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Generating Creative Scientific Ideas in Collaborative Learning Using Computer-Based Mind Mapping

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Abstract

Creativity is widely described as a key 21st-century skill. Science education has emphasized the development of creative ideas or innovative solutions with the support of technology. Several research results have shown that the collaborative learning model is the most widely applied treatment and has proven to awaken students' creative thinking abilities. This study aims to generate scientific creative ideas through scientific creative assignments by applying a computer-based Mind Mapping learning strategy in collaborative learning. This research is an exploratory study investigating how Science Education students engage in tasks to generate scientific creativity with technological support, specifically how they generate ideas in small groups by applying relevant thinking strategies, engaging in social communication, and building computer-based creative ideas. Do high- and low-performing groups differ in their idea-generation process, and if so, what are the differences? Mind mapping to facilitate group thinking. The participants were 16 3rd semester students who worked on a series of scientific creativity tasks in 4 groups. All categories emerged in the conversations, although the percentage of frequency varied. Compared to low-performing groups, high-performing groups engaged more in divergent thinking, mind mapping, and regulative discussions, in addition to making these activities more closely connected with idea generation. These findings have implications for the design of technology-supported educational interventions intended to promote and improve group creativity in science education.

Keywords: Mind mapping, collaborative learning, computer-based, divergent thinking, new idea generation, social communication

Introduction

Most students have creative thinking skills at a low level. Their thinking is still in the form of trial and error, not systematic, not detailed, and there are still many obstacles in solving a problem and compiling problem-solving steps (Puspitasari et al., 2018). According to Zubaidah et al. (2017), the average score of students' creative thinking skills is only 23.44 out of 100. Another study showed that students' creative thinking skills score in their learning was only 34 out of 100 (Nuswowati & Taufiq, 2015). According to Hakim et al. (2017), students' scores on creative thinking aspects were only 34.22 (fluency), 40.96 (flexibility), 34.33 (elaboration), and 35.45 (originality). Science is a discipline that requires creativity to discover and formulate new problems and generate diverse ideas and solutions. However, the development of creativity towards generating diverse ideas or solutions needs to be addressed in science education.In this study, university students were encouraged to generate scientific, creative ideas by applying a series of divergent thinking strategies, namely association-associating the seemingly unrelated, decomposition-decomposing into rich details by breaking the whole into parts or listing attributes to stimulate diverse perspectives and combination with adjustment-combining and/or altering. Generating creative ideas involves a complex process in multiple dimensions. First, creative idea generation is primarily a higher-order cognitive process focused on divergent thinking (Finke et al., 1996). Second, ideation involves social processes in most situations, as creativity is often a social or collaborative phenomenon (Sawyer, 2017). Third, cognitive and social thought processes may involve technology, particularly visual representation tools such as computer-based mind maps (Falloon & Khoo, 2014). The multidimensional process of idea generation is complex but crucial for creativity performance. However, research on how university students perform scientific creativity tasks through creative thinking and social communication with technology support still needs to be completed. In addition to analyzing the process of idea generation, there is a need to improve the process by investigating the features of a productive idea generation process that can lead to good performance in scientific creativity tasks. Creativity, the ability to generate new and appropriate ideas or solutions, is considered one factor that drives civilization's progress (Hennessey & Amabile, 2009). It is also a vital skill of the 21st century (Parkhurs, 1999). The literature suggests that creativity is a multifaceted phenomenon that has various aspects, including Process (e.g., the cognitive process of generating ideas), Product (e.g., creative objects, ideas, or solutions), Person (e.g., personality traits of creative people), and Press (environmental and contextual factors that encourage or inhibit creativity).

Collaborative learning has many positive impacts on the learning process. Collaborative learning can positively influence students' motivation (Ramirez & Monterola, 2022) and logical thinking skills (Singsungnoen & Piriyasurawong, 2016). In this learning, students in groups are responsible for teamwork despite learning differently. In collaborative, the learning process goes through many theories on how humans interact through and with computing machines, so this form of collaborative learning is essential for both (Stahl et al., 2014). According to Sompong (Sompong, 2018; Sun et al., 2022a), teachers may integrate collaborative learning and project-based learning to improve creative thinking skills competency by using the eLearning Courseware Learning Management System (LMS). In this study, we used *collaborative learning* to generate scientific creative ideas through *Project Computer-based Mind Mapping*. The application of *Project Computer-based Mind Mapping* assignment to generate creative ideas has been used by Sun et al. (2022). Each student in the group is encouraged to find various ideas, opinions, or thoughts. Learning does not occur in unity, but learning is the result of diversity or differences. In discussion activities, students can carry out activities such as inventorying various information needed, communicating opinions, considering/accepting other people's ideas, or making a conclusion. Students with difficulties can ask other students who are more intelligent or the lecturer. This collaborative learning model aims to improve students' ability who do not understand or have not understood a material perfectly and to exchange and interact from different sides of thoughts, opinions, and interpretations of learning materials and tasks given. These goals are expected to be achieved through assignments and sharing between students, especially in groups. Giving assignments and sharing activities emphasize concept understanding and can affect subsequent materials (Dewi et al., 2016).

Mind mapping is a technique of processing information from reading by mapping ideas based on certain concepts quickly, effectively, and easily understood (Nursoviani et al., 2019). This strategy was introduced by a British psychologist named Tony Buzan in the 1970s, the inventor of mind maps often applied in education (Aprinawati, 2018). In his book, Buzan developed the mind mapping strategy by the mechanism of mind mapping. The work of the brain in processing information. He thinks that efforts to improve the brain's ability to remember information can be made by visualizing content in the form of audio, images, and emotions (Irma et al., 2020).

Literature review

Idea generation through divergent thinking - a cognitive process

Idea generation involves a high-level cognitive process, namely creative or cognitive thinking, which can be characterized by two main stages: (1) divergent thinking, which entails generating a variety of ideas or solutions, and (2) convergent thinking, which involves selecting the most creative ideas or solutions (Sun et al., 2022). These two stages are not entirely separate but are integrated. Research has revealed that generating ideas through divergent thinking is more challenging than evaluating and selecting ideas through convergent thinking. Thinking divergently is crucial for creativity and a reliable predictor of creativity (Dumas et al., 2021; Iva Khoirus & Isnawati, 2020). Therefore, creativity assessment focuses on the ability to think divergently, often measured in terms of fluency (generating numerous ideas), flexibility (producing a variety of ideas), and originality in generating unusual ideas (Sun et al., 2022). Hence, this study emphasizes divergent thinking in analyzing the cognitive process of idea generation.

Divergent thinking requires "thinking outside the box" to explore new alternatives. However, the process remains complex and is not readily accessible to most individuals. According to Nijstad & Stroebe (2006), the cognitive process underlying divergent thinking involves activating knowledge in long-term memory and then processing this knowledge to generate ideas. Previous research has proposed various mental operations or strategies to encourage divergent thinking. For instance, drawing from memory and associating seemingly unrelated concepts or objects can evoke new ideas (Gilhooly et al., 1953). Analogies can be used to bridge the application of existing knowledge or strategies into new and unrelated contexts [31, 32]. Random and irrelevant stimuli to the given problem can generate unexpected knowledge connections [33]. Breaking something down into smaller parts or independent properties can stimulate new thinking directions [34]. Furthermore, new ideas can be generated by reorganizing or rearranging parts of a problem, replacing objects with different formats that serve the same function, adjusting or distorting attributes of a problem, or using something for a new purpose [32]. Moreover, brainstorming is encouraged to gather different ideas from a group of people [6]. These studies have proposed various strategies for divergent thinking, which is crucial for (Hu et al., 2013; Welling, 2007)creative thinking.

To help students master the core elements of divergent thinking, Sun et al. (2020) summarized a set of strategies or critical elements of divergent thinking, namely association - associating seemingly unrelated concepts, objects, or situations (COS), decomposition - breaking down COS into rich details by breaking the whole into several parts or by listing COS attributes to stimulate diverse perspectives, and combination with adjustment - combining and/or modifying COS. The approach proposed in this research has been applied in empirical studies on creativity training and has shown promising potential to enhance ideation performance (Meinel et al., 2019; Ritter & Mostert, 2017; Sun et al., 2020). However, how learners apply these strategies to generate ideas is still not adequately researched.

Idea generation through group communication - a social process

Idea generation also involves a social process because creativity is often considered a social or collaborative phenomenon (Harvey, 2013; Sawyer, 2017; Sun et al., 2022). Significant innovations often result from group work, and social assessment plays a crucial role in developing creative products (Glăveanu, 2018). Research shows that group creativity can be influenced by various factors such as task nature (e.g., task complexity), group composition (e.g., size, skills, diversity of backgrounds), group processes (e.g., sharing, negotiation), and contextual factors (e.g., social environment) (Paulus et al., 2010). Among these, group

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processes, such as group communication and interaction, are considered determinants of group creativity.

Creativity within a group is more complex than individual creativity due to human communication's intricate and dynamic nature. Group creativity is seldom achieved by merely bringing individuals together. Research indicates that each member can bring unique knowledge in a group context, allowing the group to expand its knowledge base to generate ideas (Harvey, 2013). Group communication can also enhance opportunities to unearth less accessible knowledge, which, in turn, can stimulate more ideas or associations (Brown et al., 1998). Furthermore, exposure to others' ideas tends to trigger the emergence of diverse ideas (Nijstad & Stroebe, 2006). The same perspective may stimulate members differently due to differing individual memory structures, where diverse ideas tend to surface.

On the other hand, some studies report that team collaboration, compared to individual work, can reduce output quantity and quality due to factors such as production inhibition, social barriers, and procedural issues (Mullen, 1991; Paulus et al., 2010). For example, group members might be reluctant to express their ideas due to fear of peer evaluation; situations where group members must take turns to present ideas can cause them to forget their ideas or choose not to disclose them; moreover, this can lead to high cognitive load for individuals to attend to others' perspectives while simultaneously generating their ideas (Chen et al., 2019; Oztop et al., 2018). Group divisions rigidly adhering to specific idea categories can inhibit divergent thinking (Brown et al., 1998). Additionally, when there is a high level of conflict, group members must invest extra time in managing existing differences, ultimately hindering group creativity (Harvey, 2013).

Regarding unproductive group processes, researchers have identified communication patterns within groups that can lead to productive teamwork in creative tasks, such as paying attention to others' contributions, building shared understanding, adopting a collective perspective, and building on others' ideas (Paulus et al., 2010). Paying attention to others' ideas can enhance opportunities for creating new combinations, raise questions and disagreements, trigger novel ways of looking at a problem, and shift from existing pathways to avoid fixation (Mercer & Dawes, 2008). The process of developing shared understanding or adopting a collective perspective, where group members elaborate on and value diverse perspectives and integrate individual knowledge. Building on others' ideas is crucial for group creativity during this process, especially when individuals struggle to identify new search cues using their knowledge (Kohn et al., 2011). Related research can also be found in studies on the "exploratory talk" mode, creating a shared space for reflection where open-ended questions and conflicting perspectives emerge, triggering creativity (Mercer & Dawes, 2008).

While numerous frameworks exist for analyzing group discourse in collaborative activities, few studies propose frameworks for analyzing group creativity. Tan et al. (2022) proposed a dialogic framework to assess collective creativity in computer-supported collaborative problem-solving tasks, involving a set of categories to encode convergence data in metacognitive (e.g., regulation), cognitive (e.g., solution generation), and socio-communicative dimensions (e.g., questions, responses). Another proposed coding scheme by Hawlina et al. (2019) focuses on perspective-taking behaviours, encompassing seeking perspectives (e.g., questions related to ideas), sharing perspectives (e.g., thinking out loud, providing exploration), and negotiating perspectives (e.g., agreeing, disagreeing). However, these schemes do not involve dimensions related to applying divergent thinking strategies and relevant technology. Therefore, these schemes are inadequate for analyzing group processes involving divergent thinking strategies and computer-based tools used to facilitate idea generation.

Thus, scientific creative idea generation can be achieved through divergent thinking, social communication, and the use of computer technology specifically by engaging in scientific creative tasks collaboratively, such as creating mind maps.

Technology to Facilitate the Idea Generation Process

Technological advancements have presented new opportunities to support creativity and idea generation. Research has found that computer-based communication systems can facilitate group brainstorming and idea generation by enabling simultaneous and anonymous idea contributions and visual stimuli (Ahmed et al., 2021; Sun et al., 2022). Various interactive technologies are utilized to encourage group creativity in the classroom. For example, Pifarré (2019) found that interacting with digital collaborative spaces can enhance collective creative processes, such as combining, evaluating, and bringing ideas to fruition. These tools emphasize group communication and interaction and have shown promising effects in facilitating group creativity and generating ideas.

Furthermore, generating ideas through divergent thinking involves a complex cognitive process, which tends to be silent and inaccessible to many. To facilitate this complex cognitive process, researchers have explored using visual representation tools such as maps, graphs, and diagrams to make thinking more explicit (Malycha & Maier, 2017; Sun et al., 2022). Mind maps, which allow individuals to represent ideas and their relationships in a diagram visually, are often recommended to support idea generation (Abi-El-Mona & Adb-El-Khalick, 2008; Sun et al., 2022). A mind map is typically built around a central concept, with main ideas directly connected and branching out to other ideas stemming from these main ideas. Mind maps can be created using computer-based tools or pen and paper (Falloon & Khoo, 2014).

Mind maps can provide rich details of the problem situation to stimulate creative cognition by connecting various ideas and spreading activation on the freely created map (Welling, 2007; Sun et al., 2022). Such visual representations can reduce cognitive demands on individuals by leveraging the brain's capacity to manipulate visual images rapidly (Santanen et al., 2004). Furthermore, such representations can facilitate group thinking and social communication of complex ideas (Glăveanu, 2018). They function as shared spaces, enabling group members to communicate ideas, elucidate differences, build shared understanding, construct ideas, reflect on group thinking, identify shortcomings, and reach collective solutions, thus fostering intensive discussions for high-quality ideas.

Scientific Creativity in Science Education

Creativity can be applied to various fields (e.g., arts, architecture, sciences, and technology), and this research focuses on scientific creativity. Science is a discipline that requires creativity to discover and formulate new problems, generate various ideas, and seek solutions (Summers et al., 2019; Sun et al., 2022). Previous research on stimulating students' scientific creativity has focused on developing science inquiry and problem-solving skills (Astutik & Prahani, 2018; Yang et al., 2016). Students are encouraged to learn by exploring real-world problems through data collection and evidence gathering, making scientific reasoning with interrelated variables, and formulating and justifying hypotheses to reach conclusions. Additionally, students are encouraged to collaborate on investigative or problem-solving tasks to develop their collaboration and communication skills, which are crucial parts of authentic scientific practices (Jeong et al., 2019). These skills are essential for developing scientific solutions to real-world problems or authentic tasks; however, they are insufficient to generate diverse ideas or solutions. For example, Yang et al. (2016) developed an instructional approach to encourage creative thinking among elementary school students in the context of inquiry-based learning. This approach focused on questioning, planning, implementing, concluding, reporting, and using strategies to promote openness. They found that this approach helped students improve their performance in science inquiry and convergent thinking but not in divergent thinking.

Previous research indicates that divergent thinking significantly contributes to creative performance in science (Huang et al., 2017; Paek et al., 2016). Creativity through divergent thinking is not only about diverse ideas or solutions to solve a problem but, more importantly, the creation of new problems or the development of a new understanding of the problem from various perspectives (Basadur & Basadur, 2011). As mentioned above, science is a discipline that requires creativity to discover and formulate new problems, generate various ideas, and seek solutions.

Problems statement

The problem in this study is problem 1, how students engage in social communication to generate ideas in solving scientific creativity tasks by applying divergent thinking strategies and compiling computer-based mind maps in small groups. For problem 2, do high- and low-performing groups differ in their idea-generation process, and if so, what are the differences?

The rationale of this study

Various strategies for divergent thinking are crucial for fostering creativity. To assist students in mastering the core elements of divergent thinking, Sun et al. (2020) summarized a set of strategies or critical elements of divergent thinking, namely association - associating concepts, objects, or seemingly unrelated situations (COS), decomposition-breaking down into rich details by breaking the whole into several parts or listing COS attributes to stimulate diverse perspectives and combination with adjustment - merging and/or modifying COS. The proposed approach in this research has been applied in empirical studies on creativity training and has shown promising potential to enhance idea generation performance COS (Meinel et al., 2019; Ritter & Mostert, 2017; Sun et al., 2020).

Tan et al. (2022) proposed a dialogic framework to assess collective creativity in computer-supported collaborative problem-solving tasks. This framework involves a set of categories to encode convergence data in metacognitive (e.g., regulation), cognitive (e.g., solution generation), and socio-communicative dimensions (e.g., questions, responses). Another proposed coding scheme by Hawlina et al. (2019) focuses on perspective-taking behaviours, encompassing seeking perspectives (e.g., questions related to ideas), sharing perspectives (e.g., thinking aloud, providing exploration), and negotiating perspectives (e.g., agreeing, disagreeing).

The advancement of technology has provided new opportunities to support creativity and idea generation. Research has found that computer-based communication systems can facilitate group brainstorming and idea generation by enabling simultaneous and anonymous idea contributions and visual stimuli (Ahmed et al., 2021; Sun et al., 2022). Various interactive technologies are utilized to encourage group creativity in the classroom. For example, Pifarré (2019) found that interacting with digital collaborative spaces can enhance collective creative processes, such as combining, evaluating, and bringing ideas to fruition.

Method

This exploratory study aims to investigate how Science Education students engage in computer-based mind-mapping tasks in collaborative learning. Problem 1 is how students engage in technology-enabled scientific creative idea generation, specifically how they generate ideas in small groups by applying relevant thinking strategies, engaging in social communication, and computer-based constructs. To answer both questions, students' conversations during the computer-based mind-mapping task in collaborative learning were recorded and transcribed to analyze the scientific creative idea generation process. For problem 2, do high- and low-performing groups differ in their idea-generation process, and if so, what are the differences? Mind mapping (mind map) to facilitate group thinking. The participants were

16 first-semester students who worked on a series of scientific creativity tasks in 4 groups. Furthermore, the data collection and categorization stage included the following activities: a) Collecting data through the history of group discussions in the Basic Physics course. b) Extracting sentences and words from the conversation history. c) Categorizing the data. There is a visible portion of the contribution that states the strengths and weaknesses (based on sentiment: positive or negative) of each student in the group, according to the 'contribution category' set by the lecturer in the assessment rubric, for example for this example, the scenario is a scientific, creative assignment. The way of grouping can be done flexibly depending on the agreement of the implementation. Consequently, a model that represents the grouping is required. At this stage, what is obtained is the categorization of the utterances of each group member. Each sentence can be categorized as behaviour in divergent thinking, social communication, generation of new ideas, mind-mapping technology, and metacognition.

Procedure

The time required to conduct this research was two days. On the first day, the researcher introduced the students' fundamental concepts of creativity, creative thinking, and creative mindset for 45 minutes. Following this, the students individually worked on four creative tasks for 50 minutes as an initial exercise. On the second day, the students had a face-to-face lecture for 60 minutes covering divergent thinking, creating mind maps using the Canva application, and group interaction.

During the first part of the lecture, a 45-minute session was dedicated to presenting a series of divergent thinking strategies: association, decomposition, and combination with adjustment. Next, they were taught to use the Canva application to create mind maps for 30 minutes. The trainer demonstrated the basic manipulations of the Canva application. Furthermore, the trainer provided instructions and demonstrations on applying divergent thinking strategies to create mind maps with illustrative examples. After the training, the students were given 30 minutes to familiarize themselves with the Canva application.

In the third part, the students received a 30-minute lecture on group communication and interaction based on dialogic theory (e.g., equal participation, open-mindedness, active listening, appreciating each idea, encouraging and engaging with others' ideas, suspending judgment, and avoiding personal criticism). During the training, the trainer asked the students to complete four creative scientific tasks within 40 minutes (Sun et al., 2022).

Scientific Creativity Tasks

The students from the four groups were tasked with generating ideas in response to a series of scientific creativity tasks. These tasks were based on the Scientific Creativity Test developed by (Hu & Adey, 2002) and (Sun et al., 2022) , involving a range of creativity tasks in the science domain, such as listing potential uses for common objects, posing questions for scientific inquiry, generating ideas to enhance products, and creative imagination (Sun et al., 2022).

Two science education lecturers from the Science Education program at Universitas Negeri Surabaya (Unesa), Indonesia, were chosen to review these tasks and ensure their suitability for science education students. The students in this research were tasked with generating ideas to respond to the following assignments:

Task 1: Write as many scientific uses as possible for magnetic materials.

Task 2: If you could travel in deep space on a spacecraft, what scientific questions would you like to investigate in the deep sea? Write as many as you can.

Task 3: Think of as many improvements as possible that could be made to a regular wristwatch to make it more appealing, functional, and beautiful.

Task 4: Imagine a world without friction. Describe how this world would be like.

Results

The audio recordings encompassed conversations during the four scientific creative tasks by 16 students, divided into four groups, each consisting of 4 students. Each group comprised one male and three female students for each task. The audio recordings comprised 1276 utterances, as one conversation contains several utterances. Table 1 presents an overview of the categories that emerged, illustrative examples of each category, and the frequency of occurrence of each category in the conversations among the students within the group. The illustrative examples are word-for-word translations from the original Indonesian language of the conversations among the students, which we subsequently translated into English for this article. The frequency of utterance occurrences in the conversations of the 16 students majoring in Science Education at Unesa can be explained by the fact that all categories (Sun et al., 2022b) emerged. However, the percentage of their occurrence varied. This can be understood because creative ideas emerged when students worked on the four scientific creative tasks by creating mind maps using computer-based technology, namely the Canva application. Technological advances have provided new opportunities to support creativity and ideation. Some previous studies have found that communication using computer systems can support group discussions and ideation by allowing simultaneous and anonymous contribution of ideas and visual stimuli (Ahmed et al., 2021). Various interactive technologies are used to enhance group creativity in the classroom. Pifarré (2019) found that interacting with digital shared spaces can enhance collective creative processes, such as combining ideas, evaluating ideas, and realizing ideas into reality. These tools focus on group communication and interaction and have proven promising in facilitating group creativity and idea generation. Through discourse analysis of group conversations during task completion, we found that students tend to use the association strategy more frequently than other strategies for divergent thinking. Creating mind maps helps them store ideas for elaboration and evaluation, stimulate new

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discussion paths, and organize conversations. Compared to the Low-Performing Group (LPG), the High-Performing Group (HPG) was more engaged in applying divergent thinking strategies, creating mind maps, and organizing discussions to plan and monitor their idea processes and select thinking strategies. In their conversations, divergent thinking and mind mapping were more frequently associated with each other and with the emergence of ideas. Conversely, LPG was more often involved in direct question-and-answer conversations, and group members tended to stick to their perspectives rather than construct different views. These findings can contribute to understanding scientific creativity development among students with in-depth technological support in a group context.

Table 1. Categorization of in-group interactions

Category	Description	Illustration example	Frequency = N 1276 K(%)
Divergent thinking (cognition):			
Association	Relate concepts, objects, or situations.	Task 1: Looks like a magnetic sensor.	62 (4.9%)
Decomposition	Decompose COS in detail. Merge and/or customize COS.	Task 4: There are static friction, dynamic friction, air friction, and friction between surfaces.	43(3.3%)
Combination with adjustment		Task 3: That clock, I can change the condition of the watch.	29 (2.3%)
Idea generation (cognition):			
New idea (NI)	Generate ideas from new perspectives that have not been mentioned before.	Task 3: Using holograms to make the clock change color according to the environment.	161(12.6%)
Building idea (BoI)	Modify, refine, or extend previous ideas to develop new ones.	Task 3: Wait, we can design our clock color.	41 (3.2%)
Metacognition:			
Regulation	Manage and reflect on the process.	We quickly completed the mid-map because we were pressed for time.	157 (12.3%)
Social communication:			
Elaboration	Use examples, analogies, reasoning, or provide details to explain an idea or thought.	Task 3: Change the color of the clock according to the environment around it, like a chameleon.	59(4,6%)
Question			88 (6.9%)
	Ask questions to seek further information or elaboration.	Task 2: What are the plankton in the deep sea?	
Direct response			54 (4.2%)
	Directly respond to questions without elaboration.		
Agreement			93 (7.3%)
	A positive evaluation of an idea or thought (e.g., approval, acceptance, endorsement).	There are zooplankton only.	
Disagreements			89 (6.9%)
		That's right.	

Category	Description	Illustration example	Frequency = N 1276 K(%)
Argument	Negative evaluation of an idea or thought (e.g., disapproval, non-acceptance, non-support).		117 (9.2%)
		Not true. Phytoplankton also exist in the deep sea.	
	Debate the appropriateness or value of the perspective with clear reasoning.		
		Task 2: In the ocean, there are zooplankton and phytoplankton.	
Use of technology:			
Mind map (Mapping)	Interacting with mind maps	The sphere can be enlarged.	206(16.1%
Other (off-duty)			
Off-duty	Dialogue is irrelevant to the assigned task.	There was a noise outside the classroom.	54 (4.2%)

N = total number of utterances. K = number of utterances of each category. % = percentage of utterances]

Discussion, Conclusion, Recommendations

Differences in categories in group conversations

The frequency of categories displayed in the conversations between the High-Performance Group (HPG) and the Low-Performance Group (LPG) is outlined in Table 2. The high-performance and low-performance groups were determined based on the mind maps produced by each group and the given timeframe. The research results indicate that HPG had more utterances about divergent thinking by applying Association and Decomposition strategies. In contrast, HPG and LPG had the same frequency of utterances in the Combination strategy with adjustment. Additionally, HPG had more utterances about mind mapping than LPG. Regarding social communication, HPG had more utterances about Disagreement and fewer Direct Responses than LPG. Moreover, HPG had more utterances about idea generation (i.e., New Ideas and Building Ideas) than LPG. Furthermore, HPG engaged in more regulations-related discussions and fewer off-task discussions than LPG. On the other hand, HPG and LPG had the same frequency regarding Questions and Arguments. These research findings align with previous and relevant studies, such as those conducted by (Sun et al.2022).

Table 2. Group interaction of HPGs and LPGs.

Category	Frequency					
	HPGs			LPGs		
	H1	H1	Mean	L1	L2	Mean
Association	18	14	16.00	14	16	15.00
Decomposition	10	16	13.00	10	7	8.50
Combination with Adjustment	5	12	8.50	9	3	6.00
Mapping	45	69	57.00	35	57	46.00

Elaboration	10	22	16.00	11	16	13.50
Question	27	18	22.50	21	22	21.50
Direct Response	11	12	11.50	17	14	15.50
Agreement	14	35	24.50	16	28	22.00
Disagreement	22	33	27.50	15	19	17.00
Argument	31	29	30.00	23	34	28.50
New Idea	51	41	46.00	35	34	34.50
Building on Idea	17	23	20.00	13	11	12.00
Regulation	35	56	45.50	29	37	33.00
Off-task	8	3	5.50	10	33	21.50

Research Limitations

This study has several limitations. Firstly, this study did not investigate the individual characteristics of the group and their influence on group process and performance. Secondly, this study did not consider social-emotional expression. Thirdly, this study did not collect students' perceptions of the mind-mapping tool and group task experience, which could help explain the findings from a broader perspective. Future research needs to address these issues.

Conclusion

This research investigated how third-semester science education students generate ideas in scientific creativity tasks, mainly how they generate ideas in small groups by applying relevant thinking strategies and creating mind maps using the Canva application to support group thinking. Through discourse analysis of group conversations during the tasks, we found that students tended to use the association strategy more often than other strategies for divergent thinking. Creating mind maps helped them retain ideas for elaboration and evaluation, stimulate new discussion paths, and organize conversations. Compared to the Low-Performance Group (LPG), the High-Performance Group (HPG) was more engaged in applying divergent thinking strategies, creating mind maps, and organizing discussions to plan and monitor their idea-generation process and choose thinking strategies. In their conversations, divergent thinking and mind mapping were more frequently associated with each other and generating ideas. Conversely, LPG was more engaged in conversations about direct questions and responses, and group members tended to stick to their perspectives rather than building different views. These findings can contribute to understanding the development of scientific creativity among students with technological support in a group context.]

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