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ARTICLE

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Making creativity explicit: A workshop to foster creativity in biomedical science education

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Abstract

Previously we identified that biomedical science students commonly misunderstand "creativity," mistaking it for "freedom." In the present study, we describe and evaluate a workshop designed to increase students' awareness of creativity as a highly sought-after employability skill and cognitive process applicable to scientific endeavors. To achieve this, we developed and introduced students to a process called the "Diamond Model," utilizing a case study to contextualize and signpost the creative processes of divergent and convergent thinking. This model was introduced to students in the first workshop of a 12-week undergraduate biochemistry unit (subject) within the Bachelor of Biomedical Science at Monash University, Australia. Students completed pre- and post-workshop surveys to gauge the impact of the workshop on their conceptions of creativity and Bloom's taxonomy of learning. In addition, reflective journals were completed by a small subset of students ($n = 9$) following the workshop. Following the workshop, over 65% of students indicated that their conception of creativity had changed. Thematic analysis of students' survey responses and reflections indicated that this change in the conception of creativity included broadening their definition of creativity, increased awareness of creativity as a skill and science as a creative process, and that creativity can be applied to different areas of life. Students attributed the signposting of creative elements as a contributing factor to their increased awareness. These results indicate the positive impact the workshop and our novel Diamond model had on student conception of creativity, highlighting the importance of explicit communication and signposting in skill development.

KEYWORDS

active learning, biomedical, creativity, science education, science education, workshop

1 | INTRODUCTION

Creativity is a skill highly sought by employers across many fields,[1–7] believing it will give them an advantage over their competitors.[8] The education sector has acknowledged this demand, and many have incorporated it into their ethos and outcomes.[3,9–11] Contrary to its historical bias toward the arts,[12–14] creativity is now recognized as an essential component of science[13,15,16] and a necessary skill that science students need to develop. For example, the Australian Biomedical Science Threshold Learning Outcomes (TLOs)—the national framework that describes the knowledge and skills all biomedical science graduates should acquire upon course completion—state that graduates should be able to demonstrate "creative and innovative approaches to addressing scientific problems."[17]

A learning framework that conceptualizes creativity as a skill is the revised Bloom's taxonomy. Create is the pinnacle cognitive skill of Bloom's taxonomy's cognitive dimension.[18] Create is defined in Bloom's taxonomy as "the ability to rearrange elements, in conjunction with an individual's prior knowledge, to construct a novel and functional product."[18] In the educational setting, the "product" could take the form of a student assignment or project—the hypothesizing and synthesis of knowledge is the "product." Bloom's taxonomy asserts that for students to be able to create, the previous five cognitive skills (remember, understand, apply, analyze, and evaluate) need to be mastered, in addition to having enough background knowledge of the area.[18]

In a previous study, the authors identified that the majority of the Bachelor of Biomedical Sciences (BMS) student cohort at Monash University (an Australian research-intensive university) perceived a lack of creative learning opportunities in the program and, in fact, believed the course restricted their creativity.[19] This conflicted with the number and variety of creative learning opportunities identified in the course (using Bloom's taxonomy's "create"[18]). Student responses determined that the student's perception stemmed from their lack of understanding or misunderstanding of creativity—many mistaking "creativity" for "freedom." Thus, it was identified that there was a need to develop students' skills and, importantly, their understanding of the skills they are developing through the curriculum. The literature demonstrates that the skill of creativity can be developed through explicit definition and discussion of creativity[20] and appropriately structured learning opportunities.[20–32]

1.1 | "Identifying Creativity in Science": A workshop

To address this, a workshop—"Identifying Creativity in Science"—was developed to promote student understanding of creativity and foster their "creative habit."[33] The "Identifying Creativity in Science" workshop was designed for undergraduate biomedical science students. This cohort comprises high-achieving students enrolled in a 3-year degree (each year comprised of two 12-week semesters). The workshop was implemented in the second year, first semester compulsory unit (subject) Human Molecular Cell Biology. As these students have completed the first year of the degree, they have the foundational knowledge to enable the ability to be creative within biomedical science.

The content of this unit focuses on the molecular principles of cellular functions and relationships, the basis of disease, and developmental biology. This unit comprised 2 h of lectures (with pre- and post-lecture activities) and a 2-h workshop per week. The weekly workshops were assessed (contributing to 35% of the unit's total grade) and provided students with the opportunity to apply knowledge and engage in small-group activities, helping them to reinforce and contextualize their learning from lectures and develop employability skills such as critical thinking, problem-solving, and communication skills. The workshops consisted of case-based, problem-based, inquiry-based, and peer-assisted learning.

The "Identifying Creativity in Science" workshop was designed to address the following aims:

1. *Define creativity*, the creative process, and how it can manifest in the education context.
2. *Raise students' awareness that science is a creative endeavor* by contextualizing the creative process in science.
3. *Structure explicit creative learning opportunities* to raise students' awareness of the stages of the creative process.
4. *Inform students* of the rising importance and demand for creativity in the workforce and how it relates to various aspects of their lives.

2 | METHODS

2.1 | Design of the "Identifying Creativity in Science" workshop

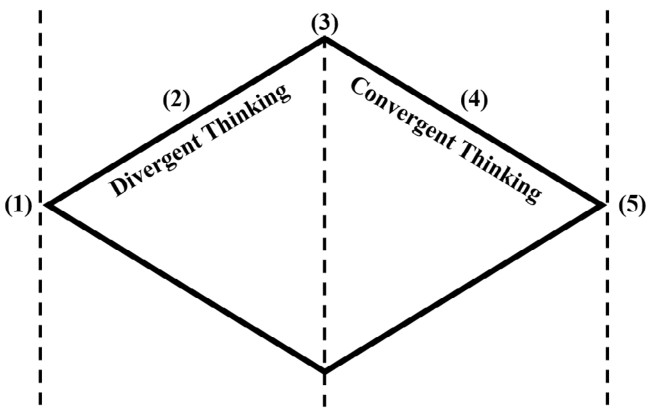
The workshop was implemented in week 1 of the 12-week semester. Results from the previous study[19] were included in the workshop to inform students of the rationale of the workshop. Evidence regarding the growing importance and demand for creativity from the literature and industry was also included to inform and engage the students with the workshop. Bloom's taxonomy and the cognitive dimension were introduced at the beginning to contextualize creativity within education and show students how they can develop creativity through their education. Bloom's creative process and the Diamond model[34] were introduced to explicitly define creativity to the students, to help them see that science is a creative endeavor, and to increase their awareness of the different manifestations of creativity in the course and other areas of their lives.

2.1.1 | The "Diamond" model

To make creative learning opportunities explicit to the students, we developed and introduced the "Diamond" model (Figure 1) based on the "Double Diamond model."[34] The "Double Diamond Model" is a conceptual framework developed by the Design Council in the United Kingdom that illustrates the creative process and the modes of thinking used at different stages—iterative periods of divergent thinking coupled with convergent thinking—to ultimately create a product.[34] The model is broken into two cycles, each consisting of a divergent and convergent phase, as represented in Figure 2. These phases are discover, define, develop, and deliver (Figure 2). The first diamond represents a wide exploration of a problem or concept (divergent) followed by a narrowing of what the problem actually is (convergent). The second diamond represents an exploration of potential solutions (divergent) followed by a phase of testing and refining potential solutions (convergent).

Divergent thinking aligns with the processes of generating or hypothesizing—the ability to brainstorm many ideas in response to a stimulus (which could be a learning activity). Convergent thinking encompasses evaluating these ideas to develop an approach to the problem/stimulus. As this cognitive process is similar to the process of scientific investigation, the model can be used to help students understand how science utilizes creativity.

Taking the concepts of divergent and convergent thinking, we developed a simplified diamond model. The "Diamond" model served various purposes: it was used to structure the activities in the workshops throughout the semester (including) case studies as problems to solve, explicitly signposting the stages of the creative process, and making creative learning opportunities explicit to the students. To help students understand the "Diamond" model and relate it to their learning, a case study activity was used to contextualize the creative process within biomedical science and to help refresh their content knowledge.



(1) Introduce the scenario + provide initial information
(2) Based on the information provided in (1), students hypothesise possible ideas or solutions
Similar to Bloom's "*generate/hypothesise*" phase in CREATE
(3) Provide additional information that helps narrow down the criteria/scope of hypotheses
Helps guide students to focus on the area/topic of interest
(4) Based on the additional information provided (3), students identify the hypothesis from the hypotheses generated in (2) that is most relevant and/or applicable to the scenario
Similar to Bloom's "*plan/design*" phase in CREATE
(5) Using their knowledge and the provided scenario, ask students to justify their choice
Similar to Bloom's "*produce/construct*" phase in CREATE

FIGURE 1 Based on the "Double Diamond Model," The "Diamond" model presented here was used to structure the redesigned workshop. A key explaining the various stages of the creative process is included. Adapted from the Design Council.[34]

2.1.2 | Incorporation of the "Diamond" model

A learning activity—"What's wrong with Ann?"—was designed to demonstrate Bloom's "Create" process and the "Diamond" model in the context of a biomedical science case study. Students were provided with instructional materials in a sequential manner. The "Diamond" model graphic was displayed on the materials provided to the students to signpost which stage of the creative

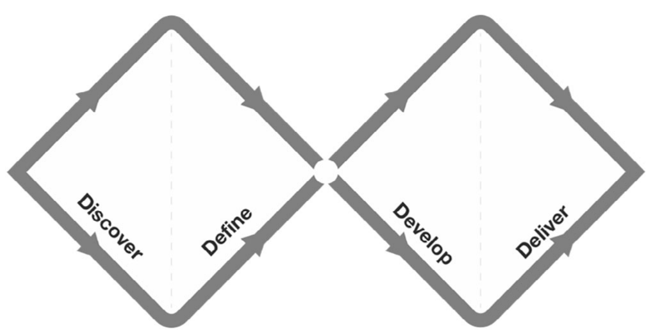


FIGURE 2 The "Double Diamond Model" depicting two iterative phases of divergent (discover and develop) and convergent (define and deliver) thinking developed by the Design Council in the United Kingdom.[34] The Double Diamond by the Design Council is licensed under a CC BY 4.0 license.

process they were at and guide them through the different stages of the case study (Data S1). Part 1 of the case study introduced the students to the scenario and asked them to think of and discuss why the doctor ordered the particular set of tests based on Ann's symptoms and students' prior knowledge of glycolysis (revision from one of the prerequisite units). This required students to employ divergent thinking to brainstorm possible reasons for Ann's symptoms and the doctor ordering that particular set of tests. Once the students had identified that the doctor suspected Ann's symptoms were caused by a defect in the glycolytic pathway, they were given the next part of the case (Part 2) with the test results. They were asked to identify what was the cause of Ann's symptoms and explain their reasoning. The second part of the activity engaged the students in convergent thinking as they had to judge the test results to formulate an answer and justify how they came to that conclusion by using their prior knowledge of glycolysis and understanding how the test results provided reasons for Ann's symptoms.

2.2 | Evaluation of the workshop

2.2.1 | Participants

Students participating in the workshop were informed of the reasons for the redesigned workshops and the nature and parameters of the research project at the start of the semester. Participation in the study was voluntary.

2.2.2 | Measures and data collection instruments

A mixed methods approach collecting both quantitative and qualitative data was used to evaluate the impact of the workshop through online surveys and reflective essays.

2.2.3 | Online surveys

Pre- and post-workshop surveys were created and administered online using the web-based survey tool "SurveyMonkey" (http://www.surveymonkey.com). The surveys were designed to evaluate if the workshop impacted the students' understanding and conceptions of creativity and creativity in science and Bloom's taxonomy of learning. Question styles used included binary (yes/no), checkbox (allowed more than one answer), 5-point unipolar Likert scale (Do not agree at all, Slightly do not agree, Somewhat agree, Agree, and Strongly agree), and open-ended (available in Data S2).

The pre-workshop survey provided a baseline for each participant. The post-workshop survey was used to determine if the workshop impacted the participant's conception and understanding of creativity. To anonymously track each participant's responses, a unique anonymous identifier was used.

2.2.4 | Reflective journals

Nine students (selected on a "first come, first serve" basis in response to an email invitation) volunteered and consented to submit (via email to the primary researcher) a reflective journal entry after the workshop. Students were provided with prompts (if needed) and asked to reflect on their workshop learning experience. Identifiers were removed prior to analysis.

2.2.5 | Quantitative data analysis

Quantitative data generated from the close-ended survey questions were coded depending on the question type—5-point unipolar Likert scale (Do not agree at all = 1; Slightly do not agree = 2; Somewhat agree = 3; Agree = 4; Strongly agree = 5) and binary and checkboxes (Selected/Checked = 1; Unselected/Unchecked = 0). The statistics program "Graphpad Prism 7.02" was used to perform a statistical analysis of the data. Data were statistically analyzed using the two-tailed Wilcoxon matched-pairs signed-ranks test to determine if there was a statistical difference between the students' responses before and after attending the workshop. A significance level (α) of 0.01 was used to determine if a difference was statistically significant.

2.2.6 | Qualitative data analysis

Qualitative data generated from the surveys' open-ended questions were thematically analyzed using NVivo 12©. The emergent coding process[35] was used to inductively analyze the data and identify the prevalence of themes in the responses.

Human ethics approval was granted for all evaluation tools by the Monash University Human Ethics Committee (Project Number: 11851).

3 | RESULTS

3.1 | Workshop design: "Identifying Creativity in Science"

The learning outcomes of the "Identifying Creativity in Science" workshop were developed (Table 1), and the

TABLE 1 Learning outcomes of the "Identifying Creativity in Science" workshop.

Workshop learning outcomes
• Review Bloom's taxonomy of learning with particular emphasis on the 'Create' process. • Define creativity in the cognitive and scientific context. • Apply the "Diamond" creative process model to approach and solve problems. • Recognize the applications of creativity in different contexts. • Identify creativity as an employability skill.

1. Introduction
Pre-workshop survey

2. Definitions of creativity
Student results from previous study. Focus on creativity as a cognitive skill

3. The creative process
The "Double Diamond" model (iterative process of divergent and convergent thinking)

4. Creativity in science
Science is creative in the sense that scientists mentally breakdown complex problems into smaller "solvable" parts (*divergent thinking*) and then using their background knowledge, identify the one that can be answered through scientific investigation (*convergent thinking*)

5. Group activity #1
Students work in groups to apply the Diamond model to solve a case study

6. Creativity and employability
Results from the Foundation for Young Australians research on the rising demand for creativity (& other skills)

7. Group activity #2
Students work in groups to brainstorm how creativity can be applied in different professions

8. Workshop wrap-up
Summarise main points/learning outcomes
Post-workshop survey

FIGURE 3 Lesson outline for the "Identifying Creativity in Science" workshop.

workshop was designed to achieve the learning outcomes in the context of the unit curriculum (Figure 3). The workshop introduced the Bloom's taxonomy framework (the Cognitive domain, Knowledge dimension, and the Cognitive Processes dimension) to the students to contextualize creativity in the learning process. The three stages of Bloom's "Create" process were explicitly explained to the students to inform them what creativity may look like in the education context and to help them realize that there are creative learning opportunities in their course, even if they are not explicitly labeled as such.

3.2 | Impact of the workshop on the students' conception of creativity

Students expressed interest in this project (verbal communication with academics), and a high participation rate was achieved with completion rates of 71% for the pre-workshop survey and 83.5% for the post-workshop survey.

Attending and participating in the workshop positively impacted students' understanding of creativity, as seen in the responses of students who completed both the pre- and post-workshop surveys (Table 2).

TABLE 2 Student views of creativity before and after workshop. "Strongly agree/Agree" response rates of students who completed both the pre- and post-workshop surveys ($n = 307$) to statements regarding their conception and understanding of creativity.

	Strongly agree/agree (%)	
Survey statements	Pre-workshop	Post-workshop
I am creative**	41.0	54.1
Creativity is a multi-step/component process**	68.7	82.7
Creativity is involved in other employability skills**	68.7	90.2
Knowledge is required in order to be creative**	36.5	65.5
Employers value creativity**	73.3	88.9
I would be able to communicate my creativity to a potential employer**	35.5	57.3
Science is a creative endeavor**	67.0	88.2
Creativity is an important skill in science**	76.1	90.2

Note: Data were analyzed using the two-tailed Wilcoxon matched-pairs signed-rank test.
**$p < 0.01$.

Over 65% of students who completed the post-workshop survey indicated that the workshop had changed their conception of creativity. Six major themes emerged when asked (via open-ended survey questions) to explain how their conceptions of creativity had changed (Table 3). When asked specifically if the workshop had broadened their understanding of creativity, over 60% of respondents indicated that it had (Figure 4).

Prior to the workshop, students (90% of survey respondents) were unfamiliar with Bloom's taxonomy. Students indicated that the introduction of Bloom's taxonomy helped them understand their learning (over 80% of survey respondents). The workshop also helped students see that creativity applies in different areas of life and is important in the sciences (Figure 5). The introduction and use of creative signposting using the "Diamond" model enabled students to be more aware of the creative elements in the workshop (Figure 5). Analysis of the student reflections showed that the workshop was generally positively received. The main theme that emerged was that the workshop had made them more aware of creativity in science and its importance as a skill (Table 4).

TABLE 3 Emergent themes from the open-ended survey question "How has your conception of creativity changed?"

Emergent themes from student responses	Frequency (%) of theme in responses ($n = 325$)
"Definition was broadened"	26.2
"Creativity can be applied/used to different areas in life"	21.2
"Science is creative"	18.8
"Creativity is useful/important"	15.1
"Realised that it is a valuable employability skill"	14.8
"Creativity has links to analytical/critical thinking and problem-solving"	14.8

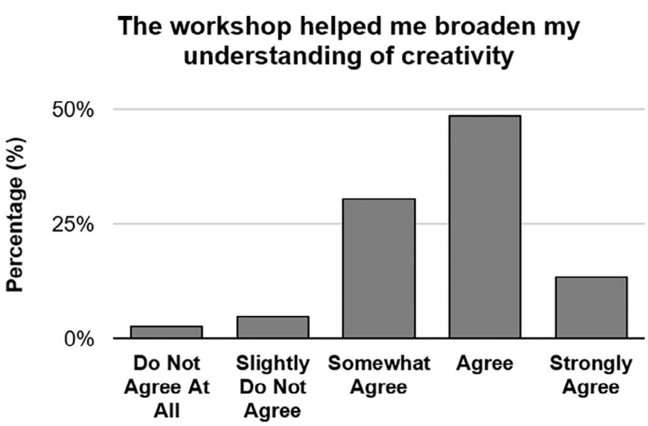


FIGURE 4 Percentage of student agreement (from *do not agree at all* to *strongly agree*) with the statement "The workshop helped me broaden my understanding of creativity" from the post-workshop survey ($n = 426$).

4 | DISCUSSION

A workshop ("Identifying Creativity in Science") explicitly discussing creativity was designed and implemented in a second-year biomedical science subject to facilitate students' understanding of creativity and enable them to recognize its manifestations in science, their education, and their lives. Pre- and post-workshop surveys and student reflective writings were analyzed to evaluate the workshop's impact on the students' conception and understanding of creativity.

4.1 | The impact of the "Identifying Creativity in Science" workshop on students

Studies on redesigning curricula based on defined outcomes have been noted in the literature with varying results.[36–39] Prior studies by the authors identified that students held misconceptions regarding creativity.[19] The workshop aimed to address students' misconceptions of creativity, demonstrate that the scientific process is a creative endeavor, and explain how learning opportunities can be used to help develop creativity. The pre-workshop survey provided a baseline for each student, enabling us to capture any changes produced by the workshop. As shown in Table 2, a significant increase in the response rates for "Strongly agree" and "Agree" in the post-workshop survey was observed, indicating that the workshop improved student understanding of creativity. In addition, over 65% agreed that the "Identifying Creativity in Science" workshop had helped them broaden their understanding of creativity (Figure 4). These results indicate that the workshop positively impacted student understanding of creativity.

The introduction of Bloom's taxonomy helped explicitly define creativity in the context of education, the skills involved, and to increase student's awareness of their learning. It has been shown that combining learning theories and scientific-content knowledge positively impacts students' ability to learn and problem-solve, which was attributed to students being more aware of their learning,[37] which was also observed in this study. By introducing learning frameworks, we (educators) can help students develop meta-cognition, enabling them to

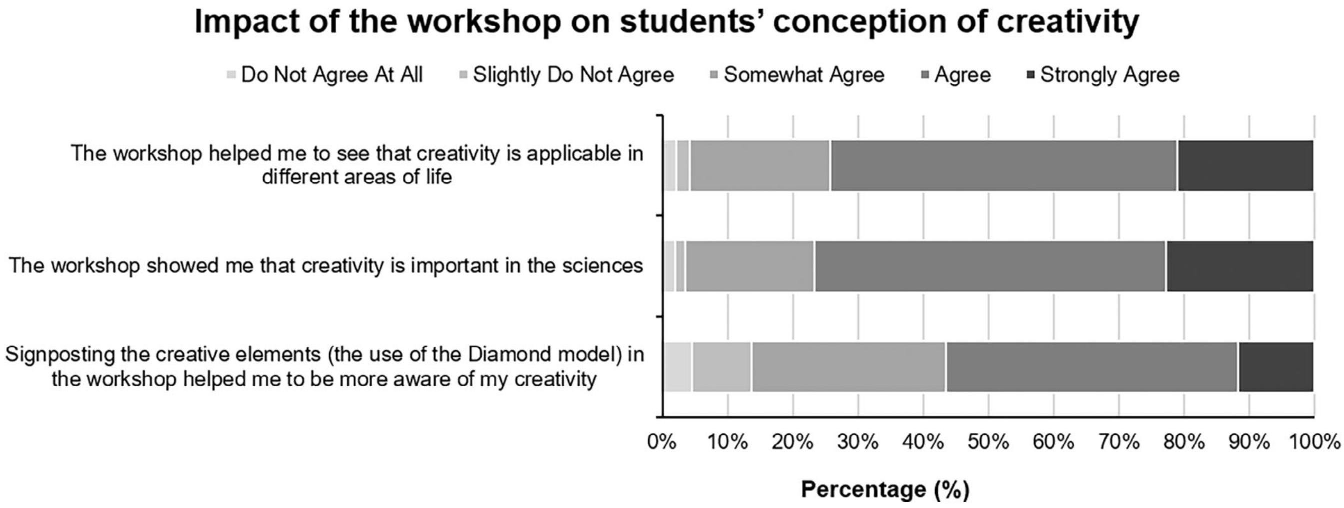


FIGURE 5 The impact of the workshop on students' conception of creativity. Percentage of student agreement (from *do not agree at all* to *strongly agree*) with three statements from the post-workshop survey ($n = 424$).

TABLE 4 Illustrative quotes from student reflections on their learning experience in the workshop.

Illustrative student quotes
"After completing the first workshop of the semester, I can say I genuinely enjoyed learning about the models of creativity and the importance of creativity not only in university but a professional setting too... I wasn't confident with the subject but going over it collaboratively, using the cases as a guide and brainstorming ideas on the whiteboard tables was a creative approach that proved to be successful."
"thinking about the double diamond model is helpful with converging our ideas together, and applying them to the relevant case study."
"I learnt that there are different ways of arriving at the solution which is what creativity entails, using convergent and divergent thinking. Having the knowledge to evaluate and create problems is crucial in the synthesis of a creative approach in biomedical science. Having the ability to brainstorm ideas of approaching a problem and narrowing the scope to figuring out how to tackle the problem is of paramount importance in the workforce."
"The introduction to Bloom's taxonomy of learning and the importance of creativity in science was a good way to give evidence to encourage the development of creativity in these contexts."

identify their strengths and weaknesses and making them responsible for their learning.

4.2 | The impact of explicitly defining and discussing creativity

The development of students' creativity through guided learning opportunities and by being explicit about its existence across different areas is noted in the literature.[21,33] This study achieved this through a clear definition and discussion of creativity as a cognitive skill, its applicability and transferability, and the implementation of the "Diamond" model. The "Diamond" model (Figure 1) was used to structure and signpost the different stages of the creative process students were at during the workshop. This model was chosen for several reasons. First, it is adapted from a well-established framework used in design thinking and product design[21,34] and represents Bloom's "Create" process and the scientific process. Second, this model can easily be applied to different situations and areas in life. Third, it conceptualizes the creative process, which helps students see that creativity is a process that requires boundaries to generate and identify an idea that is novel and relevant to the situation at hand. Demonstrating its applicability through a learning activity, can increase student understanding of the model as they can see it in action.

Signposting—using images, learning outcomes, or instruction—has also been shown to help students become more aware of the presence of factors that may otherwise have been implicit.[21] The "Diamond" model outlines Bloom's create process and the scientific process. These are similar to the work process students go through in a case study and in other creative learning opportunities to reach a conclusion using their prior knowledge and skills to make judgments on new information. One student reflected that "the [Diamond] model is helpful with converging ... ideas ... and applying them to the relevant case study." The conclusion students reached at the end of the workshop resulted from their judgments on the provided data and their ability to synthesize knowledge to construct a coherent explanation. Students have previously performed this in their studies but may not have been aware that this process is them being creative. By explicitly defining and discussing creativity (and in the context of science), we can help students identify creative instances in their studies and daily lives. As this workshop aimed to explicitly define and inform students about creativity and identify, it within themselves, science, and their learning, the workshop's aim was achieved.

5 | CONCLUSION

A workshop was developed to introduce students to creativity, explain why developing their creativity is important, and make them aware of creative learning opportunities in their course. The "Diamond" model was used to structure both the creative process and the work process found in the real world. Evaluation of the workshop identified that explicit definitions and discussions of creativity impacted students' conceptions and perceptions of creativity by raising their awareness of their creativity and ability to communicate their creativity. Based on these results, explicit definitions and discussions of creativity can be used in the development of learning opportunities to raise students' awareness and development of creativity, a skill identified as essential in the present and future.

This study has shown the importance of explicit communication between academics and students regarding curriculum design. The impact of explicit discussion of creativity resulted in changes to students' conceptions of creativity. This workshop design also provides a model to raise students' awareness of the presence of learning opportunities that utilize other skills.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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