reasoning, idea generation, and creative exploration. The second category, Teacher Responses to Students' Ideas, consists of seven elements related to how the teacher responds to student contributions. This category includes encouragement, constructive feedback, acceptance of diverse ideas, and prompts for further elaboration.

The third category, Classroom Activities that Foster Creativity, consists of seven elements related to student engagement in creative tasks, investigation, collaboration, product development, and reflection. This category evaluates whether classroom activities provide opportunities for students to explore ideas and transform them into meaningful learning outcomes. The fourth category, Creative Learning Model Implementation, consists of three elements related to the implementation of whole-lesson methods that support creativity. This category examines whether the learning model is implemented coherently across the lesson and whether it supports imagination, reflection, and metacognitive development.

The instrument used a Guttman-type scale with two response options. A score of 0 indicated that the observed teaching practice was not implemented, while a score of 1 indicated that the observed teaching practice was implemented. This binary scoring system was used to identify the presence or absence of creativity-supportive teacher behaviors during classroom implementation. Before implementation, the TCOF-based observation sheet and the learning design were reviewed by validators to ensure content relevance, clarity, and alignment with the research objectives. The validation process involved three chemistry teachers and two expert lecturers. The validators examined whether the observation indicators were appropriate for evaluating teacher practices in the AI-assisted C-R-E-A-T-E learning model. They also reviewed the clarity of the indicators, the suitability of the learning stages, and the alignment between the learning activities, chemistry content, AI integration, and creativity-oriented pedagogy.

Suggestions from validators were used to refine the observation sheet and learning procedure before classroom implementation. The refinement process included clarifying indicator descriptions, ensuring consistency between the C-R-E-A-T-E stages and TCOF categories, and improving the guidance for AI-supported inquiry. Data were collected through direct classroom observation during the implementation of the AI-assisted C-R-E-A-T-E model. The three observers independently completed the TCOF while observing the learning process. Prior to data collection, the observers participated in a briefing session to develop a shared understanding of each TCOF category, observable indicator, and scoring rule.

Observation was conducted across the full learning sequence, beginning from the introduction of the project and continuing through the constructing, reflecting, exploring, analyzing, transforming, and evaluating stages. During observation, the observers focused on teacher behaviors, especially questioning strategies, responses to students' ideas, classroom activities that supported creativity, and the coherence of the whole-lesson creative learning model. After the observation, the scores from the three observers were compared to identify general patterns of implementation. Differences in scoring were discussed to clarify interpretation of the indicators and to strengthen the credibility of the observational data.

The data were analyzed descriptively using percentage calculations. Each TCOF indicator was scored based on whether the observed practice was implemented or not. The total observed score was then compared with the maximum possible score and converted into a percentage using the following formula: Implementation Percentage = Total Observed Score / Maximum Possible Score × 100% The percentage results were interpreted using the following criteria:

Table 1. Percentage Range Criteria

Percentage Range	Interpretation
0–25%	Low implementation
26–50%	Moderate implementation
51–75%	High implementation
76–100%	Very high implementation

The analysis was conducted at the category level to identify which aspects of teacher creativity-supportive practices were strongly implemented and which aspects required refinement. Because this study did not include pretest-posttest data, a control group, or a student creativity assessment rubric, the analysis was limited to pedagogical feasibility and implementation quality. Therefore, the findings should not be interpreted as evidence of causal effectiveness in improving students' creativity.

This study involved classroom observation and AI-supported learning activities. Therefore, the learning process was conducted under teacher supervision to ensure that students used AI responsibly and critically. Students were guided to treat AI-generated information as preliminary input rather than final scientific truth. They were required to verify AI-generated suggestions through discussion, teacher guidance, and chemistry concepts.

The use of AI was also framed within academic integrity principles. Students were reminded not to copy AI-generated answers directly, but to use them as prompts for exploration, comparison, and reflection. The teacher maintained an active role in guiding students' reasoning, preventing overreliance on AI, and ensuring that the learning process remained student-centered and conceptually meaningful.

RESULT AND DISCUSSION

The implementation of the AI-assisted C-R-E-A-T-E learning model was evaluated using the Teaching for Creativity Observation Form (TCOF). The observation focused on four dimensions of creativity-supportive teaching practices: questioning techniques, teacher responses to students' ideas, classroom activities that foster creativity, and the implementation of a creative learning model. The percentage score for each category represents the extent to which the observed teacher practices were implemented during the chemistry project-based learning activity on natural paint production.

Table 2. Implementation of Creativity-Supportive Teaching Practices Based on TCOF

TCOF Category	Focus of Observation	Number of Observable Elements	Implementation Percentage	Interpretation
Category A: Questioning Techniques	Teacher use of open-ended, probing, divergent, and problem-solving questions	6	100%	Very high

Category B: Teacher Responses to Students' Ideas	Teacher encouragement, constructive feedback, acceptance of diverse ideas, and elaboration prompts	7	82%	Very high
Category C: Classroom Activities that Foster Creativity	Student engagement in investigation, exploration, collaboration, product development, and reflection	7	100%	Very high
Category D: Creative Learning Model Implementation	Whole-lesson implementation of creativity-oriented learning, including imagination and metacognitive scaffolding	3	50%	Moderate

As shown in Table 2, the highest implementation scores were found in Category A and Category C, both of which achieved 100%. These results indicate that the teacher consistently implemented creativity-supportive questioning techniques and designed classroom activities that encouraged student exploration, investigation, and product-oriented learning. The full implementation of questioning techniques suggests that the teacher was able to use open-ended and probing questions to stimulate students' reasoning and idea generation throughout the learning process. Similarly, the full implementation of classroom activities indicates that the natural paint project provided meaningful opportunities for students to engage in creative chemistry learning.

Category B, Teacher Responses to Students' Ideas, reached 82%, which also falls into the very high implementation category. This finding indicates that the teacher generally responded positively to student contributions, provided constructive feedback, and encouraged students to elaborate their ideas. However, the score also suggests that some aspects of teacher response were not implemented consistently. In particular, practices related to guiding students to systematically document, refine, and reconsider their ideas still require improvement.

The lowest score was found in Category D, Creative Learning Model Implementation, which reached only 50%. This result indicates that although the AI-assisted C-R-E-A-T-E model was implemented in the classroom, its whole-lesson implementation was not yet optimal. The moderate score suggests that certain stages of the model, especially those related to imagination-building, reflective evaluation, and metacognitive scaffolding, require further refinement. Therefore, while the model demonstrates pedagogical feasibility, it should be regarded as partially implemented rather than fully established.

Overall, the results indicate that the AI-assisted C-R-E-A-T-E learning model was strongest in supporting teacher questioning strategies and creative classroom activities. However, the model still needs improvement in ensuring coherence across all learning stages, particularly in helping students move beyond idea generation toward deeper reflection, refinement, and evaluation.

Discussion

The findings of this study indicate that the AI-assisted C-R-E-A-T-E learning model has promising pedagogical feasibility for supporting creativity-oriented chemistry instruction, particularly in the dimensions of teacher questioning techniques and classroom activities that foster creativity. The implementation results showed that Questioning Techniques and Classroom Activities that Foster Creativity achieved full implementation, each reaching 100%. Teacher Responses to Students' Ideas also reached a very high level at 82%, while Creative Learning Model Implementation remained moderate at 50%. These results suggest that the model was strongly implemented in specific teaching behaviors that support creativity, although the whole-lesson implementation still requires refinement, especially in imagination-building and metacognitive scaffolding.

The full implementation of questioning techniques is an important finding because questioning is one of the most fundamental strategies in teaching for creativity. In this study, the teacher used open-ended, probing, and problem-solving questions to stimulate students' thinking during the natural paint project. This finding is consistent with Chin (2007) and Kawalkar & Vijapurkar (2013), who emphasized that productive questioning in science classrooms can promote students' reasoning, explanation, and inquiry processes. In the context of the C-R-E-A-T-E model, questioning functioned as a scaffold across learning stages, from constructing initial understanding to evaluating the final product. For example, questions in the Constructing and Reflecting stages helped students activate prior knowledge about pigments, mixtures, and colloids, while questions in the Analyzing and Evaluating stages encouraged students to connect their ideas with scientific principles and product quality.

The role of questioning in this study also aligns with Guilford (1967) and Runco & Acar (2012) theory of divergent thinking. Guilford conceptualized creativity as involving the ability to generate multiple, flexible, and original responses. Open-ended questions used by the teacher created opportunities for students to propose alternative ideas, compare possible materials, and consider different procedures for producing natural paints. Similarly, Torrance (1987) emphasized fluency, flexibility, originality, and elaboration as important indicators of creative thinking. Although this study did not directly measure students' creativity outcomes, the observed questioning practices can be interpreted as pedagogical conditions that may support these dimensions. Questions that ask students to generate several possible pigment sources may support fluency, while questions that encourage them to compare extraction methods may support flexibility and elaboration.

The full implementation of classroom activities that foster creativity further indicates that the natural paint project provided a meaningful context for creative chemistry learning. This finding supports Bell (2010) argument that project-based learning can engage students in authentic inquiry, collaboration, problem-solving, and product development. In this study, students were not only introduced to colloid concepts theoretically but were also involved in exploring natural materials, designing procedures, producing paint samples, and reflecting on the quality of their products. Such activities are important because creativity in science learning requires students to interact with real problems, materials, and evidence rather than merely reproduce textbook explanations.

The finding is also consistent with Hmelo-Silver (2004), who argued that problem-based and inquiry-oriented learning can support students in developing flexible knowledge, self-directed learning, and collaborative problem-solving. The natural paint project required students to investigate possible natural pigment sources, consider mixture stability, and make decisions regarding product formulation. These activities encouraged students to engage in scientific inquiry while also allowing space for creative exploration. Therefore, the strong implementation of creative classroom activities suggests that the AI-assisted C-R-E-A-T-E model can provide a structured yet flexible environment for chemistry project-based learning.

However, the high implementation of classroom activities should be interpreted cautiously. While the project provided opportunities for creative engagement, the present study only evaluated teacher practices through TCOF. It did not directly assess students' creative thinking, product creativity, or conceptual understanding. Therefore, the findings support the pedagogical feasibility of the learning design, but they cannot yet be used to claim that students' creativity significantly improved. This distinction is important for maintaining methodological accuracy and avoiding overclaiming.

The high score in Teacher Responses to Students' Ideas indicates that the teacher generally provided constructive feedback, accepted diverse ideas, and encouraged students to elaborate their thinking. This finding is consistent with Beghetto & Kaufman (2021) and Kaufman & Beghetto (2009), who emphasized that creativity in the classroom depends strongly on how teachers respond to students' ideas. Students are more likely to express original or unusual ideas when they feel psychologically safe and when their contributions are treated as valuable learning resources. In creativity-oriented instruction, teacher responses should not only correct errors but also encourage students to refine, justify, and extend their ideas.

This finding also aligns with Beghetto & Kaufman (2014) view that classroom creativity requires supportive learning contexts that allow students to take intellectual risks. In the natural paint project, students may propose different pigment sources, procedures, or formulations. If the teacher responds negatively or too quickly dismisses students' ideas, students may become reluctant to explore alternatives. Conversely, constructive responses can encourage students to revise and improve their ideas. The 82% score suggests that such supportive responses were generally present, although not fully consistent across all observed elements.

One aspect that still requires improvement is the systematic refinement of students' ideas. Creativity does not end with idea generation; it also requires elaboration, evaluation, and revision. This is closely related to Dumont & Willis (2008) elaboration dimension and to the reflective aspect of creativity-oriented learning. In this study, some practices related to documenting, revising, and refining students' ideas were not fully implemented. Therefore, future implementation should include more structured mechanisms such as idea journals, reflection sheets, peer feedback, and teacher-guided revision. These mechanisms would help students move from spontaneous idea generation toward more disciplined creative inquiry.

The moderate score in Creative Learning Model Implementation is the most critical finding of this study. Category D reached only 50%, indicating that although several creativity-supportive practices were strongly observed, the whole-lesson implementation of the C-R-E-A-T-E model was not yet fully optimized. This finding suggests that creativity-oriented instruction requires more than isolated questioning strategies or creative activities. It requires coherent integration across all learning stages, from constructing and reflecting to exploring, analyzing, transforming, and evaluating.

This result can be interpreted through Vygotsky's (1980) perspective on imagination and creativity. Vygotsky emphasized that imagination develops through social interaction, cultural tools, prior experience, and guided activity. In the context of this study, AI can be considered a cultural and cognitive tool that supports students' imagination and idea exploration. However, such tools require mediation. Without sufficient teacher scaffolding, students may use AI only to obtain quick answers rather than to develop imaginative and reflective thinking. Therefore, the moderate implementation score indicates the need for stronger scaffolding to help students transform AI-supported information into meaningful scientific and creative reasoning.

The finding also reflects the importance of metacognitive scaffolding in creative learning. Zimmerman (2002) emphasized that self-regulated learning involves planning, monitoring, and evaluating one's own learning processes. In an AI-assisted C-R-E-A-T-E environment, students need to monitor how they use AI, evaluate whether AI-generated information is scientifically accurate, and reflect on how such information influences their decisions. The moderate score in Category D suggests that these metacognitive processes were not yet fully embedded in the whole lesson. Future implementation should therefore include explicit prompts such as: Why did you choose this material? How did you verify the AI suggestion? What alternative procedure did you consider? What evidence supports your final decision?

The integration of AI in this study also needs to be discussed in relation to recent literature on AI in education. Holmes et al. (2023) argued that AI has the potential to support learning, but its educational value depends on pedagogical design, teacher roles, and ethical implementation. Similarly, Ng et al. (2021) emphasized that AI literacy includes the ability to understand, use, evaluate, and ethically engage with AI. In this study, AI was positioned as a cognitive support tool to help students generate ideas, explore information, and compare possible procedures for making natural paints. However, teacher guidance remained essential to ensure that students did not simply copy AI-generated responses or accept inaccurate information without verification.

This finding is also consistent with Cooper (2023), who showed that generative AI in science education offers opportunities for exploration and explanation but also poses risks related to accuracy and misconceptions. In chemistry learning, this issue is particularly important because AI-generated explanations may not always accurately represent scientific concepts such as colloidal stability, dispersed phase, dispersion medium, or the role of binders and stabilizers. Therefore, AI-assisted chemistry learning must include conceptual verification. Teachers should guide students to compare AI outputs with scientific principles, experimental observations, and reliable references.

The natural paint project also has important implications for chemistry learning. Johnstone (2010) explained that chemistry understanding involves the coordination of macroscopic, submicroscopic, and symbolic representations. In this study, the project allowed students to observe macroscopic phenomena, such as color, texture, mixture formation, and paint stability. However, future implementation should more explicitly connect these observations with submicroscopic and symbolic explanations. For example, students should be guided to analyze how pigment particles are dispersed, how stabilizing agents affect mixture stability, and how the properties of natural materials influence the quality of the paint. Strengthening this connection would make the project not only creative but also conceptually rigorous.

The results also support the relevance of the TCOF as an observation-based instrument for evaluating creativity-supportive teaching practices. Al-Abdali and Al-Balushi's TCOF framework emphasizes questioning strategies, teacher responses, classroom activities, and whole-lesson methods that foster creativity (Al-Abdali & Al-Balushi, 2016). The present study demonstrates that this framework can be used to identify specific strengths and weaknesses in the implementation of an AI-assisted creative learning model. However, because TCOF focuses on teacher practices, it should be complemented by student-level instruments in future research. These may include creativity tests, product assessment rubrics, student reflection journals, interviews, and conceptual understanding tests.

Overall, the findings indicate that the AI-assisted C-R-E-A-T-E model is pedagogically feasible but still requires refinement. Its strongest aspects are the use of creativity-supportive questioning and the design of project-based classroom activities. These aspects are consistent with Guilford's divergent thinking theory, Torrance's creative thinking dimensions, Bell's project-based learning principles, and Hmelo-Silver's inquiry-oriented learning framework. The teacher's constructive responses also align with Beghetto's perspective on classroom creativity and psychological safety. Nevertheless, the moderate implementation of the whole creative learning model shows that stronger scaffolding is needed, particularly in imagination-building, AI literacy, metacognitive reflection, and chemistry conceptual integration. Therefore, the model should be viewed as a promising instructional approach that is feasible for creativity-oriented chemistry learning, but further studies are needed before stronger claims can be made regarding its effectiveness in improving students' multi-creativity.

CONCLUSION

This study evaluated the pedagogical feasibility of an AI-assisted C-R-E-A-T-E learning model in chemistry project-based learning through the Teaching for Creativity Observation Form (TCOF). The findings indicate that the model was strongly implemented in the dimensions of questioning techniques and classroom activities that foster creativity, both of which reached full implementation. Teacher responses to students' ideas were also implemented at a very high level, suggesting that the classroom environment generally supported idea expression, constructive feedback, and creative engagement. However, the whole-lesson implementation of the creative learning model reached only a moderate level, indicating that the model still requires refinement, particularly in imagination-building, metacognitive scaffolding, reflective evaluation, and the meaningful integration of AI into each learning stage. These findings suggest that the AI-assisted C-R-E-A-T-E model is pedagogically feasible for supporting creativity-oriented chemistry instruction, especially in project-based activities such as natural paint production, but its implementation should be strengthened to ensure greater coherence across the Constructing, Reflecting, Exploring, Analyzing, Transforming, and Evaluating stages. The study also emphasizes that AI should be positioned as a supervised cognitive support tool rather than a replacement for students' reasoning or teacher guidance. Therefore, claims regarding the direct effectiveness of the model in improving students' multi-creativity should be made cautiously, since this study focused on teacher practices rather than student creativity outcomes. Future research should involve larger samples, longer implementation cycles, direct assessment of students' creative thinking and product quality, and more rigorous designs such as mixed-method or quasi-experimental approaches to examine the impact of the AI-assisted C-R-E-A-T-E model on students' creativity, conceptual understanding, AI literacy, and scientific problem-solving skills.

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