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Science Teachers' Understanding of Creative Thinking and How to Foster It as Mandated by the Australian Curriculum

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ABSTRACT
Developing students' creativity is an important educational goal in many countries. The Australian Curriculum Authority has mandated that all teachers teach creative thinking across all subjects and grades. However, after more than 10 years working within this mandate, how do science teachers see their role in promoting creativity in the classroom? This study reports interviews with 13 Australian science teachers, from three jurisdictions, about how they understand creativity, the activities that they use and barriers to supporting creative thinking in classrooms. The findings showed that, although teachers were able to identify many of the elements of creativity and creative thinking described in the literature, many still felt unsure of what creative thinking entails. For class activities that foster creative thinking most teachers focused on project-based or inquiry learning which require long periods of class time to complete. Less emphasis was given to the importance of developing creative thinking skills in making hypotheses by supporting construction of meaning, providing personal insights and explanations through the use of possibility thinking, mental images, analogies when teaching curriculum content. The Australian Curriculum documents themselves give guidance suggesting that creative thinking in science is mainly developed through inquiry-based activities. It is imperative that schools give more support to teachers to understand and develop creative thinking tasks, including time, resources, professional learning, and accountability systems.

KEYWORDS
Creative thinking; mini-c; NOS; science education; teachers

Introduction

In the rapidly changing economic landscape, the importance of developing creative thinking skills is recognized in many countries, and teachers are encouraged to engender creative thinking under the banner of 21st century skills (Craft, 2010; Heilmann & Korte, 2010). In the Australian curriculum, teaching of creative thinking skills is mandated in all subject areas (ACARA, 2010). In science education, teaching creative thinking skills has additional meaning in the context of the nature of science (Taber, 2012). Although science is recognized as an empirical discipline, there are many places creativity or imagination are used to build scientific explanations (Taber, 2012). Newton and Newton (2010) identify three key areas where creative thinking is found: when building a hypothesis, as possibilities are

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explored and explanations put forward; when designing experiments to collect data to test hypotheses; and when applying scientific knowledge to solve practical problems.

Although creative thinking has been included in curricula in many countries, studies have repeatedly reported that teachers struggle to implement ways to develop students' creative thinking skills (Cachia & Ferrari, 2010; Sternberg, 2015). In the Australian context, since 2010 teachers have been made responsible to implement teaching strategies that develop creative thinking skills; during these 12 years it may be expected that teachers would have built a good understanding of what constitutes creativity as well as having a repertoire of teaching strategies to develop creative thinking (ACARA, 2010). However, there has been no study of the effects of this mandate on science teachers' understanding of creative thinking and teaching strategies to promote it. This interview study investigated how teachers from three states in Australia understand creative thinking and how they enact strategies to support creative thinking in science classrooms. This study will help identify ways forward in supporting teachers to promote creative thinking amongst science students.

Creative thinking in the literature

Creative thinking is understood as being an essential element of cognitive processes such as divergent thinking, creative ideation, or creative reasoning (Dikici et al., 2018; Kind & Kind, 2007; Rojas & Tyler, 2018). Further, creative thinking needs to be exercised together with critical thinking because without thorough examination, new creative ideas may not be relevant and consistent with the evidence, norms, and knowledge (Tsai, 2019).

In understanding the role of creative thinking in the context of creative processes, Glaveanu's 5A framework (2013) is instrumental. Within the systematic view of creativity, Glaveanu recognizes the dynamic interactions of creators, creative actions, creative products, and the social and historical contexts. He identifies five components at work in the creative system and advocates including all five components in analyses: Actors, actions, artifact, audience, and affordance (Glaveanu, 2013). Creativity occurs due to material and sociocultural *affordances* that interact with the characteristics of the *actor* (in this case the science student) as they engage in creative *actions (or creative thinking)* to produce a new *artefact* that addresses or communicates with an *audience* (Table 1).

To better understand creative thinking in the context of students' learning in contrast to field defining creativity (such as that of Picasso or Einstein), Kaufman and Beghetto (2009) introduced different levels of creativity. Big-C creativity is the kind of revolutionary creativity exhibited by eminent scientists such as Einstein, pro-C creativity is that evidenced by professional peers such as scientific experts, little-c or everyday creativity is the kind of creativity displayed by people or teachers as they solve problems in their everyday lives, and

Table 1. The 5A's framework for creativity (Glaveanu, 2013).

Characteristic	Description
Affordances	The material and sociocultural environment that the actor is found in which support the actor in taking creative actions
Actor	Attributes of the person in relation to their social context. For example, persisting in the face of difficulties
Action	Behaviour of the actor as a result of ideation, divergent thought and insight to implement plans which are intentional and are constantly being self-evaluated for appropriateness (creative thinking)
Audience	The social aspect of creativity—the audience observes, judges, contributes, critiques and evaluates the artifact. It involves communication between the actor and their social context
Artefact	Artefact or creative act produced as a result of creative action within the cultural context

Table 2. Four levels of creative thinking in science.

Levels of creative thinking	Who judges that the action is creative	Examples of actions and artifacts (5 As framework)
Big-C	Public, the research community	Action: Developing a new scientific theory such as the theory of relativity. Developing the first mRNA vaccine. Artefact: Peer-reviewed, theoretical publication describing the theory. m-RNA vaccine
Pro-C	Professional peers	Action: Designing a new bridge to span a challenging terrain. Using available vaccine technology to design a new vaccine for a disease. Artefact: The bridge or new vaccine
Little-c	People, teachers	Action: Deciding on the most efficient way to carry out an experiment to test a hypothesis. Designing a solution to a practical problem e.g. how to hang shelves on a nonstandard wall. Artefact: Lab report describing the design of the experiment. A well-hung shelf.
Mini-c	People, teachers	Action: Constructing understanding for themselves of a concept that is new to the student. Transferring scientific understanding into an explanatory drawing. Artefact: A verbal, written or pictorial representation of the newly constructed explanation

mini-c or subjective creativity is seen where individuals have personal insights that develop meaning for them as they learn (Table 2).

Supporting creative thinking in relation to the nature of science

Just as scientists engage with creative thinking, students should also be encouraged to develop creative thinking when building scientific explanations in class (Newton & Newton, 2010; Taber, 2012). For example, in relation to building scientific hypotheses, students could be supported to wonder about their observations of the world and to create mental images, analogies, or models through open-ended activities and careful questioning (Craft, 2001; de Souza Fleith, 2000; Hadzigeorgiou, 2005; Hadzigeorgiou et al., 2012; Nersessian, 2008; Taber, 2012). In relation to scientific experiments, students could be encouraged to design and modify methods for testing the hypotheses, critically evaluate the findings, and draw conclusions (Newton & Newton, 2010; Taber, 2012). For application of scientific knowledge, students could be involved in project-based learning to solve practical problems (Newton & Newton, 2010). Although there are various ways to encourage creative thinking in learning and practicing science in class, the educational literature tends to focus on the experimental design and application of scientific knowledge aspects, suggesting inquiry tasks (Barrow, 2010; Cremin et al., 2015; Hetherington et al., 2019; Kind & Kind, 2007; Park et al., 2006) and STE(A)M projects, as ways to foster students' creative thinking across contexts (Ben-Horin et al., 2017; Buck et al., 2018; Colucci-Gray et al., 2017; Hetherington et al., 2019).

Creative thinking framed by the Australian curriculum

The Australian curriculum broadly describes creative thinking in relation to building scientific knowledge and skills. It notes that students need to be encouraged to develop creative thinking as they "learn to generate and evaluate knowledge, ideas and possibilities, and use them when seeking new pathways or solutions" (ACARA, 2016a). In particular, creative thinking is encouraged in order for students to develop "ideas that are new to the individual" as they "speculate about their observations of the world" (ACARA, 2016a). The Australian curriculum also highlights the dispositions of students, including "inquisitiveness, reasonableness, intellectual flexibility, open- and fair-mindedness, a readiness to try new ways of doing things and consider alternatives, and persistence" (ACARA, 2016a). It should be noted that the curriculum documents combine critical thinking with creative thinking, without differentiating between these two constructs.

Despite this broad definition of creative thinking, the curriculum documents predominantly give examples of experimental activities for developing creative thinking skills rather than strategies to help students build mental models or hypotheses (ACARA, 2016b). In addition, the ACARA secondary school documents list learning areas in order of the proportion of content descriptions within that subject that involve critical and creative thinking, placing Science 12th in a list of 13 subject areas, well below such subjects as Humanities and Social Science or Art/Music (ACARA, 2016a). This very low position of the subject Science indicates an implicit arts bias within the guiding documents themselves (c.f., Patston et al., 2018). It is not yet clear how this position of science in the ACARA document has influenced science teachers' willingness to consider and develop creative thinking in their science lessons.

The role of teachers in supporting creative thinking

Teachers play a key role in nurturing students' creative thinking. Consequently, to build a nurturing learning environment, it is essential for teachers to understand the nature of creative thinking themselves and be supported to develop their own creative thinking skills (Beghetto & Kaufman, 2014; Davies et al., 2014; Richardson & Mishra, 2018). Unfortunately, teachers' views of what constitutes creative thinking and how to promote it are often at odds with research findings (Andiliou & Murphy, 2010; Bereczki & Kárpáti, 2018; Skiba et al., 2010). This research study is designed to investigate this dilemma.

Research questions

Based on the importance placed on developing students' creative thinking skills by education systems world-wide, we sought to determine the ways in which a sample of 13 Australian science teachers understand and support creative thinking within the classroom. As noted earlier, it is more than 10 years ago that ACARA first mandated teaching for creativity so there was an expectation that creativity would be part of a teacher's everyday thinking.

Research question 1: What do teachers understand about creativity and creative thinking in science?

Research question 2: What barriers do teachers perceive for students developing creative thinking skills?

Research question 3: What barriers do teachers experience when teaching for creative thinking?

Research question 4: What are the most common activities that teachers use to foster creative thinking?

Methods

This study used a phenomenographic approach based on an iterative sorting of responses to semi-structured interview questions into "qualitatively different categories representing variations of individuals' experience" of teaching for creative thinking (Han & Ellis, 2019, p. 10). These categories were then organized under themes from the 5 A's framework of Glaveanu (2013) and Bronfenbrenner's Ecological Systems categories (1979) as appropriate.

Context and participants

Science teachers from schools in Western Australia (WA), Australian Capital Territory (ACT) and New South Wales (NSW) were invited to participate in semi-structured interviews. All jurisdictions have curricula which are underpinned by ACARA. The first author contacted schools with which she had prior relationships and an invitation letter was sent to invite science teachers at those schools to participate, hence this is a sample of convenience rather than a randomized sample. Table 3 summarizes details about 13 teachers from the six schools who agreed to be interviewed.

Data collection

Ethics approval was obtained from the University Human Ethics Committee (HRE2017-0516) prior to commencing research. Interviews were carried out either in person or via Zoom™, recorded and transcribed. The authors met together to design a series of questions to probe teachers' understanding and experience of creativity and creative thinking in the science classroom. These were arranged under themes and refined over several iterations to ensure articulation of teachers' experience over a broad range of classroom activities. The semi-structured interview protocol was made up of questions under the following sub-headings: information about the teacher and their experience; defining creativity; what does creativity look like in science students' work; how they foster creativity; describing creative artifacts; the importance of creativity; teaching practice and how they incorporate creativity

Table 3. Description of teachers interviewed.

			Teacher			
State	School	Teacher	Gender	No of years teaching	Position	Grades taught (major)
WA	Arrowfield	Christine	female	13	Science & STEM teacher	7–12 (Biology)
		Matthew	male	15	Classroom teacher with a science focus	7 (Primary)
		Sarah	female	11	Head of Science	7–12 (Chemistry/Biology)
	Burrow	Robert	male	28	Science teacher	7–12 (Physics/Chemistry)
		Tanya	female	2	Science teacher	7–11 (Chemistry/Biology)
		Sonya	female	1.5	Science teacher	7, 9–12 (Physics/Chemistry/Biology)
ACT	Crimmins	Cathleen	female	11	Head of science	6–12 (Chemistry/Biology)
	Dunedin	David	male	21	Head of science	6–12 (Chemistry)
		Evelyn	female	10	Science teacher	7–10 (General science)
	Excalibur	Wendy	female	1.5	Science teacher	7–9 (General science)
		Patrick	male	8	Science teacher	7–11 (Chemistry)
		Veronica	female	6	Head of science	7–12 (Chemistry/Physics)
NSW	Firestein	Douglas	male	23	Science teacher	7–12 (Physics)

into their teaching to address the Australian curriculum general capability of creativity; barriers or challenges for teaching for creativity/students developing creativity; and how they assess creativity. The interviews took between 0.75-1.0 hours. In each case teachers were given opportunity to present their understanding and the researcher asked follow-on questions to encourage elaboration (Han & Ellis, 2019).

Analysis

Interviews were transcribed and coded for themes using nVivo™ software. Following a reading of the transcripts by authors for the purposes of familiarization to understand the breadth of responses, qualitatively different responses by interviewees to each question were identified by the first author (Han & Ellis, 2019). The categories that arose were then condensed, by agreement between authors, by combining similar categories of response. Data analysis was iterative as the initial categorization, condensation and reduction processes were repeated several times to ensure agreement between authors about the uniqueness of the categories that arose, the appropriateness of the condensation decisions and the logical relationships between the categories and the themes under which they were categorized (Han & Ellis, 2019). Following condensation and reduction of the categories, each category was classified under major themes: according to the 5A categories of Glaveanu (2013) for responses related to research question 1; and according to categories based on Bronfenbrenner's Ecological Systems framework Theory (1979) for responses related to research questions 2 and 3. Since questions related to research question 1 in the semi-structured interviews were originally designed to probe teachers understanding of creative thinking in terms of creative actions, affordance, characteristics of the student and creative products or actions, use of the Glaveanu (2013) (Table 1) was appropriate for thematically categorizing the responses. On analysis of responses to research questions 2 and 3 it became evident the categories that arose were related to the environment within which the actions were taking place and that these actions were related to three of the five influences on students (or teachers) identified by Bronfenbrenner (1979), namely, individual decisions (agency), experiences within the classroom (microsystem) and the wider school environment (macro-system). A decision was made to categorize responses to research question 4 under two themes related to the length of time over which the activity occurred because this aspect correlated with teacher concerns about time constraints identified under research questions 2 and 3.

Results

Coding of the 13 teacher interviews provided responses to the four research questions: teacher definitions of creativity, barriers to students exercising creativity, barriers to teachers teaching for creativity and descriptions of teacher developed activities to promote creativity. These four categories are presented in Tables 4–8.

Response to research question 1: what do teachers understand about creativity and creative thinking in science?

There were a variety of views about what constitutes creativity and creative thinking in the science classroom which are summarized in Tables 4 and 5 and arranged under the 5As of

Table 4. Teacher understanding of creativity in the science classroom: creative actions and artifacts (Glaveanu, 2013).

Themes and examples	No of teachers
1. Creative actions of students—process or mechanism	
Applying concepts or theories in other contexts—linking concepts (mini-c)	13
Unique thinking (Big-C or Pro-C)	8
Enacting design thinking strategies—creating, evaluating and improving solutions (Little-c)	7
Exploring different perspectives (mini-c)	5
Considering aesthetics and expressing personality	4
Visualising the invisible (mini-c)	3
2. Types of creative artifacts produced by students	
A product which was specifically designed and produced to solve a problem (Little-c)	12
A scientific explanation constructed by students themselves (mini-c)	11
Representation of understanding through poetry, story, drawing, concept map (mini-c)	9
Inquiry learning: experiments designed by students (little-c)	8

Table 5. Teacher understanding of how creativity can be displayed in the science classroom: audience, actor attributes and affordances for creativity (Glaveanu, 2013).

Themes and examples	No of teachers
1. Communication to an audience	
Communication of ideas in unique and persuasive ways	7
2. Attributes of students (actor) that foster creativity	
Resilience or persistence in the face of challenges/willing to take risks or be wrong	8
An innate characteristic that some students have more than others	7
Open-minded (open to other ideas)	6
Personal interest/joy in being creative motivates the student (not grades)	6
3. Affordances—social and material aspects of the classroom environment that support creativity	
Encouraging student collaboration within small groups (classroom design facilitates this)	11
The teacher asks open-ended questions, allows exploration of ideas and gives choice	11
Purposeful allocation of time to explore ideas and be creative (e.g. combining learning outcomes)	10
Students supported through provision of content knowledge, skills and scaffolding	9
Ensuring a safe environment for making mistakes	4
Celebrating creativity—making it visible in the class (both of students and scientists)	4

Table 6. Barriers identified for students exercising creativity.

Themes and examples	No of teachers
1. Macrosystem factors	
Limitations due to lack of time. Students need time to express creativity	7
Creativity is not prioritized or supported by school	7
Physical environment or the school rules (e.g. safety) limit creativity	5
A fixation on grades (parents and students)	3
2. Microsystem factors	
Creativity is not prioritized or supported by teacher	7
Creativity overload (especially during COVID-19 lockdown)	1
Lack of clear or realistic expectations from teachers	1
3. Student agency	
Student resistance to thinking deeply, taking risks or being wrong	11
Lack of practical skills/content knowledge needed to pursue creative solutions	2

Glaveanu (2013): creative *actions* (creative thinking), *artefacts* produced, *audience* (communication or presentation of ideas), the *actor's* personal attributes necessary for being creative and *affordances* that support creativity.

At first, nine out of 13 teachers struggled to give a definition of either creativity or creative thinking in science classrooms. For instance, Sarah, head of the science

Table 7. Barriers identified to teaching for creativity.

Themes and examples	No of teachers
1. Macrosystem factors	
Time limitations	10
Curriculum contains a lot of content knowledge that must be addressed	10
Supporting creativity is not a school or departmental focus	6
Competing priorities or strategies	6
Lack of resources, time for setting up and safety issues	4
Teacher (or parent) concerns that student grades will suffer	3
Planning requirements across all classes in a grade limit flexibility in teaching	3
Lack of accountability for encouraging creativity	2
2. Microsystem factors	
Increased workload—extra effort in planning and marking	3
Resistance from students	2
3. Teacher agency	
Resistance from teachers including fear of losing control/not knowing answers	7
Difficulties assessing creative tasks or creativity within tasks	6
Not knowing what creativity is and how to support it	5

Table 8. Activities teachers used to promote students' creativity/creative thinking.

Themes and examples	No of teachers
1. Projects over a number of lessons	
STEM projects or PBL that involve designing and building/making a product or solution (Little-c)	8
Inquiry learning. Designing an investigation (Little-c)	5
2. Creativity included in everyday class activities	
Students present understanding in unique formats e.g. drawings, poems, class presentations, concept maps (mini-c)	8
Students asked to apply concepts or theories in other contexts (mini-c)	6
Students construct explanations for a phenomenon in answer to open-ended questioning (mini-c)	5
Looking at the importance of creativity in science as a human endeavor	1

department at her school said, "I think I probably don't actually know enough about what creativity in science actually looks like" and she added that she didn't think that many other teachers understood what it is, how to measure it or how to encourage it. Other teachers (5) found it hard to differentiate between critical and creative thinking. However, as teachers described examples of creative thinking that they had observed in their classrooms, greater understanding of creative thinking emerged. The fact that the ACARA documents combine critical and creative thinking and give limited guidance for how these capabilities are related to the curriculum outcomes in science may be one of the sources of confusion for teachers. This became evident when many of the ideas described in Tables 4 and 5 only emerged as teachers clarified their thinking by giving examples of creative and non-creative actions, artifacts or attributes.

Creative actions or thinking of science students (Table 4)

The first response that many teachers gave (8) was that creative actions involve unique thinking, novelty or "thinking outside the box." This suggests that teachers, think of the big-C or pro-C creativity that represent huge breakthroughs in science or the design work or professional scientists and engineers when they first think about creative actions.

> Christine: I think creativity is offering unique solutions or ways in which a problem could be solved that nobody has tried solving in that way before.

Four teachers focused on the necessity for a student to focus on aesthetics and expressing personality for an action to be creative, suggesting that they held a view that creativity is essentially a characteristic found in the world of art and humanities.

However, with continued questioning about the types of actions of students that they would consider creative or not creative, most teachers gave examples of actions related to producing solutions to problems, for instance while designing experiments or solutions to real world problems encountered in project-based learning. Production of these solutions required students to find genuine, economical solutions, recognize limitations of the solution and work to improve the product, including through making creative choices of materials (7). These examples represent little-c creativity—the everyday creativity exhibited as someone applies scientific knowledge and processes to solve real world problems that they encounter in their daily lives.

As teachers began to elaborate examples of creative actions, most (12) also included mini-c creative actions which involved applying a concept or theory in new contexts and linking ideas. This could involve such actions as visualization of invisible entities such as atoms or molecules (3) or exploring ideas or solutions from different perspectives (5) which are examples of creative thinking in making hypotheses (Newton & Newton, 2010). Douglas gave the clearest example of mini-c creative thinking in his response where he recognized that creative thinking can be a personal construction of understanding. He suggested, however, that this is often not seen as creativity nor acknowledged as such.

> *Douglas:* Look, I'm thinking it's coming up with a technique or a method or some action that you haven't been shown directly, you've had to either synthesize from what you already know, or from something you've just guessed in the past. So it's the opposite to just repetition or mimicking. If you haven't seen the question before, you need to draw on a whole lot of—maybe some equations you've seen before, or some information that you know from somewhere else and pull things together. And I think that's creativity.

Creative artifacts (Table 4)

In terms of the creative artifacts that students produce in the science classroom, teachers most frequently described projects in which students researched and then designed a solution to a problem using creative thinking in application of their knowledge and ideas (Newton & Newton, 2010) (12). The final product may be a written report, a physical model or prototype, involve digital design or robotics. Reports generated as a result of creative thinking in conducting experiments (Newton & Newton, 2010) that asked students to design experiments to investigate scientific questions were another example of little-c creative thinking (8).

A second type of creative artifact that teachers described was when students constructed understanding or explanations for themselves (mini-c creative thinking) (11). Representation of understanding or explanations in formats such as poetry, drawing, storying or concept mapping or in the form of a lesson presented to other students (9) were also believed to give greater opportunities for students to engage in creative thinking. Whatever the creative artifact was, teachers stressed that creativity depended on the solution to the problem or the explanation being personal to the student rather than copied from others. For instance, Douglas elaborated on the personal aspect of creative thinking.

> *Douglas:* I was at a [physics] conference in Italy and an Italian speaker gave his talk and at the end someone said, 'what you've said is not really new, and it's not all that interesting.' And the guy got up proudly and he said, 'Yes, but I did it.' And I thought, 'for him it was new.' And [for] my lower level year 10 class that's what you want them to experience-that desire to link things together and to put together the knowledge. . . and then for them to see the importance of it. So even if it's not terribly creative from someone else's point of view, for them, if they've made that link, if they have put that knowledge together, then that's what I'm seeking.

Communicating to an audience (Table 5)

Seven teachers noted that creative thinking in science necessitates effective and persuasive communication of ideas to an audience. The mode of communication could be unique, such as through poetry, story-telling or drawing, as described above, giving further opportunity for creative thinking through transferring understanding to new formats.

Actor's personal attributes (Table 5)

Teachers identified a number of personal characteristics that help students engage in creative thinking and argued that these should be supported. Most notable was a willingness to take risks and make mistakes and persistence/resilience in the face of challenges (including belief in their ability to find solutions) (8), and openness to new ideas (6).

Although seven teachers believed that creativity and creative thinking were innate characteristics which come more naturally to some students than others, these teachers recognized their own role in supporting the development of greater creative thinking. However, six teachers noted that students who pursue thinking creatively have intrinsic motivation due to personal interest or joy in being creative, and this is a greater motivating factor than grades or other extrinsic motivators. So the challenge is for teachers to engender this motivation by presenting suitable affordances.

Affordances that promote creative thinking (Table 5)

Finally, teachers discussed ways in which students may be encouraged to display creative thinking such as opportunities for group collaboration (facilitated by the physical layout of the classroom) (11), asking students open-ended questions that allow them to explore a variety of ideas and giving students choice in what aspects of a topic they will pursue (11), setting aside extended time periods for students to explore ideas, for instance, by combining learning outcomes (10), and providing a safe environment for trying out ideas and allowing students to make mistakes (4). Nine teachers highlighted the importance of ensuring that students possessed the necessary content knowledge and skills in order to successfully apply creative thinking to tasks.

Response to research question 2: what barriers do teachers perceive for students developing creative thinking skills?

Teacher responses identifying barriers to students exercising creative thinking (Table 6) were categorized according to Bronfenbrenner's Ecological Systems Theory (Bronfenbrenner, 1979) as macrosystem factors (related to barriers within the system or school), microsystem factors (related to barriers within the classroom) and barriers related to personal decisions (teacher agency).

Macrosystem barriers

Seven teachers identified time constraints as a major barrier to exercising or developing creative thinking, expressing the belief that students need time in which to think and create ideas but that teachers often allow students to move on without encouraging them to pursue and elaborate ideas.

> *Christine:* I think one of the things we do really poorly is that . . . we ask students to be creative, and they go with their first solution. And they just don't spend the time essentially having conversations or even negotiating or thinking critically, or talking to their peers around, 'I don't think [this is right] how about we do this?' I think that they go, 'Oh, yeah, that's good enough, let's just go with that idea.' [Creative thinking] takes a long time for adults to do it. So it's very unfair to expect students to be able to go through that process [of thinking creatively] in an even more constrained environment.

The limited class time available to encourage deeper thinking and giving students the opportunity to develop their own explanations and solutions to problems was mainly blamed on a content heavy curriculum which mandates a lot of scientific knowledge that must be covered (see Response to Research Question 3) and this problem is compounded by a lack of prioritization or support for development of creative thinking by the school or science department. Additionally, some parents (and students) hold a transmissive view of education, believing that it is the teacher's responsibility to give the 'right' answers, especially if high-stakes assessments are looming, resulting in students being unwilling to engage in creative thinking tasks (3).

Other macrosystem factors acting as barriers to exercising creative thinking by students were the lack of flexibility within the physical environment (e.g. inability to move desks around for collaboration) and school rules (e.g. limiting risk in the classroom) which limited the types of activities in which students could engage (5). These responses were related the frequent connection that teachers made between creative thinking and group projects, such as PBL or Inquiry Learning which typically requires more flexibility in classroom arrangements and whole school support

Microsystem barriers

In terms of barriers to creative thinking within the classroom, teachers did acknowledge that science teachers themselves often do not prioritize creative thinking (7). One teacher noted that they may not have clear or realistic expectations of students and how they will display creative thinking, due to their own lack of clarity about what constitutes creative thinking. One interesting observation from a teacher named Evelyn was that during COVID-19 lockdowns, where students were working online, so many teachers of different subjects had given creative projects or assignments to complete that students had, what she described as 'creativity overload.'

Student agency

Teachers identified two areas which result in students not fully engaging with activities meant to promote creative thinking. Related to student resistance to activities that require more effort than 'normal,' teachers noted that when students had to think more deeply about 'why' questions they sometimes were unwilling to engage. This may be as a result of a fear of making mistakes or lack of confidence in students who have learned to rely on teacher support rather than take initiatives for themselves (11). The importance of relevant content knowledge and skills to enable students to engage in creative thinking was also noted (2).

Response to research question 3: what barriers do teachers experience when teaching for creative thinking?

Teacher responses identifying barriers to students developing creative thinking (Table 7) were also categorized as macrosystem and microsystem factors and barriers related to teacher decisions (teacher agency).

Macrosystem barriers

The theme of lack of time for teachers to develop lessons which support creative thinking (10) was evident as a major barrier for teachers. The main cause cited was that the curriculum was crowded with content knowledge that must be addressed (10). These concerns were exacerbated by a perceived lack of support at the school level for developing creative thinking in students (6). In addition, the school may have competing priorities or strategies within the classroom, such as a focus on numeracy or literacy or on testing and collection of data for reporting. Teachers also spoke of lack of resources, time to set up activities and safety as barriers to teaching for creative thinking (4), highlighting that these teachers see teaching creative thinking as being inextricably linked with practical activities, such as experiments or STEM projects. Interestingly, two teachers noted that there was a lack of accountability for encouraging creative thinking within the school which meant that they tended to focus on those aspects of teaching for which they would be held accountable.

Three teachers spoke of pressure that they experienced from parents to focus on direct instruction that parents believed would enhance students' grades. This affected both student engagement and teacher willingness to provide what were perceived as new and experimental ideas and methods designed to support creative thinking. This effect was compounded where teachers were required to collaborate with other teachers, who may be less interested in supporting creative thinking, across classes within the same grade level to prepare common assessments. This once again highlights a common belief, which will be discussed later, that creative thinking in science mainly occurs during longer term assessment tasks such as inquiry learning and project-based learning (PBL). All teachers interviewed also said that they had never had an opportunity to attend professional development courses about how to teach creative thinking. One early career teacher indicated that initial teacher training had only addressed creative thinking to a limited extent.

Microsystem factors

Three teachers discussed the increased workload that may result from giving opportunities for creative thinking—due both to extra planning or differentiated marking (as allowing for creative thinking meant that, in their view, students produce widely varying responses). Two teachers also said they were hesitant to introduce activities that they perceived as encouraging student creative thinking due to student resistance to these kinds of activities. Herein lies a problem from the student perspective for introducing creativity skills in the classroom that is worthy of further study.

Barriers related to teacher agency

In terms of teacher decisions, seven teachers said that teachers may be resistant to change and that teaching for creative thinking may require a considerable adjustment in teaching practices. This resistance is compounded by not knowing how to recognize or assess creative thinking (6) or not even really knowing what creative thinking in science is and therefore how to support it (6). For instance, one teacher admitted their fear that encouraging creative thinking in students may result in not knowing the answer themselves or losing control of behavior in the classroom.

Response to research question 4: what are the most common activities that teachers use to foster creative thinking?

Teachers were asked to identify activities that they carried out in the classroom which they believed promoted creative thinking in students. A summary of these activities is found in Table 8. Two main categories of activities were evident: those that involved a major project or assignment with experiments or applications (little-c creative thinking), and those that involved mini-c creative thinking.

In the first category, inquiry projects which involved student designed experiments to test hypotheses (5), STE(A)M projects and project-based learning which applied learning to solve problems (8) featured prominently.

In the second category, activities that happened in everyday classes rather than during longer-term projects were described. Several of the activities involved students communicating understanding in unique formats such as poems, drawings, classroom presentations or using concept mapping (8) (mini-c). While these tasks have the potential to provide students with opportunities to express creativity by hypothesizing as they construct understanding of concepts, the degree to which students were using creative thinking to generate their own explanations was not evident. For instance, some of these activities appeared to involve students organizing information in alternate formats rather than engaging in possibility thinking (Craft, 2001). Activities which involved synthesizing concepts or ideas and applying concepts in new contexts (mini-c) (6) were considered an important way to develop creative thinking. Many of these activities were described as occurring as students completed research assignments, such as researching and presenting a lesson to the class which taught concepts that were new to students. One teacher noted that students can be made more aware of what big-C, pro-C and little-c creative thinking in science involves as they consider how scientists, engineers and inventors have exercised creativity to develop ideas/products which have changed our lives.

Of the 13 teachers interviewed, only four teachers discussed the benefits for students of being encouraged to construct their own explanations (mini-c creative thinking through making hypotheses) for phenomena through open-ended questioning. Christine talked about the importance of letting students ask questions and investigate alternative theories or explanations. It is interesting and of concern to these researchers that she noted that she should not be doing this as it is outside the remit of the curriculum as she or others perceive it.

> Christine: [Lessons should be] as student led as possible. I often give opportunities for us to go down rabbit holes of ideas and concepts and theories. And you know, I've just had the year 9s doing structure of the earth, and they all posed the flat earth and the hollow earth theory. I was like, 'let's have a look at those theories properly. Let's look at who are these people who are proposing it and some of the evidence that they're presenting, and yeah, let's pick them apart, if we can,' and you know, not an outcome that we were supposed to explore. Probably shouldn't have, but it was meaningful.

Another teacher, Robert, rather than discussing PBL or inquiry learning as others had, focused entirely on encouraging mini-c creative thinking in students by asking open-ended questions. He particularly appreciated the CASE project (Lin et al., 2003) (known as Thinking Science in this context) which he was implementing in his class; he said that it had encouraged him to use the same kind of open-ended questioning and student-centered construction of understanding in other lessons. The CASE project was also mentioned by Patrick as an example of teaching that supported student creativity by encouraging students to construct their own understanding.

Discussion

Sternberg's article entitled "Teaching for creativity: The sounds of silence" (2015) gave a rather dispiriting analysis of the status of teaching for creativity: "There are hundreds of books and thousands of articles on how to teach children to think creatively. If one walks into a classroom, however, one is not likely to see a lot of teaching for creative thinking (p. 115)." To what extent is Sternberg's experience replicated in the Australian science education context? Has the mandate for all teachers, including science teachers, to teacher for creative thinking, introduced into the Australian Curriculum since at least 2010, had an effect on science teachers' classroom practice?

Despite the mandate for teaching creative thinking in the Australian Curriculum (ACARA, 2016a) from the initial difficulties that the teachers interviewed in this study demonstrated in defining creative thinking in science and the four teachers, in particular, who felt that they really didn't know how to define creativity in science (Table 7), it was clear that what constitutes creativity in the science classroom and guidance for teaching for creativity are not at the forefront of professional discourse within Science departments or schools. Initial responses of teachers which focused on big-C, pro-C and little-c creative thinking are possibly a consequence of the mixed messages regarding supporting creative thinking in the science classroom provided by ACARA. Even though the ACARA documents mention that creative thinking in general entails supporting students to construct meaning and explanations for themselves (mini-c creative thinking in developing hypotheses), limited examples of creative thinking by hypothesizing are given within the science curriculum content descriptors and the focus is on creative thinking in the experiments through inquiry-based tasks. It seems that ACARA itself may hold restricted or even uninformed views of creative thinking in science, since they rank science 12th out of 13 subjects in terms of the opportunities to support critical and creative thinking.

It is not surprising, therefore, that these 13 science teachers are unsure of what creative thinking in the science classroom looks like and the ways that it can be supported. In addition, the lack of professional development and training being provided to both pre-service and in-service teachers to develop understanding of the theoretical constructs underpinning creativity and creative thinking was evident, including training in how to support students to progress from mini-c to little-c and then pro-C creative thinking (c.f., Kaufman & Beghetto, 2009) and the importance of supporting development of creative thinking in forming hypothesis, designing experiments and applying that knowledge (Newton & Newton, 2010). As Richardson and Mishra (2018) and Beghetto and Kaufman (2014) contend, without a good understanding of the nature of creativity and creative thinking it is difficult for teachers to encourage and support these capabilities in their students.

On the other hand, *all* 13 teachers were convinced of the importance of teaching creative thinking and many were able to describe strategies they are actively using within their classrooms (Tables 4 and 8). Although there was some agreement with prior studies in other countries of teachers' restricted or alternative understanding of creativity and creative thinking, it seems that the teachers interviewed possessed many of the views identified in the literature as constituting ways to support and teach creative thinking. For instance, while teachers tended to focus initially on creative thinking in designing experiments and application of knowledge through inquiry-based or project-based learning activities (c.f (Barrow, 2010; Cremin et al., 2015; Park et al., 2006), the majority of teachers did identify some mini-c aspects of creative thinking later in their interviews, such as students applying concepts in new contexts (applications), exploring different perspectives and constructing scientific explanations for themselves (making hypotheses) (Table 4). This observation suggests that, despite limitations within the ACARA guidelines, teachers do recognize the importance of developing students' mini-c creativity competencies.

Analysis of teacher definitions of creative thinking in terms of the 5A's framework of Glaveanu (2013) showed mixed levels of understanding about important factors in teaching for creativity. Although eight of the 13 teachers recognized that creative thinking involved unique thinking (to the student) and 13 believed that it included applying understanding in new contexts (c.f. Amabile, 1996; Kaufman & Beghetto, 2009; Sternberg & Lubart, 1991), as previous reviews had shown (Andiliou & Murphy, 2010; Bereczki & Kárpáti, 2018), fewer teachers recognized the importance of appropriateness in creative thinking (Table 4: Finding genuine solutions to problems-4, recognizing limitations-3). Seven teachers noted the importance of students communicating ideas persuasively to an audience (Glaveanu, 2013; Sternberg, 2003). However, despite the evident lack of confidence displayed by teachers in their knowledge and understanding of creativity, unlike Sternberg's (2015) disappointing findings, on the whole this sample of 13 teachers were able to identify many of the important constructs and supportive factors for developing creativity and creative thinking in students but also recognized the curriculum and school structure limitations to implement them.

However, looking at the tasks they designed and the barriers that teachers encountered for teaching creative thinking, it is clear that there is still a strong emphasis on inquiry and PBL tasks, that take place over several lesson in the experimental and application spaces (Tables 6–8). This observation is consistent with other studies that focus on longer activities for developing creativity as described in the literature review (c.f., Kind & Kind, 2007) and the findings of Taber (2012) and Newton and Newton (2010) that indicate that making hypotheses for creative thinking is often neglected compared to the designing experiments and applying knowledge. This may be in part due to lack of recognition by many teachers of the important role of "speculat[ing] about their observations of the world" (ACARA, 2016a) for developing creative thinking. There is a need for more explicit guidance and examples of ways in which to foster creative thinking in all science lessons, not just those that involve inquiry or PBL, including a focus on supporting students to create mental images and analogies (Hadzigeorgiou et al., 2012), use scientific models as thinking tools (Taber, 2012) or mental simulations (Nersessian, 2008; Taber, 2012), and engaging in divergent thinking to create explanations through "possibility thinking" (Craft, 2001).

The main barriers for engendering students' creative thinking that teachers identified were related to time constraints and the need to impart curriculum mandated content. This observation suggests that many teachers have not recognized that there are opportunities for creative thinking in any lesson where students are encouraged to construct their own understanding and the benefits to the student of doing so. The oft-repeated concern that creative tasks take time away from covering a 'crowded' science curriculum (c.f., Andiliou & Murphy, 2010; Beghetto & Plucker, 2006) and preparing students for tests (c.f., Akyıldız & Çelik, 2020; Hetherington et al., 2019), highlights this misunderstanding of the benefits of creative thinking for developing content knowledge and understanding (Baer & Garrett, 2010). It appears that some of the teachers interviewed still see addressing creative thinking as an 'add on' to the main curriculum, rather than an essential part of a student-centered pedagogy which allows students to construct understanding and engage with higher order thinking throughout the curriculum. Nevertheless, it was pleasing to see that some teachers in this study gave opportunities to students to develop their creative thinking through narrative thinking or telling explanatory stories (c.f., Hadzigeorgiou et al., 2012) and the production of explanations (Table 8). Christine's and Robert's discussions of the importance of allowing students to ask questions and consider alternative explanations as they construct their understanding indicates an understanding of the importance of engaging students' creative thinking in the hypothesis space. However, Christine's concern that she was veering from the path prescribed by the curriculum was revealing and suggests that there are systemic problems within the macrosystem which are limiting the engagement of teachers with teaching creative thinking, particularly in science.

Despite teaching for creativity being mandated for all subjects under the Australian Curriculum for over 10 year, lack of teacher training and professional development or professional learning, adequate resourcing and support for teachers was evidenced by the fact that none of these teachers had ever had the opportunity to attend any professional development or professional learning about creative thinking. This finding includes the early career teacher participants who had recently graduated from education faculties and had limited training in teaching for creative thinking in their courses (c.f., Patston et al., 2018). This was apparent in other national education systems and schools (Beghetto & Kaufman, 2009; Lucas et al., 2013) and suggests that teacher education faculties in universities need to build conceptual understanding and provide concrete strategies to help build confidence and a more diverse repertoire of activities.

Another area of concern that teachers raised was that creative thinking was not a school focus and there were no accountability structures in place to ensure that this general capability was being addressed (Table 7). They also found assessing creative thinking or creativity challenging (Table 7) and hence did not include aspects of creativity or creative thinking in marking rubrics that they gave to students. As teachers noted, where aspects of the curriculum are not assessed, a message is inadvertently sent to students that creativity or creative thinking in science is not important. Providing teachers with a more comprehensive understanding of characteristics of creativity and creative thinking in science through targeted professional development programs may support them in being able to identify aspects of creative thinking that could be assessed in the formative/summative assessment cycle.

The implications of this study are that teachers need more support and professional development or professional learning on understanding what constitutes creative thinking and how to teach for creative thinking within the classroom, other than PBL and inquiry learning. In particular, professional learning for understanding of mini-c creativity, how to recognize this in students and a wider variety of strategies to support students in developing possibility thinking are desperately needed. Even though it seems that mandating teaching creative thinking across all subject areas has resulted in some progress toward teachers considering how to support their students in developing creative thinking skills, more support for these teachers is required.

Limitations

This study was only able to obtain the views of 13 teachers from three different teaching jurisdictions within Australia, and as such cannot be considered to accurately represent the understanding of all Australian teachers. However, the insights provided by these teachers, ranging from early career teachers, to teachers with many years of experience do provide a snapshot of the state of teaching for creative thinking as a result of the educational reforms to mandate teaching for creative thinking. This study serves to document ways forward for other countries attempting to support greater attention to teaching for creative thinking.

Conclusion

Our study of teachers suggests that, while Australian teachers recognize many of the characteristics of creative thinking found in the literature, there remains a greater focus on the designing experiments and application of knowledge for creative thinking than on the developing hypotheses. The role of mini-c creative thinking in student-centered learning through personal insights and developing meaning is less well understood by teachers and teachers are less confident in recognizing these skills in their students. It appears that, not only teachers, but school leaders would benefit from professional development or professional learning which helps them to understand the importance of developing creative thinking in students and ways in which this may be achieved and assessed through a more student-centered approach to learning where students are given opportunities to construct their understanding of concepts.

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