International Journal of Instruction
e-ISSN: 1308-1470 ● www.e-iji.net

October 2025 ● Vol.18, No.4
p-ISSN: 1694-609X
pp. 89-110

Article submission code: 20250122102116

Received: 22/01/2025
Revision: 13/04/2025

Accepted: 25/04/2025
OnlineFirst: 01/07/2025

Scientific Problem-Based Creativity Learning Model for Enhancing Students' Creative Traits and Developing Scientific Creative Process

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Scientific creativity in chemistry is unique and differs from that in other sciences. Previous studies have found low levels of students' scientific creativity and limited research on scientific creativity in chemistry education, especially concerning colloid systems, a topic closely related to everyday life. The research used a quasi-experimental design, employing instruments namely the chemistry scientific creativity test and Think Aloud Protocol. Data were analyzed using descriptive statistics (rubric scoring and percentages) and inferential statistics. Qualitative data were analyzed through thematic analysis to explore students' creative processes. Results showed that SPBCL significantly improved students' creative traits ($p < 0.001$). Moreover, SPBCL fostered the development of students' creative processes. This study emphasizes adopting SPBCL to nurture students' scientific creativity. The findings contribute to chemistry education by highlighting scientific creativity and equipping students with the essential skills needed for chemistry and beyond.

Keywords: scientific creativity, colloid system, 21st century skills, chemistry, problem-based learning

INTRODUCTION

Creativity is a vital skill that enables individuals to produce and implement innovative, logical, and effective ideas for problem-solving (Gunawan et al., 2018; Chan & Yuen, 2014; Soland et al., 2013). There is a need to increase creativity for educational human resources to be enhanced (Mulyoto et al., 2024). In education, creativity plays a central role in enabling students to engage deeply with their learning, discover new perspectives, and innovate in applying their knowledge to diverse contexts. Within science education, this concept is refined into scientific creativity, which involves the capacity to produce original, scientifically grounded ideas and hypotheses that solve

Citation: Nursiwan, W. A., Hanri, C., & Ibrahim, N. H. (2025). Scientific problem-based creativity learning model for enhancing students' creative traits and developing scientific creative process. *International Journal of Instruction*, *18*(4), 89-110.

problems and advance understanding (Hu & Adey, 2002; Antink-Meyer & Lederman, 2015). In contrast to general creativity, which often emphasizes artistic open-ended problem-solving, scientific creativity necessitates a solid grounding in scientific knowledge and reasoning. It empowers students to develop practical solutions based on scientific principles, enhancing their engagement with concepts, encouraging innovative problem-solving, and facilitating decision-making in scientific contexts (Wicaksono et al., 2020; Overton et al., 2013; Hadzigeorgiou et al., 2012).

Despite its importance, studies reveal that students' scientific creativity remains low across various educational contexts. In Kenya and Malaysia, for example, the level of students' scientific creativity was low, particularly in chemistry classes (Ikiao, 2019; Jamal et al., 2020). In Indonesia, a similar trend is observed, with students struggling to exhibit creativity in chemistry, especially in topics such as acids & bases, chemical formulas, and reactions (Wahyu et al., 2017; Ulfah et al., 2020; Wahyuliani et al., 2022). The low level of scientific creativity can be attributed to several factors, including conventional teaching methods that emphasize rote memorization instead of critical thinking and creativity (Heliawati et al., 2021; Redhana et al., 2018). Additionally, many educators tend to concentrate on motivational strategies rather than adopting active, student-centered learning approaches that promote creativity (Chelang, 2014; Suyidno et al., 2020).

The colloid system is a promising area in chemistry education for fostering scientific creativity. However, students often find it challenging to grasp the abstract and complex nature of colloid systems (Rachmayanti & Amaria, 2013). The studies indicate that students frequently rely on memorization rather than developing a conceptual understanding of colloid properties and applications, resulting in poor performance and limited problem-solving abilities (Zahro et al., 2022; Dewi & Mashami, 2019). This issue is compounded by the lack of creative engagement in traditional teaching methods, which fail to leverage the real-life relevance of colloids to inspire students' curiosity and creativity (Sternberg, 2010).

Creativity in colloid systems is crucial as it prompts students to link scientific concepts with everyday phenomena, improving their capacity to address real-world issues. However, research shows that students often lack opportunities to develop creativity in this area due to teacher-centered approaches that limit their active participation and idea generation (Ulfah et al., 2020; Wahyu et al., 2017). Teachers play an important role in nurturing students' scientific creativity, yet many do not implement strategies that effectively foster traits such as fluency, flexibility, and originality (Hu & Adey, 2002; Gupta & Sharma, 2019). Instead, teaching practices often focus on delivering content and assessing students' memorization skills, neglecting the development of scientific creativity.

Addressing these challenges requires a shift toward teaching approaches that actively engage students in creative scientific problem-solving. Constructivist-based methods, which emphasize student-centered learning and active participation, have been shown to enhance scientific creativity by encouraging students to explore ideas, ask questions, and apply their knowledge in meaningful ways (Masek & Yamin, 2010). These methods are especially pertinent in the context of the colloid system, where the link between scientific concepts and real-world applications offers numerous chances for students to devise creative problem-solving solutions.

Considering the need to improve students' scientific creativity and the potential of the colloid system as a context for fostering creativity, this study aims to enhance students' scientific creativity by implementing Scientific Problem-Based Creativity Learning (SPBCL). This innovative approach combines constructivist principles with problem-based learning, the creative process, and chemical representation to actively engage students in generating and applying ideas. By focusing on creativity in the colloid system, the study aims to address gaps in current teaching practices and contribute to the broader goal of preparing students for the challenges of the 21st century through enhanced scientific creativity.

LITERATURE REVIEW

Scientific Structure Creativity Model

Creativity is an essential skill that equips individuals with the ability to generate and apply novel, reasonable, and practical ideas to solve problems (Gunawan et al., 2018; Chan & Yuen, 2014; Soland et al., 2013). There is a need to increase creativity for educational human resources to be enhanced (Mulyoto et al., 2024). Creativity is crucial for allowing students to immerse themselves in their learning, uncover new viewpoints, and innovate by applying their knowledge in various contexts. This concept is refined within science education into scientific creativity, which involves producing original, scientifically grounded ideas and hypotheses that solve problems and advance understanding (Hu & Adey, 2002; Antink-Meyer & Lederman, 2015). Unlike general creativity, which may focus on open-ended problem-solving artistically, scientific creativity requires a firm foundation in scientific knowledge and reasoning. It enables students to generate applicable solutions grounded in scientific principles, fostering deeper engagement with concepts, promoting innovative problem-solving, and encouraging to make decisions in science (Wicaksono et al., 2020; Overton et al., 2013; Hadzigeorgiou et al., 2012).

Research indicates that students' scientific creativity is consistently low across different educational settings, despite its significance. For instance, in Kenya and Malaysia, students demonstrated low levels of scientific creativity, particularly in chemistry classes (Ikiao, 2019; Jamal et al., 2020). A similar pattern is evident in Indonesia, where students face challenges in displaying creativity in chemistry, especially in areas such as acids and bases, chemical formulas, and reactions (Wahyu et al., 2017; Ulfah et al., 2020; Wahyuliani et al., 2022). This low level of scientific creativity is attributed to multiple factors, including traditional teaching methods prioritizing rote memorization over critical thinking and creativity (Heliawati et al., 2021; Redhana et al., 2018). Furthermore, many teachers focus on motivational strategies rather than implementing active, student-centered learning approaches that foster creativity (Chelang, 2014; Suyidno et al., 2020).

The colloid system is one area of chemistry education that provides a promising context for fostering scientific creativity. Colloids are significant in daily life, from soy milk and air fresheners to industrial processes such as adsorption and refining (Sumarni &

Kadarwati, 2020; Hayati et al., 2014). However, students often find it challenging to grasp the abstract and complex nature of colloid systems (Rachmayanti & Amaria, 2013). The studies indicate that students frequently rely on memorization rather than developing a conceptual understanding of colloid properties and applications, resulting in poor performance and limited problem-solving abilities (Zahro et al., 2022; Dewi & Mashami, 2019). This issue is compounded by the lack of creative engagement in traditional teaching methods, which fails to leverage the real-life relevance of colloids to inspire students' curiosity and creativity (Sternberg, 2010).

Creativity in colloid systems is crucial as it prompts students to link scientific concepts with everyday phenomena, improving their capacity to address real-world issues. However, research shows that students often lack opportunities to develop creativity in this area due to teacher-centered approaches that limit their active participation and idea generation (Ulfah et al., 2020; Wahyu et al., 2017). Teachers are essential in nurturing students' scientific creativity, yet many do not implement strategies that foster fluency, flexibility, and originality (Hu & Adey, 2002; Gupta & Sharma, 2019). Instead, teaching practices often focus on delivering content and assessing students' memorization skills, neglecting the development of scientific creativity.

Addressing these challenges requires a shift toward teaching approaches that actively engage students in creative scientific problem-solving. Constructivist-based methods, focusing on student-centered learning and active participation, have improved scientific creativity by prompting students to explore ideas, pose questions, and apply their knowledge meaningfully (Masek & Yamin, 2010). These methods are especially pertinent in the context of the colloid system, where the link between scientific concepts and real-world applications offers numerous chances for students to devise creative problem-solving solutions.

Considering the need to improve students' scientific creativity and the potential of the colloid system as a context for fostering creativity, this study aims to enhance students' scientific creativity by implementing Scientific Problem-Based Creativity Learning (SPBCL). This innovative approach integrates constructivist principles with problem-based learning, creative process, and chemical representation to actively involve students in generating and applying ideas. By focusing on creativity in the colloid system, the study aims to address gaps in current teaching practices and contribute to the broader goal of preparing students for the challenges of the 21st century through enhanced scientific creativity.

Scientific Creative Process

The scientific creative process in this study involves the combination of divergent thinking (Sun et al., 2020), and scientific imagination (Ho et al., 2013), which is a dynamic approach that individuals use when solving scientific problems. The process consists of initiation, dynamic adjustment, combination with adjustment, and virtual implementation stages. This phase encourages curiosity and divergent thinking, enabling students to explore multiple possibilities. Students generate initial ideas by drawing from their prior knowledge and experiences, laying the groundwork for deeper problem-solving. Furthermore, in the dynamic adjustment, students work on expanding and connecting their ideas containing scientific knowledge. This process of dynamically adjusting and expanding their ideas ensures that they do not settle on the first solution but explore a wide range of possibilities before moving forward. The third stage, combination with adjustment, involves merging different ideas and adjusting them to create new, refined solutions. Students analyze the feasibility of their ideas and modify them based on logical reasoning and scientific principles. This step fosters creativity by allowing students to experiment with different ways of combining knowledge, leading to innovative and well-structured solutions.

Ultimately, the virtual implementation stage is where students arrange and convert their ideas into concrete results. They create prototypes or practical solutions that showcase their creative problem-solving process. In the context of chemistry, virtual implementation pertains to concepts of chemical representation.

Scientific Problem Based Creativity Learning

Scientific Problem-Based Creativity Learning (SPBCL) is a model that combines Problem-Based Learning (PBL) (Tan, 2002) with creative processes, including Initiation, Dynamic Adjustment, Combination with Adjustment, Virtual Implementation (Ho et al., 2013; Sun et al., 2020), and chemical representation. This model enhances scientific creativity in chemistry education by encouraging students to engage in problem-solving, creative thinking, and chemical representation.

SPBCL comprises five stages, each with specific objectives to foster different aspects of scientific creativity:

1.Meeting the Problem with Initiation. This stage focuses on improving students' fluency by encouraging them to identify problems from multiple perspectives through brainstorming. Students freely explore ideas without judgment, generating a variety of solutions. Additionally, this stage promotes flexibility by urging students to perceive problems from diverse perspectives, dismantling old concepts, and linking new ideas (Al-Khatib, 2012). Being open to various perspectives trains students to transition smoothly between concepts, enhancing their creative flexibility.

2.Problem Analysis and Generation of Learning Issues with Dynamic Adjustment. This stage strengthens fluency and flexibility by encouraging students to connect problems with scientific concepts. By associating and dynamically analyzing, students investigate relationships between ideas, enhancing their capacity to produce multiple solutions. Studies by Kiran and Farooq (2022) and Sun et al. (2020) suggest that this process enhances scientific creativity by helping students uncover new connections between scientific concepts.

3.Discovery and Reporting with Combination with Adjustment. Students explore and report original solutions to scientific problems during this stage, fostering their originality. The brainstorming process and collaborative group work play vital roles in improving originality. Through exchanging and combining ideas, students generate unique solutions, as evidenced by Siew (2017) and Sun et al. This stage emphasizes fostering originality by promoting exploration, association, and collaboration.

4.Solution Presentation and Reflection with Virtual Implementation and Chemical Representation. Students represent their ideas in this stage using chemical forms such as macroscopic, sub-microscopic, and symbolic representations. By presenting and reflecting on their solutions, students build new knowledge and deepen their comprehension of chemistry (Treagust, 2018). Awawangi et al. (2021) observed that active participation in problem-solving, group presentations, and knowledge exchange fosters creativity and enhances cognitive learning outcomes. Representing ideas through multiple forms strengthens students' conceptual understanding and creative abilities.

5.Overview, Integration, and Evaluation. The final stage brings together the learning process, consolidates knowledge, and assesses students' creative outputs. By reflecting on their educational journey, students gain a deeper understanding of their creative processes and results, which further enhances their scientific creativity.

In summary, SPBCL is an all-encompassing instructional model that fosters scientific creativity through a well-organized yet flexible methodology. This study employs the SPBCL model to enhance scientific creativity in the context of learning about colloid systems, utilizing its multidimensional approach to actively engage and empower students.

METHOD

Research Design

This study employed a quasi-experimental design with pre-test and post-test measures to assess the effectiveness of the Scientific Problem-Based Creativity Learning (SPBCL) in enhancing students' scientific creativity on the colloid system topic. The experimental group participated in learning activities developed within SPBCL, while the control group followed a conventional Problem-Based Learning (PBL) approach. Both groups undertook pre-tests and post-tests, which were essential for ensuring comparability between groups before the intervention and evaluating the intervention's impact on scientific creativity (Gravetter & Forzano, 2018). Prior to the pre-test, students were given a brief overview of the colloid system to equip them with adequate background knowledge for answering the test questions. This measure ensured that the pre-test results accurately represented students' scientific creativity rather than their unfamiliarity with the subject. Furthermore, the pre-test outcomes were used to create balanced student groups for collaborative activities, with the teacher facilitating the grouping process to ensure a diverse mix of abilities that would promote effective peer interactions.

To maintain homogeneity among the chosen classes, a preliminary test was administered to assess students' previous academic achievements, given the positive correlation between academic performance and scientific creativity (Kamonjo et al., 2015). Following the chemistry teacher's advice, an afternoon class was excluded due to scheduling issues and variations in student performance relative to the other classes. Homogeneity testing was conducted using SPSS on the remaining three classes, and Levene's Test confirmed no significant variance between the two classes (11 MIPA 5 and 11 MIPA 6), with a p-value of 0.435 ($F = 0.615$). Consequently, 11 MIPA 5 was designated as the control group, and 11 MIPA 6 as the experimental group, with each group consisting of 35 students selected purposively in line with the non-random sampling approach typical of quasi-experimental designs (Cook, 2015; Etikan, 2017).

Research Instruments & Data Analysis

Chemistry Scientific Creativity Test

In this study, the Chemistry Scientific Creativity Test (CSCT) was employed to assess students' scientific creativity during both the pre-test and post-test phases, which took place before and after the intervention. The test was based on the components of the Scientific Structure Creativity Model developed by Hu & Adey and was specifically designed for the chemistry context. It incorporated elements of divergent thinking and scientific imagination to evaluate students' creative processes, which were further analyzed using the Think Aloud Protocol. The CSCT was developed and reviewed by four experts, all of whom are professors with educational backgrounds in chemistry education and extensive research experience in scientific creativity within the field, as evidenced by their publications. The validation process included assessments of construct, content, and language validity, yielding an Intraclass Correlation Coefficient (ICC) value of 0.828, which indicates acceptable reliability. The results confirm that CSCT is valid and reliable for evaluating students' scientific creativity.

Descriptive Data Analysis

The descriptive data analysis method was used to measure scientific creativity in terms of creative traits. The method used rubric of scoring that has been developed and validated by the researchers. The scoring rubric was deemed valid with Intraclass Correlation Coefficient (ICC) value of 0.983, in terms of content, construct and criterion. Table 1 presents the scoring rubric utilized in this study.

Table 1
Rubric of scoring

Creative Traits	Indicator	Score
Fluency	Student cannot provide ideas.	0
	Student can come up with one idea/answer.	1
	Student can come up with two ideas/answers.	2
	Student can come up with three ideas/answers.	3
	Student can come up with more than three ideas/answers.	4
Flexibility	No ideas / Students are not able to provide correct ideas/methods.	0
	Students can come up with one correct category of idea/method	1
	Students can come up with two correct categories of ideas/methods.	2
	Students can come up with three correct categories ideas/methods.	3
	Students can come up with more than three correct categories of ideas.	4
Originality	Student do not answer/ideas are wrong/incomplete answer.	0
	If the ideas produced are general/common ideas/no originality (ideas produced by students are more than 10% of similar to each other).	1
	If the ideas produced by students are 5 to 10% of similar to each other.	2
	If the ideas produced are smaller than 5% of similar to each other.	3
	If the ideas produced are very unique (the ideas produced are only one student).	4

Inferential Data Analysis

To assess the effectiveness of Scientific Problem Based Creativity Learning, this study employed inferential statistical methods, specifically Wilcoxon Signed-Rank Test and Mann-Whitney U Test. The Wilcoxon Signed-Rank Test was utilized to analyze paired data from the same group of participants, comparing observations before and after the intervention (Gravetter & Wallnau, 2013). This test is especially suitable for repeated measures designs and was employed to assess changes in students' scientific creativity within each group. The Mann-Whitney U Test was used to evaluate if there were statistically significant differences between the two independent groups (control and experimental) regarding scientific creativity, creative traits (MacFarland & Yates, 2016). This test is suitable for non-normal data and is aligned with the study's research objectives. Additionally, effect size also was utilized to measure the magnitude of the relationship or effect, complementing the statistical tests. The rank biserial correlation (r), derived from the Wilcoxon or Mann-Whitney U Test statistics, was used as the effect size measure (Fritz et al., 2012). This additional analysis offered a more nuanced understanding of the differences observed between the experimental and control groups in terms of their scientific creativity dimensions.

Think Aloud Protocol and Thematic Analysis

The Think Aloud Protocol (TAP) was implemented after students completed the post-test and task activities as part of the Scientific Problem-Based Creativity Learning (SPBCL) intervention. TAP was conducted in a retrospective format, where students were asked to recall and explain their cognitive processes after answering the questions. This method reduced disruptions during the test-taking process, enabling researchers to understand students' cognitive processes without pressuring them to articulate their thoughts immediately. The Think Aloud Protocol was adapted from Wolcott & Lobczowski’s (2020) guidelines to align with the research objectives and ensure it captured relevant cognitive processes. The development and validation of the protocol involved four experts with significant expertise in chemistry education and qualitative methodologies. The validation process achieved S-CVI (Scale-Content Validity Index): 1.00, indicating unanimous agreement that the protocol is valid and I-CVI (Item-Content Validity Index): 1.00, confirming that the guideline was clearly formulated and aligned with the research objectives. It effectively explored the students’ creative process, the questions were free from bias and encouraged clear responses, and the language was simple, communicative, and adhered to proper linguistic rules. The finalized protocol is included in the appendix. TAP sessions were conducted face-to-face, with each session lasting less than one hour. Students were given the flexibility to pause or stop the session at any time. Participants for TAP were selected based on their scientific creativity scores and their levels of creativity as determined by Chemistry Scientific Creativity Test (CSCT). This guaranteed that the protocol encompassed a variety of creative processes. During the validation phase, trial sessions were held with two students from the chemistry club. These sessions revealed that students often repeated their answers when similar questions were asked. To address this, the study opted to use a single open-ended question: How could you solve the questions presented in the test (Question numbers 1, 2, 3, and 4)?. This question was designed to allow students to describe their stages of problem-solving, from understanding the problem to identifying a solution. It indirectly addressed all aspects of the creative process while giving students the freedom to elaborate on their exploration of various ideas and approaches.

The data obtained from Think Aloud Protocol (TAP) sessions underwent analysis using a thematic analysis method by Braun & Clarke (2012), widely acknowledged for identifying, analyzing, and reporting patterns in qualitative data. Through systematic identification of patterns and themes, thematic analysis facilitated a more profound comprehension of students' creative problem-solving processes. Thematic analysis comprises six key phases: (1) Familiarizing Yourself with the Data, (2) Generating Initial Codes, (3) Searching for Themes, (4) Reviewing Potential Themes, (5) Defining and Naming Themes, and (6) Producing the Report. Within this study, similar responses were grouped into initial codes, which were then categorized into sub-themes. Subsequently, related sub-themes were consolidated into major themes representing different aspects of the creative process. To ensure the accuracy and reliability of the coding process, qualitative research experts reviewed the codes and themes. Incorporating their feedback into the final revisions enhanced the analysis's validity. The thorough coding and validation process ensured the accurate capture of the cognitive processes underpinning students' scientific creativity in the TAP sessions.

Ethical Considerations

In this study, respondents' consent was obtained by having them sign a consent form, indicating their willingness to participate. This process ensured that participants were fully informed about the study's purpose, procedures, and their rights, including the ability to withdraw at any time without repercussions. To uphold confidentiality and safeguard respondents' identities, real names were substituted with pseudonyms like R1, R2, and so forth, ensuring the privacy and anonymity of their personal information. Additionally, participation in this study was entirely voluntary, and respondents were assured that their involvement would not result in any negative consequences. The study was also structured to mitigate any potential risks, ensuring that participants did not encounter psychological, emotional, or physical discomfort. Additionally, all data collected was securely stored and utilized exclusively for research purposes, in compliance with ethical research standards.

FINDINGS & DISCUSSION

Creative Traits

Creative traits consist of fluency, flexibility, and originality. The following Table 2 reveals the descriptive data analysis result in terms of the proportion of students for each score obtained.

Table 2
Percentage of students obtaining each score of pretest and post-test (Creative Traits)

Score	Fluency		Flexibility		Originality	
	Pretest	Post-test	Pretest	Post-test	Pretest	Post-test
0	27.14%	0.00%	52.86%	4.29%	53.57%	5.71%
1	47.14%	34.29%	38.57%	25.71%	20.71%	55.00%
2	14.29%	15.71%	7.14%	34.29%	11.43%	9.29%
3	7.14%	10.00%	1.43%	18.57%	5.71%	16.43%
4	4.29%	40.00%	0.00%	17.14%	8.57%	13.57%

Table 2 above shows that the high proportion of students obtaining a score of 0 ranges from 15.79% - 49.34% and only 1.98% - 4.94% of students could obtain a score 4 overall conclude that creative traits remain low level. The finding is confirmed by the inferential data analysis method (Wilcoxon statistics analysis data) as showed in the following Table 3.

Table 3
Wilcoxon signed ranks statistics result (Pre-test & Post-test- Creative Trait)

Statistics Test[a]	Value
Z	-5.166[b]
Asymp. Sig. (2-tailed)	< 0.001
r	-0.873

Based on Table 3, it shows that Asymp. Sig. (2-tailed) obtained is <0.001 and Z value of -5.166 where it is less than 0.05. Hence, there was a statistically significant difference in creative traits of students before and after implementing Scientific Problem-Based Creativity Learning. The value of r (-0.873) obtained shows that there was a high level of a large effect size. This means that there was a large impact from Scientific Problem-Based Creativity Learning on creative traits. Fluency was discussed in the context of colloid system. Based on Table 2, the decrease in the proportion of students obtaining score of 0 from 27.14% (pre-test) to 0.00% and the enhancement in the proportion of students obtaining score of 4 from 4.29% (pre-test) to 40.00% (post-test) show that Scientific Problem Based Learning could enhanced fluency. Furthermore, flexibility is the student’s ability to produce categories of ideas or methods as many as possible. The enhancement of flexibility (Table 2) was observed as the high proportion of students getting score of 0 decreased to 4.29% (post-test). In addition, there was an increase of scores 2, 3 and 4. Meaning that the ability of students to generate more than one method increased. Ultimately, Originality refers to the uniqueness of ideas expressed by students. As shown in Table 2, the significant decrease in the proportion of students with a score of 0 from the pre-test to the post-test (53.57% to 5.71%) reveals that students’ originality improved significantly. Furthermore, the rise in the percentage of students achieving scores of 1, 3, and 4 signifies an improvement in students' originality.

In enhancing creative traits, structured stages and collaborative processes were utilized. Initially, fluency and flexibility are predominantly cultivated during the Meeting the Problem and Initiation stage, where students were urged to identify numerous problems from varied perspectives. Brainstorming serves as a critical activity in these stages, enabling students to explore multiple ideas and solutions. By engaging in perspective-taking and dynamic thinking, students break down conventional ideas, form new connections, and expand their knowledge boundaries (Al-Khatib, 2012; Rubenstein et al., 2019). This aligns with research indicating that brainstorming and perspective-taking positively correlate with fluency and flexibility (Doron, 2017). Furthermore, the association process in the Dynamic Adjustment stage further improves fluency by prompting students to connect concepts related to colloid systems with recognized problems, thereby promoting divergent thinking and fostering innovative connections. (Sun et al., 2020; Haim & Aschauer, 2022). Additionally, originality is nurtured during the Discovery & Report stage, where problem-solving tasks encourage students to develop innovative solutions. The open-ended format of these activities enables students to explore creative avenues and reinterpret information through collaborative discussions. Discovery activities inspire the generation of ideas, while group reporting enhances communication and facilitates the integration of diverse concepts into distinctive conclusions. (Seechaliao, 2017). This collaborative process not only enhances individual creativity but also strengthens group dynamics by encouraging collective problem-solving and information exchange (Reiter-Palmon et al., 2012; Siew, 2017). The reinterpretation and integration of ideas during these interactions facilitate the production of original and meaningful solutions (Wang et al., 2014). Collaboration and brainstorming are essential components of SPBCL's effectiveness in boosting creativity. Working in groups facilitates the exchange and improvement of ideas, utilizing the varied experiences of team members to produce rich and innovative results. (Hidayah et al., 2021; Pi et al., 2019). Brainstorming sessions provide students with the freedom to explore and expand their ideas without constraints, which are essential for fostering fluency and originality (Hidayanti et al., 2018; Al-Khatib, 2012). Moreover, the cyclical nature of the SPBCL stages guarantees that students consistently participate in activities that stimulate their critical thinking, thereby fostering the development of creative habits and skills. (Ho et al., 2013; Gupta & Sharma, 2019).

Overall, SPBCL enhances students' creative traits by combining problem-solving, collaborative learning, and brainstorming activities. These elements enable students to generate a high quantity of ideas (fluency), explore diverse perspectives (flexibility), and create novel solutions (originality). By integrating these processes into structured learning stages, SPBCL offers a solid framework for nurturing scientific creativity in students.

Creative Process

The creative process was assessed through Think Aloud Protocol activity. The result of Think Aloud Protocol was transcribed, coded into sub-themes, and then generated into themes. Table 4 shows codes, sub-themes and themes obtained from thematic analysis of creative process of students in the experimental group after implementing SPBCL.

Table 4
Thematic analysis result of creative process (Experimental Group)

Codes	Sub-Theme	Theme	Creative Process
R16: - Problems is about determination of colloids, suspensions and solutions. - Separating samples - Matching the characteristics of each sample R34: The classifications of samples are done by analysis of several points from the explanations R12: Observing the differences among the three samples	Sub-theme1: Revealing the purposes of question to be solved	Theme 1: Specifying the problem before giving solution	Initiation (Specifying the problem before giving solution)
R16: Questions related to how to make colloids R34: Problem 2 about the process of making colloids R12: Problems about designing a simulation of making colloids	Sub-theme 2: Revealing the purposes of question to be solved		

R16: Problems regarding types of colloids R34: Questions regarding mentioning examples of colloids in everyday life R12: Questions ask to mention the purpose of the question, namely determining examples of colloids	Sub-theme 3: Revealing the purposes of question to be solved		
R16: The problem keyword is the condition of water is unclear R34: Problems related to water pollution R12: The question shows water that is yellow and smelly	Sub-theme 4: Revealing the problems containing in the question to be solved		
R16: - Sample A, including suspension because its particles can be filtered - Sample C is included in the solution because its particles cannot be filtered R34: - Sample A has particles that can be filtered - Colloids cannot be filtered using ordinary filters but must use ultra filters. R12: The particles are easy to filter	Sub-theme 5: Identifying sample based on filtering	Theme 2: Filtering system	Dynamic Adjustment (Connecting to chemical concept and colloid system)
R16: Water filtration using sand, coconut fibre, gravel R12: Water filtration	Sub-theme 6: Filtering system		
R16: - Sample A, including suspension because its particles can provide Tyndall effect - Sample B can provide a Tyndall effect - Characteristics of solutions cannot provide Tyndall effect R12: Sample A is a suspension due to the nature of Tyndall effect	Sub-theme 7: Identifying sample based on Tyndall effect	Theme 3: Tyndall effect	
R16 Sample B, is a colloid because the dispersed phase and the dispersing medium are both liquid (emulsion) R34: The solution is difficult to distinguish from the dispersing particles.	Sub-theme 8: Identifying of sample based on dispersion system	Theme 4: Dispersion system	
R16: Example of sample B is a type of emulsion colloid such as milk, coconut milk and mayonnaise	Sub-theme 9: Identifying of sample based on colloid type	Theme 5: Colloid type	
R12: Relating to the type of colloid, namely aerosol.	Sub-theme 10: Aerosol as type of colloid		
R34: - Sample A is a suspension, if the particles are relatively large that are spread - Sample B can be said to be a colloid if the size of the particles is larger than the solution but smaller than the suspension - Sample C is a solution because the particle size is very small	Sub-theme 11: Identifying sample based on particles size	Theme 6: Particles size	

R12: - Sample A has a relatively large size - Sample A is a suspension because the particles are quite large - Sample B is a colloid because the particles are quite small - Sample C is a solution because the particles are very small		
R12: Sample B is a colloid because it exhibits Brownian motion.	Sub-theme 12: Identifying of sample based on Brownian motion	Theme 7: Brownian motion
R16: Dispersion of colloids R34: Dispersion includes mechanics, namely grinding	Sub-theme 13: Colloid manufacture techniques using dispersion	Theme 8: Dispersion method
R34: Bredig arc by flowing a high voltage current through two electrodes R12: Making a metal sole using Bredig arc method	Sub-theme 14: Bredig Arc	Theme 9: Bredig Arc
R12: Condensation includes double decomposition reactions, ion exchange reactions, redox reactions.	Sub-theme 15: Colloid manufacture techniques using condensation	Theme 10: Condensation method
R16 Condensation is a method of changing solution into colloidal particles.	Sub-theme 16: Condensation as changes in solution into colloid particle	
R34: The grinding process in the manufacture of sulfur	Sub-theme 17: Griding process to produce colloid	Theme 11: Griding process
R16: Types of foam include shaving cream, and whipped cream R34: - Separating gene fragments in biotechnology - Filtering dust in chimneys. - Identifying DNA and the dialysis process	Sub-theme 18: Application of colloid properties in everyday life	Theme 12: Application of colloid properties in everyday life
R34: - Peptization is the making of colloids by adding one type of ion to the precipitate - Making jelly by peptization in water - Rubber peptized with gasoline Nitrocellulose peptized by acetone	Sub-theme 19: Peptization method as colloid manufacture	Theme 13: Peptization
R12 An example of making colloids by preparing the necessary ingredients such as sulphur	Sub-theme 19: The manufacture of sulphur sol	Theme 14: The manufacture of sulphur sol
R34: Alum example of colloid system R12: Adding alum	Sub-theme 20: Using alum as colloid example	Theme 15: Using alum as colloid example
R34: The application of colloidal properties is coagulation. R12: Alum acts as a coagulant	Sub-theme 21: Coagulation as colloid property	Theme 16: Coagulation
R12: Coagulation of colloidal particles	Sub-theme 22: The coagulation of colloid particle	

R12: - Delta formation at river mouths - Rubber processing	Sub-theme 23: The example of coagulation		
R34: Alum is a hydrophobic colloid	Sub-theme 24: Alum as hydrophobic colloid	Theme 17: Hydrophobic colloid	
R34: Alum adsorbs dirt	Sub-theme 25: Alum as adsorbent	Theme 18: Adsorbent	
R34: Precipitation of particles as a way of working of colloids	Sub-theme 26: Particle sedimentation	Theme 19: Sedimentation	
R12: - Color changes and thickening of the mixture during the reaction - Addition of emulsifier solution to maintain colloid stability	Sub-theme 27: Physical observation and emulsifier in colloid system	Theme 20: Combination of physical observation and emulsifier in colloid system concept	Combination with Adjustment (Combining various chemical concept)
R12: - Instructions for placing metal electrodes in solvent solution - Ensure the electrodes are completely submerged in solvent solution - Ensure the distance between the two electrodes is not too close or too far to enter a stable electric arc	Sub-theme 28: Electrode arrangement to support electrochemical processes	Theme 21: Combination of electrode arrangement and electrochemical processes concept	
R12: The electric arc produces small metal particles dispersed in a solvent solution.	Sub-theme 29: Production and dispersion of metal particles by electric arc in solution	Theme 22: Combination of production concept and dispersion of metal particles by electric arc in solution	
R16: Emulsion colloids are dispersed phases and dispersing mediums that are both liquids, for example milk and mayonnaise.	Sub-theme 30: Emulsion and dispersion system equipped with examples	Theme 23: Combination of emulsion and dispersion system concept equipped with examples	
R16: Sol is a dispersed phase in which the solid and the dispersing medium is gas, examples of sols are starch in water, paint, metal sols and sulfur sol.	Sub-theme 31: Sol and dispersion system equipped with examples	Theme 24: Combination of sol and dispersion system concept equipped with examples	
R12: Sulfur dioxide evaporates and forms sulfuric acid, which is dispersed in the earth's atmosphere, sulfuric acid liquid and dispersed in the air together with water vapor and forms aerosols in the form of volcanic clouds which will cause acid rain.	Sub-theme 32: Transformation of sulphur dioxide into sulfuric acid with a dispersion system	Theme 25: Combination of transformation of sulphur dioxide into sulfuric acid with a dispersion system, and the process of acid rain formation	
R16: The condition of the water becoming cloudy is a property of colloids	Sub-theme 33: Relating the cloudy water to colloid property	Theme 26: Combination of cloudy water and colloid property concept	
R12: Heating, cooling, and adding electrolytes	Sub-theme 34: Coagulation by heating, cooling, and adding electrolytes.	Theme 27: Combination of coagulation and heating, cooling, and adding electrolytes concept	
R34: Particles are larger than solution but smaller than suspension. R12:	Sub-theme 35: Identifying of sample based on particle size Sub-theme 36:	Theme 28: Macroscopic: Visualisation in term of particle size, light	Virtual Implementatio n (Implementati

Solution particles can only be observed using an ultra-microscope R34: - Light in the solution is not visible - Colloid cannot be seen directly - Particles in the solution cannot be seen R34: No particles in Sample C were found R16: Colloids are seen from the presence or absence of particles R12: Sample A has light scattered R34: Suspension particles can scatter light and in the visible light path R16: Colloidal particles scatter light R12: These materials can help clarify the cloudy water R16: The condition of the water becoming cloudy R12: The colour changes and thickening of the mixture during the reaction	Identifying sample based on the presence of particles Sub-theme 37: Identifying sample based on light scattered Sub-theme 38: The observation on water condition Sub-theme 39: The observation on colour changes and thickening	scattered, water condition observation, presence of particles, and colour change and thickening.	on of chemical representation)
R12: Volcanic aerosols consist of sulphur dioxide	Sub-theme 40: Chemical compound	Theme 29: Symbolic: Mentioning chemical compound	
R34: The particles in sample B move randomly R12: Sample B has particles that are randomly moving R16 Solution particles combining changed into colloidal particles.	Sub-theme 41: Particles movement Sub-theme 42: The change of particle	Theme 30: Sub-Microscopic: Visualization of the change of particle and movements	

Table 4 reveals thematic analysis results in terms of codes, sub-themes and themes. The codes are obtained from Think Aloud Protocol transcript regarding the way students conducted the post-test. This indicates that before solving the problems, students tend to specify the goal of the questions. Additionally, in sub-theme 4, students revealed the problems containing in the question to be solved. Therefore, the theme obtained is specifying the problem before giving solution, reflecting the creative process, specifically initiation. Upon reviewing the obtained codes, students tended to mention the problems in the items or the purpose of questions asked before generating ideas. This means that initially, students tried to understand by specifying the problem. In conclusion, this process reflects students' initial thinking when solving problems or going through an initiation process.

Subsequently, other sub-themes obtained show that students associated various chemical knowledge (colloid system) to problems, generating a variety of ideas encompassing colloid system concepts. The colloid concepts utilized include filtering system (theme 2), Tyndall effect (theme 3), dispersion system (theme 4), colloid type (theme 5), particles size (theme 6), Brownian motion (theme 7), dispersion method (theme 8), Bredig arc (theme 9), condensation method (theme 10), griding process (theme 11), application of colloid properties in everyday life (theme 12), peptization (theme 13), manufacture of sulphur sol (theme 14), using alum as colloid example (theme 15), coagulation (theme 16), hydrophobic colloid (theme 17), adsorbent (theme 18), and sedimentation (theme 19). The list of colloid system concepts used shows the students' capability to link ideas to colloid system. Based on the themes identified, it can be summarized that the students employed their association skills to link ideas to chemical concepts and the colloid system, reflecting a dynamic adjustment goal. Dynamic adjustment entails association as a crucial element (Ho et al., 2013). This process necessitates students to connect related ideas, expanding on the concepts underlying these ideas. The objective is for students to establish as many connections as possible through the association component, emphasizing quantity, where students must connect related ideas or extend concepts (Cheng et al., 2010; Pelaprat & Cole, 2011). Hence, the primary goal is to identify as many connections between ideas as feasible. Based on the themes identified, it is evident that the students from the experimental group could associate the problems with 19 colloid system concepts, It means that students could show their dynamic adjustment process.

In addition, the students also combined the chemical concepts as shown in the themes obtained such as "Combination of physical observation and emulsifier in colloid system concept (theme 20), Combination of electrode arrangement and electrochemical processes concept (theme 21), Combination of production concept and dispersion of metal particles by electric arc in solution (theme 22), Combination of emulsion and dispersion system concept equipped with examples (theme 23), Combination of sol and dispersion system concept equipped with examples (theme 24), Combination of transformation of sulfur dioxide into sulfuric acid with a dispersion system, and the process of acid rain formation (theme 25), Combination of cloudy water and colloid property concept (theme 26), and Combination of coagulation and heating, cooling, and adding electrolytes concept (theme 27). The themes obtained indicate that students not only connected the colloid system concepts but also combined the colloid system concepts with other concepts to create new solutions. The ability of students of combining the concepts into solutions is in line with combination with adjustment. This process involves combining two or more related concepts or elements to form new ideas. In other words, the students will combine many ideas into one or more new ideas to solve the problem (Sun et al., 2020). Thus, the students from the experimental group could show their combination with adjustment.

Furthermore, based on the themes obtained, it shows their virtual implementation by explaining the ideas in terms of chemical representations. For example, theme 28 obtained is "Visualization in terms of particle size, light scattered, water condition observation, presence of particles, and color change and thickening", indicating that students visualized their ideas in the form of macroscopic. It can be seen from sub-theme 35 (Identifying of sample based on particle size) and sub-theme 37 (Identifying sample based on light scattered). Both examples show students' ability to explain ideas in the form of macroscopic. Moreover, the explanation of ideas in the form of symbolic also was shown where students mention chemical compound (theme 29) with the code of "volcanic aerosols consist of Sulphur dioxide (R12). Then, the theme obtained shows the ability of students to explain ideas in terms of sub-microscopic. In this case, the students visualize the change of particles and movements (theme 30). For example, the codes of "The particles in sample B move randomly (R34), Sample B has particles that are randomly moving (R12)" belong to sub-theme 41 (particles movement), and "Solution particles combining changed into colloidal particles (R16)", referring to sub-theme 42 (The change of particle). Therefore, the explanation of ideas in term particles characteristics shows the students could explain the ideas in the form of sub-microscopic. In conclusion, sub-themes and themes obtained in this study reflect the creative process which consists of initiation, dynamic adjustment, combination with adjustment, and virtual implementation (chemical representation). It means that Scientific Problem-Based Creativity Learning successfully develops students' creative process. The following Figure 1 shows the creative process framework after implementation of SPBCL.

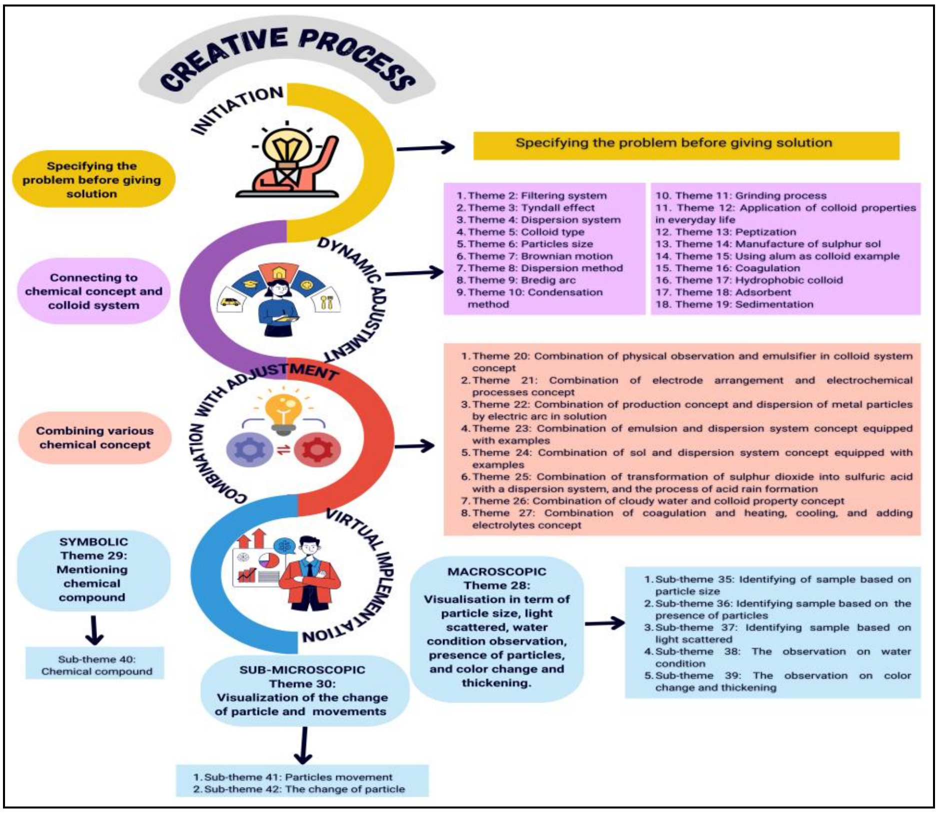

Figure 1
Creative process of students after implementation of scientific problem based creativity learning

CONCLUSION

The implementation of Scientific Problem Based Creativity Learning (SPBCL) has proven to be highly effective in enhancing students' scientific creativity especially creative traits (fluency, flexibility, and originality). The high effect size obtained highlights the effectiveness of SPBCL in fostering creative traits. Additionally, the finding underscores SPBCL's comprehensive approach to nurturing creative process (comprising initiation, dynamic adjustment, combination with adjustment, and virtual implementation- chemical representation). The framework derived from the study illustrates how SPBCL systematically develops students' creative process. In conclusion, SPBCL significantly enhances students' scientific creativity by improving creative traits and supporting the progression of creative process. These findings highlight the potential of SPBCL as a transformative educational approach in chemistry learning and beyond.

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