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Unleashing Scientific Creativity in Chemistry: Transformative learning activities using Nominal Group Technique

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Abstract
This study aims to examine activities to enhance scientific creativity in secondary school chemistry. Despite its significance, conventional chemistry education frequently stifles creativity due to inflexible, rote memorization strategies. Employing the Nominal Group Technique (NGT), seven experts identified essential activities, including formulating hypotheses, creative experiments, and visualization, as effective strategies. These activities increase scientific creativity dimensions, such as fluency and originality. The findings indicate that all proposed strategies obtained above 70% expert consensus. Future research should investigate the long-term effects with respect to these activities and the integration of digital tools to further enhance scientific creativity in chemistry teaching.

Keywords: Scientific creativity; chemistry; Nominal Group Technique.

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1.0 Introduction

In recent years, scientific creativity has emerged as a key focus to encourage chemistry education. It is an essential component in contemporary education where it is resulting in potential future advancements in scientific discoveries. Scientific creativity can be defined as the creation of new knowledge, the synthesis of multiple concepts, the innovative utilization of existing information and knowledge and the reconsideration of traditional approaches to handling scientific problems (Rahmawati et al., 2019). By integrating creativity into learning, then scientific creativity among students will be enhanced by a very big percentage. Promoting this attribute to students is important as it allows them to engage with the content in a deeper way and approach problems in a more creative manner. This is particularly important in Chemistry because the students have to use it to engage in experiments with chemical activities and materials (Veerasinghan et al., 2021).

The gap between theoretical knowledge and practical understanding limits the student's ability to engage the chemistry contents creatively. Concerns have been made with regard to the need to provide more experience-based activities and practical work that can help students understand chemical events more directly. This indirectly promotes a deeper understanding and enhances creative thinking abilities. The creative activities provide chemistry students greater autonomy to design their own experiments, address authentic chemical challenges, or execute chemical concepts creatively, such as bonding and electronegativity (Danckwardt-Lillieström et al.,

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2020). The integration of contemporary technologies in learning activities of chemistry may enhance scientific creativity by offering new tools for experimentation. For example, virtual laboratories, simulations and various technological tools allow students to conduct chemical reactions and phenomena that are hazardous or too expensive to perform in a normal laboratory. These technologies help to combine the idea with the application, thus developing critical and creative thinking abilities when applied to Science, Technology, Engineering, and Mathematics (STEM) (Zeeshan et al., 2021).

While the importance of fostering scientific creativity in chemistry is recognized, several existing voids prevent its implementation in secondary school. One of those issues is an emphasis on the use of tests and quizzes and memorization of the information. Most curricula focus more on procedural knowledge where the instructions are rigid and pre-scheduled rather than the investigative kind, which would allow the students to come up with hypotheses and try out different possibilities of chemical reactions, that is, a lesser potential for innovative problem-solving (Veerasinghan et al., 2021). Instead of developing hypotheses and considering other outcomes, students may devote their efforts to conforming to standard experimentation procedures. It offers the student a limited chance to engage in discovery or innovative processes. This situation indirectly reduces the desire of students to solve cognitive problems that are necessary for the development of scientific imagination and further practical advancements in chemistry.

Furthermore, many chemistry learning classrooms lack adequate use of chemical concepts in relation to the realities of life. Abstract chemistry may be difficult for students to understand as they cannot easily apply concepts when they are taught in terms of symbols and theories. A lack of understanding of chemistry as a subject entrenched in individuals' lives makes learners less inclined to participate in the learning process, reducing their creativity. Studies show that creative potential progresses when the student is given a chance to solve social issues like environmental issues or sustainable chemistry via creative thinking (Bitermirova & Ussen, 2023). However, more often than not, teaching chemistry in most schools is done without regard to real-life circumstances in which the students can use their creativity productively.

There is also a significant lack of training for teachers regarding the issue. Establishing this domain among secondary school students is tasking because of conditions such as the absence of creative teaching methods and infrastructural support (Haim & Aschauer, 2022). Many chemistry teachers are deficient in training and proper tools required for incorporating elements of scientific innovation into the teaching-learning process. Although teachers and professors realize the significance of creativity in teaching chemistry, they often are bound by constraints based on curricula, time, and a lack of instructional resources appropriate for encouraging chemical creativity in chemistry courses (Keiner et al., 2020). Teachers may not be ready for open-ended experiments or creative activities and may need to shift from a knowledge transmitter to knowledge process enabler. It is possible to increase student's scientific creativity in chemistry through the application of professional development for teachers involving concepts of innovative teaching strategies augmented with the use of technology (Rahmawati et al., 2019).

2.0 Literature Review

The identified gaps of limited understanding that hinder students' ability to engage with chemistry contents creatively require an appropriate framework that might help to transform learning activities in chemistry. The studies on scientific creativity have mainly drawn on several prevailing paradigms, which include the Fourfold Classification of Creativity (Stumpf, 1995), the Dynamic Creativity Framework (Corazza & Lubart, 2020), and the Scientific Creativity Structure Model (SCSM) (Hu & Adey, 2002). Other theories that can be used in conjunction with the present work are the framework suggested by Stumpf (1995) to explain the concept of creativity, particularly in the scientific domain. This theory asserts that scientific creativity can be explained In terms of the product, the person, the process and the situation. It helps identify inputs that may lead to scientific creativity, that is, the maker's personality and conducive setting. On the other hand, Corazza and Lubart's framework acknowledges creativity as a process of interactions between emotions, ideas and the environment constantly and continuously. The four phases outline are motivation, research, ideation, and evaluation. The framework emphasizes on how different settings can either foster diverse thinking and innovation or stifle it. Besides, it also highlights the interplay between emotions and thinking during creative process.

SCSM by Hu and Adey (2002) is a model developed specifically to assess scientific creativity among science students at the secondary school level. This model draws on various aspects of scientific creativity found in literature. It is relevant to chemistry education because having been modified to evaluate scientific creativity among science field students. The SCSM emphasizes three fundamental aspects of traits that uncovered scientific creativity namely, fluency, flexibility, and originality. Furthermore, the model also analyses additional aspects such as imagination, product design, and problem sensitivity. Table 1 illustrates a description of the characteristics.

Table 1: Description of the characteristics.

Characteristic	Description
Fluency	The capacity to rapidly produce several ideas or answers.
Flexibility	The capacity to consider other viewpoints or alter strategies when addressing challenges.
Originality	The capacity to generate ideas or solutions that are distinctive or uncommon relative to others.
Imagination	The capacity to conceive and contemplate scenarios beyond current reality
Product Design	The development or enhancement of scientific items.
Problem Sensitivity	The capacity to discern or identify issues requiring resolution.

Recent studies on scientific creativity further develop the basic framework of SCSM proposed by Hu and Adey (2002). This paradigm identifies essential elements of scientific creativity that need to be adapted in chemistry education contexts. For example, the Chemistry Scientific Creativity Test (CSCT), derived from the SCSM, demonstrates substantial validity and reliability in evaluating scientific creativity among pre-university chemistry students (Ramly et al., 2022). The study by Jamal et al. (2020) represents a notable advancement through the creation of the Chemistry Creativity Test (CCT), which modifies dimensions from the SCSM specifically for chemistry education. This assessment evaluates creativity in aspects of fluency, flexibility, originality, and elaboration, which has been verified for application by secondary school chemistry students. Besides, contemporary research regarding scientific creativity provides novel insights into the promotion of learning activities to enhance scientific creativity among students. Table 2 illustrates the learning activities and the suggested domains of SCSM that can be attained through the activities.

Table 2: The Activities and Scientific Creativity Aspects Matrix.

Activities	Fluency	Flexibility	Originality	Imagination	Product Design	Problem Sensitivity
Formulating Hypotheses	/					/
Creative Thinking		/	/	/		
Creative Experiments	/		/			
Visualization				/		
Creating and Designing Product		/	/		/	
Creative Problem Solving	/	/	/			
Theory Development	/	/	/			

Based on recent studies, seven learning activities can be suggested to be implemented by chemistry teachers to enhance scientific creativity dimensions related to SCSM. Firstly, formulating hypotheses activity, which promotes the aspects of fluency and problem sensitivity. Throughout this activity, students are encouraged to consider various perspectives when identifying fundamental issues and engage in finding potential solutions for the issues. In the context of the students, when they are challenged to develop a hypothesis and conduct the experiment, they get the basic skills of scientific thinking, which are pertinent to learning and understanding chemistry (Bicak et al., 2021).

Secondly, creative thinking activities are recommended to promote the aspects such as flexibility, originality and imagination. This activity is done deliberately to enhance general creative skills, including brainstorming, creativity, and flexibility, since the activity will present as many ideas as possible. Some of the activities are mind mapping, freewriting, and diverging thinking. As pointed out by Rahmawati et al. (2019), learning activities related to creative thinking, including STEAM integration activities, enable students to enhance flexibility and originality in chemistry. As it compels students to look for more than one perspective and to think of something that is not conventional, it enhances creativity and adaptability at the same time. It also enables students to apply science in creative ways because this activity enables them to come up with fresh linkages that can solve given problems. In the use of knowledge integration in creative ways in chemistry education, Ramly et al. (2022) have also employed it in the construction of the Chemistry Scientific Creativity Test (CSCT). This test is relevant to creative thinking activities since the students are required to come up with unique ways of solving chemistry problems and think out of the box.

Creative experiment activity is another powerful tool to encourage students to develop fluency and originality. This activity creates a lively environment context that allows the students to freely generate, elaborate and optimize ideas, thereby creating conditions that allow the students to be fluent and original in their scientific creativity. It enables students to use the knowledge learnt in chemistry lessons, which encompasses open-ended investigation and the development of new methods. Research conducted by Hasanah et al. (2020) pointed to the importance of creative experiments, which refer to hands-on and exploratory types of activity for enhancing chemistry students' problem-solving capabilities regarding their fluency and originality.

Visualization is another suggested activity that can enhance the aspect of imagination. In the field of chemistry education, these activities include simulation, molecule or chemical modeling sets and AR applications that can help make concepts that would have otherwise been more abstract or complex more concrete. This activity has also been discussed by Smyrnaiou et al. (2020) through scientific storytelling. Shertayeva et al. (2023) also established that visualization activities in teaching chemistry enhance students' creativity and visualization abilities in teaching chemistry classes.

Fifth, developing and implementing product activities that cultivate characteristics of flexibility, novelty, and product design. It is also an effective way to help students find chemistry in application throughout this activity to build something new, useful, and functional. Holme (2022) found that, in teaching chemistry, design activities improve flexibility, originality, and product design skills.

The sixth learning activity is creative problem solving that yields fluency, flexibility, and originality. This activity is intended to address a certain challenge or concern. Activities like group problem-solving discussions and root cause analysis make this activity more structured and methodical. The study of Fatmawati et al. (2022) found that the addition of problem-solving activities can enhance high school chemistry students' creativity by a large margin. This activity fosters numerous strategies, effective practices, and innovative strategies which help improve fluency, flexibility, and originality.

Finally, a theory development activity that helps students to increase their fluency, flexibility and originality. During this activity, students are able to identify patterns or behaviors in chemical reactions, make hypotheses, and create more comprehensive theories. Therefore, this activity can help enhance students' scientific creativity by engaging the students to work out problems and come up with hypotheses based on evidence. Concept-development activities leading to learning help to develop a flow of ideas and fluency, flexing between concepts and flexibility, and incorporating new approaches to reach originality (Ernawati et al., 2019).

The objective of this particular study is to examine activities to enhance scientific creativity in secondary school chemistry. The researchers draw conclusions and make recommendations of the activities based on the views of the experts.

3.0 Methodology

This study suggests the Nominal Group Technique (NGT) is the main method to be used. NGT is an organized approach that identifies the group's overall view of a particular issue. The concept was originally formulated as a "participation approach for social planning contexts" (Delbecq et al., 1975), in which social planning contexts are characterized by exploratory research, citizen engagement, the involvement of interdisciplinary specialists, as well as proposal evaluation (Kennedy & Clinton, 2009; Mustapha et al., 2022). The ideal sample size of participants for NGT studies is a topic of debate among researchers. NGT can be implemented as a single cohort or a big group (Mustapha et al., 2022). Still, it can also be divided into smaller groups based on the needs of the study to have productive communication. Table 3 delineates an overview of sample sizes reported in previous studies.

Table 3: Expert sample.

Author	Sample
Van de Ven and Delbecq (1971)	5 – 9 experts/participants
Horton (1980)	7 – 10 experts/participants
Harvey and Holmes (2012)	6 – 12 experts/participants
Abdullah and Islam (2011)	7 – 10 experts/participants
Carney et al. (1996)	Min. 6 experts/participants

(Sources: Mustapha et al., 2022).

The researchers selected seven chemistry education experts to participate in the NGT process of this study. Considering the present circumstances that limit interactions, this quantity is considered appropriate for the research. As the process of gathering experts at a time remains impractical, researchers conducted two-hour NGT sessions online via Google Meet. Experts gathered for a brainstorming session employing the NGT to collect ideas and solutions based on their insights. At the end of the session, the researchers conducted calculations utilizing the NGT method to derive conclusions that address the aims of this study. To summarize the methodologies for this study, NGT consists of four phases:

1. Brainstorming: Refer to the silent generation of ideas in writing. In this phase, participants write their answers to a stimulus question in a quiet and individual manner.
2. Round Robin session: Every participant presents an idea sequentially, which is documented on a flipchart and displayed on the wall. Discussion is prohibited. The facilitator asks for ideas until the group agrees they have sufficient input.
3. Discussion of the list of ideas: Participants engage in discussion regarding each idea to ensure comprehensive understanding.
4. Voting: Participants determine the most significant ideas, optionally rank their preferences and cast votes directly on the flipchart. Subsequently, they analyse the vote trends. This procedure promotes authentic outcomes and commitment through anonymous voting in accordance with the regulations mentioned earlier.
5. Finally, NGT establishes a permanent record of the group's process and conclusion by documenting all inputs and approved revisions on flipchart pages. These documents facilitate the group's ability to effectively resume discussions from prior meetings and inform individuals who were absent from any portion of the session.

4.0 Findings

After a comprehensive literature analysis, we propose activities to enhance scientific creativity among chemistry secondary school students. Table 4 provides a description of activities that may be used.

Table 4: Activities descriptions.

Suggested Activity	Meaning
Formulating Hypotheses	Students cultivate scientific creativity by formulating hypotheses to explain chemical interactions and anticipate consequences based on observed patterns.
Creative Thinking	Students are encouraged to explore innovative solutions for complex chemical problems, enhancing their comprehension of concepts.
Creative Experiments	Engaging in creative experiments to design unique approaches to test students' ideas, enabling hands-on investigation of scientific principles in chemistry.
Visualization	The key to comprehending abstract chemical concepts by imagining and modelling atomic and molecular structures, and reaction mechanisms.
Creating and Designing Product	Students participate in the creation and design of chemical products, such as eco-friendly materials or novel products, to creatively apply their knowledge and tackle real-world issues.
Creative Problem Solving	Fostering creative problem-solving by encouraging students to address challenges, such as optimising reaction conditions using innovative methods and multidisciplinary knowledge.
Theory Development	Directing students to think like scientists by utilizing experimental findings to create or refine scientific theories for generating novel discoveries in the discipline.

The finding reflects the consensus and evaluation ratings for the learning activities to enhance scientific creativity among chemistry students. All the activities' construct concentration levels are within the optimal range, as has been determined from this assessment. Therefore, it is imperative that the percentage derived from this study be in excess of 70%. The analysis results showed that all the items exceeded the 70% level of acceptance by the subject experts. The unanimous consensus among experts on activities such as creative experiments presumably arises from their capacity to engage students in knowledge application actively. This helps the researchers to infer that the learning activities received a warm response from the intended target group. The modified NGT technique is used as the relatively time-saving solution for the rounds' expert assessment, which the Delphi method requires. Table 5 illustrates voter consensus on learning activities.

Table 5: Voter Consensus of Learning Activities.

Learning Activities	Percentage	Rank Priority	Voter Consensus
Formulating Hypotheses	100	1	Suitable
Creative Thinking	95.24	2	Suitable
Creative Experiments	100	1	Suitable
Visualization	100	1	Suitable
Creating and Designing Product	100	1	Suitable
Creative Problem Solving	100	1	Suitable
Theory Development	95.24	2	Suitable

5.0 Discussion

The results indicate activities of creative problem solving, creating and designing products, visualization, creative experiments, and formulating hypotheses, with 100% of respondents acknowledging their significance. Meanwhile, activities of theory development and creative thinking, with 95.24%. This strong consensus indicates that there is increasing awareness in current literature regarding situating scientific imagination through engagement and constructed, enquiring learning methodologies (Ramly et al., 2022). Engaging students with problem-solving activities that involve dealing with scientific problems from different angles enhances cognitive versatility and creativity, which are critical in creativity. That's why chemistry, as the field that combines theory and practice to a certain extent, receives such interventions.

Moreover, the improvement in the assessment of other activities like imagination, visualisation, and designing scientific products also confirms the importance of scientific creativity in chemistry. Using imagination, students are able to picture processes that are occurring chemically, which are not easily seen. This is important when working on abstract thought and scientific reasoning, as noted by (Smyrnaiou et al., 2020). Likewise, designing scientific products promotes creativity and strong problem-solving skills since the students have to devise ideas from the content to solve existing problems. Consequently, it was found that incorporating these activities in a chemistry learning environment may enhance their understanding of chemistry and their ability to think creatively in scientific realms. This ability is essential as it builds students' critical thinking and problem-solving skills. Besides, it will indirectly improve educational systems by guiding teachers to enhance creativity in learning chemistry and develop better outcomes among 21st-century students.

6.0 Conclusion and Recommendations

In conclusion, this study has established that activities enhance scientific creativity in learning chemistry among secondary school students. These findings support previous research on the need for chemistry education to go past traditional knowledge reproduction, incorporating activities that foster scientific thinking to improve students' ability to solve scientific problems creatively. Linking these activities with the key elements of scientific inspiration directly sets up the development of future generations of chemists and scientists. This study is limited by its focus on secondary school chemistry students and the sample of experts in the chemistry education field. Thus, the proposed activities rely heavily on experts' input throughout the NGT phases. It is recommended in future research for educators or curriculum developers to examine the effectiveness of these creativity-focused activities within various educational contexts and interdisciplinary to provide insights on promoting scientific creativity in science education. Besides, future research could benefit from employing NGT in diverse educational contexts, which offers a systematic approach to generating ideas.

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Paper Contribution to Related Field of Study

This paper contributes to chemistry education by proposing a research strategy focused on investigating the suggested learning activities that can foster scientific creativity. It is also addresses existing gaps in the literature by exploring the effect of learning activities on aspects of scientific creativity in chemistry education. The study provides teachers with practical strategies and suggests future research directions to enhance scientific creativity in educational contexts.

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