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Scientific creativity of secondary school students on colloid system

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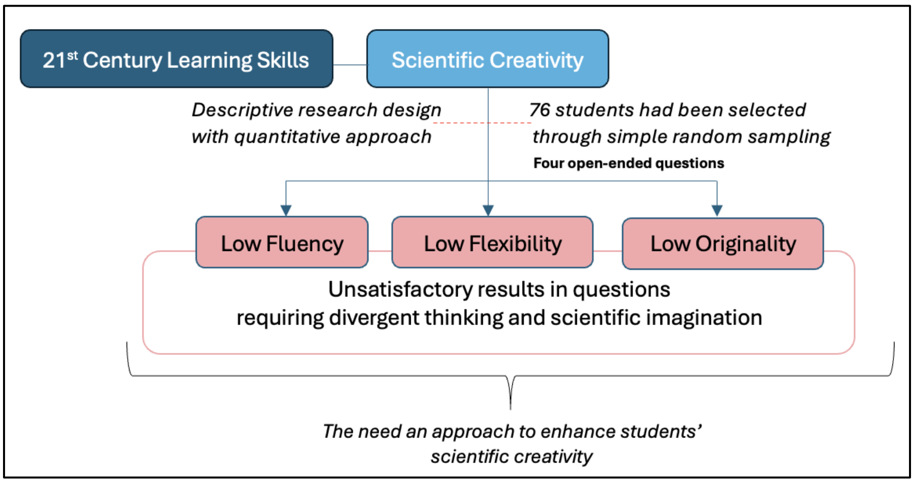
Abstract

The significance of scientific creativity in science has been highlighted for nearly two decades. In chemistry education, this involves students' ability to generate concepts related to chemical problems and phenomena, such as the colloid system found in daily life. Understanding the colloid system requires students to produce scientific ideas for problem-solving. Therefore, assessing students' scientific creativity is crucial. This research aimed to determine students' scientific creativity concerning the colloid system using a descriptive, quantitative approach. Seventy-six students were selected through simple random sampling. Data collection involved four open-ended questions, analyzed using a scoring rubric and percentage scores. The study revealed that students' fluency, flexibility, and originality were low, leading to unsatisfactory results in questions requiring divergent thinking and scientific imagination. These findings highlight the need to enhance students' ability to generate scientific ideas, emphasizing the importance of fostering scientific creativity in education.



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Highlights

- Fluency, flexibility and originality low levels need to focus on creativity.
- Focusing on the colloid system as a key topic in chemistry education.
- Assessing students' scientific creativity using a descriptive/quantitative approach.

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1. Introduction

The skills necessary in the 21st century encompass fundamental capabilities like creativity, problem-solving, effective communication, critical thinking, innovation, logical reasoning, adaptability, managing complexity, and self-direction (Beers, 2011; Soland *et al.*, 2013). These skills are intended to equip individuals for the distinct challenges of the contemporary era, setting them apart from the previous century (Tirri *et al.*, 2017). Within this skill set, creativity plays a prominent role, being recognized as a vital competency across various contexts within the 21st century (Chan and Yuen, 2014; Nakano and Wechsler, 2018; Soland *et al.*, 2013; Tirri *et al.*, 2017; Zulkarnaen *et al.*, 2018).

The significance of creativity lies in its engagement with high order thinking skills. It proves invaluable in presenting solutions to diverse issues through the generation of creative ideas. In the educational context, creativity is defined as students' ability to participate in learning activities aimed at discovering and implementing novel and unconventional ideas while maintaining a foundation of logical and rational thinking (Gunawan *et al.*, 2018). Therefore, the educational field places substantial importance on the process of uncovering and nurturing creative potential (Kanematsu and Barry, 2016).

Additionally, Liang (2002) determined that creative individuals cannot be generally creative across all fields, as someone might exhibit creativity in art but not necessarily in scientific subjects. In the domain of science, creativity is referred to as scientific creativity. This includes the ability to tackle problems through the formulation of ideas and hypotheses. The difference between scientific creativity and general creativity lies in the involvement of innovative experiments, discoveries, problem-solving activities, and the associated characteristics (Obote, 2016). Over the past six years within Indonesia's education system, student creativity concerning the colloid system has exhibited a low level in terms of creative thinking (Sulastri *et al.*, 2019; Ulfah *et al.*, 2020; Wahyu *et al.*, 2017; Wahyuliani *et al.*, 2022). The colloid system is a chemical concept that explains natural phenomena and has numerous applications in daily life (Arini *et al.*, 2021). However, many people are still unaware of the presence of colloids in daily life. For instance, soy milk (Sumarni and Kadarwati, 2020) and air fresheners (Isbullah *et al.*, 2019) are examples, and processes like bleaching, deodorizing, tanning, dyeing, and refining involve adsorption on the surface of colloidal particles, as do the production of fish oil, capsule medicine, and injectable penicillin. Hence, it is essential to study this topic in depth (Hayati *et al.*, 2014).

The low creative thinking is attributed to students' inability to generate their original ideas or novel insights during learning, resulting in insufficient development of their creative thinking skills (Wahyuliani *et al.*, 2022). Moreover, students lack practice in generating new ideas or multiple viewpoints (Ulfah *et al.*, 2020). In essence, there are lack of teachers who employ learning methods aimed at nurturing creative thinking skills and enhancing students' grasp of colloids (Sari and Hidayat, 2017), even in sub-topics like various types of colloids. Students often struggle to differentiate between different types of colloids, and their ability to provide diverse opinions and creative ideas is limited (Wahyu *et al.*, 2017).

The capability of students to think and generate ideas to address forthcoming chemical problems associated with the colloid system is imperative. This ability to think and understand the value of studying colloidal materials is closely tied to students' competence in chemistry (Arma and Supriadi, 2022; Hairida, 2017; Hasanah *et al.*, 2020). However, the involvement of creative thinking in creativity exploration within the realm of chemistry education remains incomplete. It necessitates scientific creativity because, as per Ikiao (2019), scientific creativity influences students' sensitivity to chemical problems, scientific observations, and scientific concepts, thereby fostering flexible thinking in solving chemical problems.

Furthermore, Hu and Adey (2002) contend that creativity in science extends beyond creative thinking to encompass other dimensions such as creative products, processes, and traits. Creative products encompass technical products, scientific knowledge, scientific phenomena, and problems. The creative process entails thinking & imagination, and creative traits encompass fluency, flexibility, and originality. Moreover, scientific inquiry skills, scientific knowledge, creative experimentation, scientific investigation, creative problem-solving, and scientific creative activities constitute elements of scientific creativity (Kirimi *et al.*, 2017; Park, 2004; Suyidno *et al.*, 2018; Zulkarnaen *et al.*, 2018). Consequently, investigations into students' creative thinking within the field of chemistry have yet to comprehensively portray the entire creativity in chemistry. Hence, there is limited information regarding scientific creativity that specifically focuses on the colloid system. Recognizing the importance of scientific creativity in chemistry, this study aims to discern students' scientific creativity concerning the topic of the colloid system.

2. Methodology

This study employs a descriptive research design with a quantitative approach. A total of 76 secondary school students in grade XI (science class), aged 17-18 years, were selected randomly using a simple random sampling technique from the same school. The selected secondary school holds an 'A' accreditation, and its teachers have previously taught the colloid system, ensuring that the students possess the basic knowledge to generate their ideas.

The scientific creativity test was conducted over the course of one hour to assess the overall scientific creativity of the students. The test took place in a classroom setting, with the teacher present and the researchers providing initial instructions. The research instrument utilized was a chemistry scientific creativity test, consisting of four open-ended questions developed by the researchers. The instrument was validated by professors in chemistry education. The validation process begins with sending instruments to professors, and then the feedback is the foundation for researching instrument improvement. The experts provided feedback in terms of quantitative (score) and qualitative (comments). Once the experts agree to accept the research instrument, the validation score is analyzed and confirmed by referring to the validation criteria and the experts' decision. The valid instrument was further tested on 30 students to test reliability and found Cronbach's alpha of 0.62 (reliable).

The scientific creativity model used in this study is the *Scientific Structure Creativity Model* (SSCM) by Hu and Adey (2002). The SSCM encompasses three main components: trait, process, and product. In this study, the traits assessed include originality, fluency, and flexibility. The creative product evaluated is the students' chemical knowledge when faced with scientific problems related to the colloid system. The process in this study involves divergent thinking and scientific imagination, both of which are integrated into the test items. For example, items 1 and 3 involve divergent thinking, while items 2 and 4 involve students' scientific imagination. To determine the level of scientific creativity, the scores for traits and products are combined, then calculated using a specific formula and compared against the levels of scientific creativity to identify the students' overall creativity level.

Table 1 below details each dimension of scientific creativity assessed in this study, with each product representing four questions that include both process and trait dimensions.

The result of the chemistry scientific creativity test was analyzed using a rubric of scoring. Students' score was calculated in the form of a percentage of the score and compared to the criteria level. Table 2 shows the rubric of scoring for creative traits. Table 3 shows the scoring criteria for chemical knowledge (creative product).

Table 1. Detail of chemistry scientific creativity test.

Item	Product (chemical knowledge)	Process	Trait
1	Type & Properties of colloid	Divergent thinking	Fluency, originality
2	Colloid manufacture	Scientific imagination	Flexibility, originality
3	Principle of colloid	Divergent thinking	Fluency, originality
4	Colloids in daily life and industry	Scientific imagination	Flexibility, originality

Source: Elaborated by the authors.

Table 2. Creative trait scoring criteria.

Creative trait	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	Students are not able to provide category of ideas/Ideas are at same category	0
	Students can come up with one category of ideas	1
	Students can come up with two categories of ideas	2
	Students can come up with three categories of ideas	3
	Students can come up with more than three categories of ideas	4
Originality	Student do not answer/ideas are wrong	0
	If the ideas produced by students are general/common ideas/no originality (9 and above)	1
	If the ideas produced are moderately unique (ideas produced by students are 5 to 10% off like each other) (4-8 students)	2
	If the ideas produced are moderately unique (the ideas produced are smaller than 5% like each other) (2-3 students)	3
	If the ideas produced are unique (the ideas produced are only one student)	4

Source: Elaborated by the authors.

Table 3. Creative product scoring criteria.

Creative product	Indicator	Aspect	Score
Chemical knowledge	Unanswered / Misunderstanding / Misconception	If students do not answer/Ideas produced are wrong concept/Ideas produced are misconception	0
	Partial understanding	If the students' ideas are correct and ideas cover one chemical representation	1
		If the students' ideas are correct and ideas cover two chemical representations	2
	Understanding	If the students' ideas are correct and ideas cover all chemical representations namely symbolic, macroscopic, and sub-microscopic	3

Source: Elaborated by the authors.

The score obtained was further calculated in the percentage form of the score using (Eq. 1) and compared to level criteria as shown in Table 4.

$$\text{Percentage Score} = \frac{Total\ Score}{Score\ Maximal}\ x\ 100 \quad (1)$$

Table 4. Level criteria.

Percentage of score	Level criteria
68–100	High
34–67.9	Moderate
0–33.9	Low

Source: Elaborated by the authors.

3. Results and discussion

Scientific creativity holds significance as an important skill because of its connection with the ability of students to problem-solve from a scientific standpoint, and showcasing a mastery of scientific reasoning (Demir, 2014; O'Donoghue *et al.*, 2014). Moreover, it enhances students' capacity to grasp scientific knowledge and engage in scientific issue resolution (Wang and Yu, 2011). Furthermore, it provides insight into an individual's cognitive ability to tackle challenges by generating unique concepts (Antink-Meyer and Lederman, 2015). Unfortunately, the result identifying scientific creativity shows that most students are at a low level. Table 5 below shows the level of scientific creativity of most students.

Table 5. Level of scientific creativity of students.

Level of scientific creativity	Frequency	Percentage (%)
High (68–100)	0	0
Moderate (34–67.9)	17	22.4
Low (0–33.9)	59	77.6

Source: Elaborated by the authors.

Based on Table 5, 77.6% of students are at a low level of scientific creativity and only 22.4% of students are at a moderate level. The low level of scientific creativity shows that most students are not capable of generating large numbers of ideas with different categories in solving colloid system problems. Also, the ideas produced are common / not unique. In addition, 22.4% of students with moderate levels of scientific creativity show students can produce ideas, however, the ideas are still limited either in terms of the total of ideas or various ideas. The finding in this study corresponds with Ikiao (2019) and Kamonjo (2019), that there is a low level of scientific creativity among students in Kenya. Moreover, similar findings also have emerged in Malaysia, indicating a low level of scientific creativity among chemistry students (Jamal *et al.*, 2020; Omar *et al.,* 2017). In conclusion, the scientific creativity of students in chemistry still needs to improve.

According to Hu and Adey (2002), there are three dimensions of scientific creativity: creative trait, creative product, and process. The level of scientific creativity is measured by calculating the score from creative trait and product. In this case, the creative process (scientific imagination and divergent thinking) is integrated into two creative traits and product. It is because to produce the ideas with scientific knowledge, the students involved their scientific imagination and divergent thinking in which the items specifically are developed based on those skills. Table 6 below shows the level of creative traits found in students (fluency, flexibility and originality).

Table 6. Level of creative trait.

Aspect	Percentage of score	Level criteria
Fluency	27	Low
Flexibility	23	Low
Originality	21	Low

Source: Elaborated by the authors.

Based on Table 6, the level of creative traits (fluency, flexibility, originality) of students is low. The lowest score of creative traits is originality with a percentage of score is 21. It means that the ideas produced by students are common or the ability of students to produce unique/original ideas is still low. Besides, the flexibility of students is also low (percentage of score = 23), meaning that students cannot generate a variety of ideas. Besides originality and flexibility, the fluency of students is also at a low level. It indicates that students' ability to produce a large of number ideas is low. To conclude, the student's ability in this study to solve problems related to the colloid system is low.

Furthermore, the quality of ideas relates to the scientific knowledge of students. It is proved by Hu and Adey (2002) and Park (2004) that scientific knowledge is a prerequisite of scientific creativity. Consequently, to exhibit scientific creativity, students must possess a firm grasp of scientific knowledge through a deep comprehension of scientific concepts. In this case, students' ideas need to contain the correct concept of the colloid system. Table 7 shows the result of creative product (scientific knowledge) integrated with divergent thinking ability.

Table 7. The result of creative product in divergent thinking question.

Aspect	Score	Divergent Thinking			
		Item 1		Item 3	
		Frequency	Percentage (%)	Frequency	Percentage (%)
Unanswered / Misunderstanding / Misconception	0	32	42.10	42	55.26
Partial understanding	1	41	53.95	34	44.74
	2	3	3.95	0	0
Understanding	3	0	0	0	0
Total		76	100	76	100

Source: Elaborated by the authors.

Table 7 shows students' creative product ability (scientific knowledge related to the colloid system) in item 1 and item 3. Item 1 and item 3 contain scientific knowledge related to the type and properties of colloids and the use of the principle of colloids in daily life. Both items involve a creative process, namely divergent thinking. Item 1 requires students' ability to produce ideas related to air pollution as a chemical phenomenon in colloid systems. Based on Table 7, 42.10% of students obtained a score of 0. It means students cannot give the correct answer or the ideas produced are wrong concepts or misconceptions. Furthermore, 53.95% of students obtained a score of 1, meaning that the students' ideas are correct, however, it only covers one chemical representation. Besides, only 3.95% of students can afford to obtain a score of 2 which means the ideas generated are correct and cover two chemical representations. In conclusion, most students' ideas range from wrong conception to partial understanding.

Item 3 requires a question emphasizing colloid principle in solving water pollution. According to Table 7, 55.26% of students obtained a score of 0, meaning that the ideas produced are wrong concepts or students cannot produce ideas for solving water pollution. Besides, 44.74% of students obtained a score of 1 which means the ideas produced are correct, however, it only covers one chemical representation. To sum up, the students have a partial understanding of the colloid principle in solving water pollution.

Both items involve divergent thinking, according to Runco and Acar (2012), divergent thinking is the main contributor to creativity and a manifestation of creative potential. It includes individuals associating situations that occurred with the colloid system concept, describing the situation and the applicable colloid system principles, and combining components from situations, objects, and colloid system concepts into a new conclusion, it is adopted from divergent thinking (Sun *et al.*, 2020). According to the findings, 42.1% of students were unable to correctly relate and describe the issues in the questions regarding the colloid system and draw accurate conclusions about air pollution as a chemical phenomenon (item 1). Similarly, 55.26% of students struggled to connect and explain the issues in the questions related to the colloid system, leading to incorrect conclusions about the colloid principle in addressing water pollution (item 3). This indicates that students' divergent thinking skills still need improvement.

Furthermore, the creative product is also discussed related to colloid manufacture and the colloid principle in waste treatment which is integrated with the scientific imagination aspect as a creative process. Table 8 discusses in detail.

Table 8. The result of creative product in scientific imagination question.

Aspect	Score	Scientific imagination			
		Item 2		Item 4	
		Frequency	Percentage (%)	Frequency	Percentage (%)
Unanswered / Misunderstanding / Misconception	0	35	46.05	42	55.26
Partial understanding	1	41	53.95	34	44.74
	2	0	0	0	0
Understanding	3	0	0	0	0
Total		76	100	76	100

Source: Elaborated by the authors.

In terms of scientific imagination, items 2 and 4 are considered. Item 2 requires students' ability to answer questions regarding design experiments on colloid manufacturing. Based on Table 8, as many as 46.05% of students cannot give ideas to design experiments of colloid manufacture or the answers are not correct. In addition, a total of 53.95% of students could design experiments, however, it only covers chemical representation namely macroscopic. This means most students have a partial understanding of design experiments about colloid manufacturing. Furthermore, the ability of students to use the colloid principle in waste treatment is still lacking. This is because 55.26% of students obtained a score of 0, meaning that the students cannot generate ideas to use the colloid system to solve waste treatment. Besides, this is only 44.74% of students can produce ideas for good treatment of waste. However, all ideas only cover one chemical representation. Therefore, it can be concluded that students' abilities either in designing experiments of colloid manufacture or using the colloid principle in waste treatment are lacking.

4. Study limitations

This study was limited to identifying students' scientific creativity regarding their scientific knowledge of the colloid system. In addition, students' scientific creativity refers to the scientific structure creativity model by Hu and Adey (2002). Thus, students' scientific creativity would be different from other scientific knowledge and the use of another scientific creativity model could influence the result. In terms of traits, this study only involved fluency, flexibility and originality, so further research still needs to be conducted.

5. Implication and future studies

This study provides valuable insights into the scientific creativity of students specifically related to their understanding of the colloid system. However, given that the study focused on this particular area of scientific knowledge, the implications of these findings may not fully extend to other scientific domains. Future research should explore students' scientific creativity in other areas of science to determine if similar patterns emerge or if different knowledge areas elicit distinct creative responses.

Moreover, the study's reliance on the scientific structure creativity model by Hu and Adey (2002) suggests that different models of scientific creativity could yield varying results. Future studies should consider utilizing alternative models to provide a more comprehensive understanding of how different approaches might influence the assessment of scientific creativity.

Finally, this study focused on three traits of scientific creativity: fluency, flexibility, and originality. Future research could expand on this by including additional traits or dimensions of creativity, such as elaboration or curiosity, to offer a more holistic view of students' creative potential in science. This would help to identify a broader range of creative abilities and contribute to the development of more effective educational strategies that foster scientific creativity across various contexts.

6. Conclusions

The study revealed that students' fluency, flexibility, and originality were at a low level, resulting in unsatisfactory outcomes when addressing questions that necessitated divergent thinking and scientific imagination. This result implies a need to enhance students' ability to generate scientific ideas. Hence, the result of this study could be an overview of students' scientific creativity and the need for heightened attention to students' scientific creativity.

Authors' contribution

Conceptualization: Wimbi Apriwanda Nursiwan; **Data curation**: Wimbi Apriwanda Nursiwan; **Formal Analysis**: Nor Hasniza Ibrahim; **Funding acquisition**: Not applicable; **Investigation**: Wimbi Apriwanda Nursiwan; Chuzairy Hanri; **Methodology**: Wimbi Apriwanda Nursiwan; Chuzairy Hanri; **Project administration**: Wimbi Apriwanda Nursiwan; Chuzairy Hanri; **Resources**: Nor Hasniza Ibrahim; **Software**: Wimbi Apriwanda Nursiwan; Nor Hasniza Ibrahim; **Supervision**: Chuzairy Hanri; Nor Hasniza Ibrahim; **Validation**: Wimbi Apriwanda Nursiwan; Chuzairy Hanri; **Visualization**: Wimbi Apriwanda Nursiwan; Chuzairy Hanri; **Writing – original draft**: Wimbi Apriwanda Nursiwan; Nor Hasniza Ibrahim; **Writing – review & editing**: Wimbi Apriwanda Nursiwan; Chuzairy Hanri.

Data availability statement

Data sharing is not applicable.

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Conflict of interest

The authors declare that there is no conflict of interest.

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