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Incorporating creativity in science and mathematics teaching: Teachers' views on opportunities and challenges

Abstract

Although creativity constitutes part of 21st century skills, realizing a curriculum that emphasizes creativity in science and mathematics appears to be a challenge. In this study, we investigate how lower secondary science and mathematics teachers understand the concept of creativity, how it can be promoted, and what hinders creativity in schools. Eight teachers were involved in the study, and their views were investigated through group interviews. It was revealed that teachers adopt three perspectives pertaining to how

creativity can be fostered in the classroom: the nature of tasks and how they are presented and organized, the need for background knowledge, and the requirement of a supportive classroom environment. A major concern for teachers was how creativity could form part of the assessment process, since assessment systems influence what occurs in the classroom. Further, school cultures that emphasize objectivity and documentability tend to result in teachers prioritizing convergent thinking and the reproduction of knowledge, preventing the inclusion of creativity in teaching. The core values and principles for learning stated in the new curriculum introduced in Norway in 2020 include that students should experience the joy of creating, engagement, and the urge to explore. The results indicate that assessment dilemmas are the main obstacles in the realization of these intentions.

INTRODUCTION

Creativity is perceived as an important part of 21st century skills, which are the knowledge, skills, and attitudes required by citizens to enable them to fully participate in (and contribute to) the knowledge society (see e.g. Binkley et al., 2012). It is generally agreed that fostering the creative and innovative skills of young people should be a key mission for education. However, what creativity is, how it can be represented in the curriculum, and how creative and innovative skills could be assessed are often not clear (see e.g. Nielsen, 2015).

This paper reports on an interview study conducted in Norway, investigating teachers' views of creativity in the context of science and mathematics teaching, the ways it can be promoted in schools, and the aspects that hinder its development. The study involved eight Norwegian lower secondary school science and mathematics teachers who were recruited to the KreTek project (see www.ntnu.edu/skolelab/kretek). The aim of KreTek is to develop teaching resources that incorporate programming with students' creativity and learning in science and mathematics, in line with the new curriculum implemented in 2020. The project in itself has no ready-made model for how creativity should be incorporated in science and mathematics teaching, and collaboration with the teachers is important for the development. The interview study was undertaken at the outset of the project and formed one important basis for the project. At this juncture, teachers were not influenced by the project, which means that the results have wider relevance as they highlight the challenges and opportunities in incorporating creativity in schools from a teacher's perspective.

The research question is as follows:

> *What are teachers' views of creativity and how it can be promoted, and what hindrances do they envisage when incorporating creativity in science and mathematics teaching?*

In the following, we review the concept of creativity, both in general terms within the science area and in the school context, and present and discuss the results in light of how creativity is conceptualized in the research literature.

CREATIVITY

What is creativity?

Creativity is a broad concept without a unique definition (Plucker, Beghetto, & Dow, 2004; Simonton, 2017). There seems to be a general agreement in the literature that creativity involves the creation of something original that has value—a novelty (Csikszentmihalyi & Wolfe, 2014; Kaufmann, 2003). However, the value of novelty is not always easy to define (Klapwijk, 2018), mainly because it has different levels (Cropley & Cropley, 2010). Pertinent questions here would be whether refinement of an existing solution constitutes a novelty, what are the assessment criteria for novelty, and who is in a position to judge. A possible solution to these problems is to include the context in which creativity appears (Beghetto & Kaufman, 2014). Plucker et al. (2004) formulated the following definition of creativity that considers context: "… the interaction among aptitude, process, and environment by

which an individual or group produces a perceptible product that is both novel and useful as defined within a social context" (p. 90).

This presents a relative view of creativity: solutions could be novel in one context and well-known in another. The concepts of "Big-C" and "little-c" creativity (Craft, Jeffrey, & Leibling, 2001) are in accordance with this view. Little-c creativity is related to generating outcomes that are original and valuable in relation to the individual, whereas Big-C creativity involves ingenious ideas and breath-taking masterpieces. Kaufman and Beghetto (2009) extend this idea to their hierarchical "4 C-model" of creativity, in which they introduce two more levels of creativity: "mini-c" and "Pro-c". Mini-c is the creativity involved in individual learning processes and consists of new insights that are only novel and useful for said individual. Pro-c creativity represents creativity expressed by professionals that is not yet judged as Big-C level. Kaufman, Beghetto, and Dilley (2016) state that mini-c and little-c are the levels of creativity that can be expected in classroom contexts.

Divergent thinking, the ability to think "outside the box", has been considered an important characteristic of creativity (Cropley, 2006). Convergent thinking, on the other hand, orients towards finding the most correct and logical answer to a clearly defined problem (Cropley, 2006; Runco & Acar, 2012). Cropley (2006) argues that creative production requires a combination of convergent and divergent thinking.

According to Aljughaiman and Mowrer-Reynolds (2005), teachers often include the characteristics of deep thinking and intelligence when describing their creative students. This illustrates that the distinction between intelligence and creativity is not obvious. An essential hallmark of intelligence is the ability to create novel mental models (see Kaufmann, 2003), which is similar to the definition of mini-c creativity. However, Kaufmann (2003) states that a major difference between intelligence and creativity is that creative solutions require some degree of unconventional reasoning, in contrast to intelligent adaptation (the use of known solutions in new tasks), which might require more intelligence than creativity.

Amabile (1983) presents a componential theory of creativity, which includes a framework for the social and psychological components necessary for an individual to produce creative work. The framework involves three internal components that influence creativity:

- Domain-relevant skills (expertise, technical skills, and knowledge)
- Creativity-relevant skills (flexible cognitive style, openness, persistence, and problem-solving skills)
- Intrinsic task motivation

In addition, an external component is included (the social environment), which influences all the internal components. While the social environment can affect both domain-relevant and creativity-relevant skills, the most prevalent influence is on the motivational component (Amabile, 1983).

Scientific Creativity

Creativity is often associated with aesthetics and arts, whereas the sciences are represented by logical reasoning and rationality (Andiliou & Murphy, 2010; Kind & Kind, 2007). However, there is agreement in the literature that science is inherently a creative discipline where scientific ideas are considered creative products and scientists are perceived as creative people (Hetherington et al., 2020; Kind & Kind, 2007; Meyer & Lederman, 2013). Progress in science is often a result of Big-C creativity, where ideas have resulted in major breakthroughs. Less spectacular, working with science more often includes both mini- and little-c creativity in the thinking processes of individuals, creating novelty in their own minds. Regardless, new ideas in science should relate to the real world rationally, which is the main difference between scientific and general creativity (Hu & Adey, 2002; Kind & Kind, 2007). Accordingly, new ideas must fit into (or at least address) established theories and principles. Consequently, a domain-specific knowledge base is of great importance in scientific creativity for two reasons: to facilitate the necessary convergent thinking concerning a new idea, and to enable flexible and divergent thinking (Cropley, 2006; Meyer & Lederman, 2013).

Creativity in the school context

Traditionally, schools do not promote creativity in academic subjects due to a school system emphasizing convergent thinking and content replication (Csikszentmihalyi & Wolfe, 2014). Carlone (2003) reports on how such emphasis might result in a "culture of achievement" which inhibits working innovatively in the classroom. Further, Davies, Newton, and Newton (2018) revealed that even if teachers valued creativity, little evidence of promoting creativity was found in practice. According to this study, the school culture resulting from external pressure of performability, time constraints due to crowded curricula and the view that creativity has to do with arts, act as severe obstacles for including creativity in science and mathematics. Davies et al. (2018) conclude that an education policy with content-based curricula, national testing, and external school inspections, means that creativity is not considered an essential 21st century skill in the field of education.

Davies et al. (2013) performed a systematic literature review to detect important factors that can promote creativity in school contexts. The review showed that it is important that the learning activities are motivating and relevant and with the right balance between structure and freedom. The classroom atmosphere should encourage taking risks and support open dialogues and collaboration, and sufficient and flexible use of time was found to be important. Baruah and Paulus (2019) maintain that since collaborative creativity is essential in many workplaces, it should receive more emphasis in education.

In the context of science and mathematics education, research literature has addressed two main perspectives: creative teaching and teaching for creativity (Kind & Kind, 2007; Lev-Zamir & Leikin, 2011). While creative teaching focuses on flexible approaches made by the teacher, teaching for creativity aims to increase student learning. One method of teaching for creativity is to enhance scientific inquiry by *inquiry-based science education* (IBSE) (see e.g. Barrow, 2010). Another aim of teaching for creativity is to enhance academic understanding, where creativity is used as a tool for learning. For example, art could be used as a way of communicating scientific ideas and concepts (Kind & Kind, 2007). Extensive attention is paid to creative learning in mathematics, where students are challenged to use their creativity to make mental connections (Lev-Zamir & Leikin, 2011; Lithner, 2008; Sidenvall, Lithner, & Jäder, 2015). Askew (2013) argues that creative thinking can be facilitated in both science and mathematics by letting students combine divergent and convergent thinking to connect "the hypothesis/conjecture space" with "the experiment/justifying space".

Several studies report on teacher perceptions of how creativity is included in academic subjects such as mathematics and science in schools (Harris & de Bruin, 2018; Hetherington et al., 2020; Leikin, Subotnik, Pitta-Pantanzi, Singer, & Pelczer, 2013). Although there is general agreement on the importance of involving creativity, the reasons for this differ according to subject. In mathematics, teachers perceive creative reasoning as important for success, often correlating it with high ability and giftedness (Leikin & Pitta-Pantanzi, 2013). In science, Hetherington et al. (2020) reported a consensus among teachers on the importance of developing scientific creativity in terms of questioning and problem-solving competencies. However, there were disparate views concerning the relation between creativity and knowledge outcomes. Further, Harris and de Bruin (2018) found that science teachers emphasize the role of inquiry for developing creativity in students, which could be achieved through interdisciplinary approaches.

The impact of assessment on students' creativity seems to be essential (Askew, 2013; Beghetto, 2005; Nielsen, 2015). To avoid loss of motivation and support willingness to take risks, Beghetto (2005) recommends assessment that minimize social comparisons and focuses on individual mastery. Further, this study underscores the importance of the informational aspect of assessment, in line with the view of Klapwijk (2018) that creativity should be assessed formative rather than summative. Still, if students are to be assessed on innovative competences like to create or to explore, the criteria for such process competences must be established and included in the assessment system (Nielsen, 2015). Binkley et al. (2012) refer to the assessment and measuring of creativity and innovation as challenging. Further, Lucas et al. (2012) identified five core habits of the creative mind (to be imaginative,

inquisitive, persistent, collaborative and disciplined) and tested a system for summative assessment based on these habits. They found "a strong sense of reluctance by teachers to make summative judgments on the level of creativity in their pupils" (2012, p. 2). To support teachers in this type of assessment, Nielsen (2015) developed assessment criteria for five sub competencies relevant to innovation competency (creativity, collaboration, navigation, action, and communication). In addition, a concretization of the assessment of these competences was provided within the framework of existing disciplines.

Creativity in the Norwegian curriculum

In Norway, a broad view of competences and 21st century skills (Binkley et al., 2012) is represented in the new national curriculum by the core curriculum (Ministry of Education and Research, 2017). The core curriculum elaborates on the values and principles of learning on which all the subject-specific curricula in primary and secondary education in Norway are to be based. One of these values is that "schools shall allow the pupils to experience the joy of creating, engagement and the urge to explore, and allow them to experience seeing opportunities and transforming ideas into practical actions" (Ministry of Education and Research, 2017). This means that even though creativity is not explicitly expressed in the competence aims of science and mathematics, it should still be facilitated and included in classroom practice. Furthermore, the competence aims for subjects in the new curriculum (which are assessed) often include the verb "explore". This is important, because the central parts of exploring are related to processes such as questioning and experimenting to create explanations. However, there is no reference in the curriculum to how such process competences should be assessed and how they could include creativity given the formulations in the core curriculum.

DATA COLLECTION AND ANALYSIS

This study is based on interviews with eight lower secondary school teachers in science, mathematics, arts, and craft. The interviews were undertaken before the new curriculum referred in the foregoing was implemented in 2020. The teachers were recruited to the project KreTek for collaboration with educational researchers and technology experts on developing teaching designs that enhance student creativity in science and mathematics through the use of programmable technology. This can be seen as purposeful sampling (Palinkas et al., 2015), which means selection of information-rich cases related to the phenomenon of interest. The teachers represent resourceful lower secondary teachers who show interest in including creativity and technology in science and mathematics teaching. Data collection was conducted at the outset of the KreTek project, so the results are not affected by the teachers' participation in the project. This way, in addition to being an opportunity to exchange thoughts for the commence of the project, the interviews give insights in ideas and concerns teachers in general may have for the incorporation of creativity in science and mathematics teaching.

The interviews were undertaken as two group interviews with four teachers in each group, and focused on teachers' views on creativity and how it could be fostered in schools in the context of science and mathematics education. The interviews incorporated aspects of focus group interviews where topics were discussed freely, with the interviewers acting as moderators and occasionally participants in the discussion. The interviews lasted for approximately one hour, were recorded with the participants' consent, and were fully transcribed.

The data were analysed using a combination of inductive and deductive approaches, reflecting an experiential orientation (in contrast to critical orientation) of thematic analysis, as described by Garreth, Hayfield, Clarke, and Braun (2017). The experiential orientation involves focusing on what participants think, feel, and do, with the assumption that this represents a reality in terms of how the participants experience the topic under investigation. As a first step in the analysis, broad themes for coding were established by an inductive analysis of the interview transcripts. Some exemplar codes were challenges (relating to aspects that hinder creativity), new to the student (relating to novelty), and assessment. The codes and their content were then viewed in relation to research literature on creativity using a more deductive approach, and further analysed within three main topics which

also reflect the research question: the nature of creativity in schools, what is promoting creativity, and what is hindering creativity. The presentation of results is structured around these three topics rather than in terms of the codes initially used for analysis. Further, the group of teachers is analysed as a whole (not with individual teachers as units of analysis), although their views differed at some junctures. Individuals can still be traced by means of the fictive names used in the report of the results.

RESULTS

Teachers' views on creativity

In discussing what constitutes creativity in school science and mathematics, the teachers emphasized that creativity should be part of the learning process rather than the resulting product. Thus, it is important that students have the opportunity to find their own way to a solution, not just follow a "recipe" given by the teacher or the textbooks. For example, teacher T3 described this as follows:

> T3: [Something] that not everyone else may have thought of, something a bit new that stands out from the most standardized, common way of thinking or solving a problem. If everyone sees the same solution, then it's not really…

However, this does not mean that students have to come up with something genuinely novel to be creative:

> T3: it doesn't have to be something completely new. You are not [expected] to develop a new mathematical proof or a new scientific theory or relationship, it must be something new to you. Where you have been creative on your own terms, according to your abilities, according to your knowledge base.

In this teacher's view, the novelty in creativity resulted in insights that were new to the student and a result of their own ideas and thinking. Several teachers commented that creativity does not need to result in something new at all; rather, it is about connecting creativity to students' mental skills. Teacher T8 connected creativity to student reflections and wondering, skills in posing questions, and to developing their thinking:

> T8: …. in a traditional understanding, I think that to be creative you should make something, or you should come up with something. But I agree with what has been said that creativity has to do with that process. [With regard to] reflection, it is the wondering, asking questions, further developing a way of thinking.

Similarly, teacher T3 described students as creative when approaching new problems they had not encountered previously:

> T3: When you meet a new type of task that is a bit different than what you have seen before, and you don't really see what should I do now … how do I approach this? What is the task about? And you start on that process to figure out how to solve the problem. Then you are creative, really.

The teachers perceived creativity as strongly context dependent. When the classroom is the context, the mission is to learn something of value. However, the nature of this value can differ from subject to subject and from student to student. One teacher upheld that creativity in mathematics could be the discovery of commutative laws, which is basic knowledge to someone with more insight in the subject:

> T3: If your knowledge level is very low, then it is very easy to say "that's ok", you have achieved a little bit beyond what you were able to before, [meaning there] must have been some innovation, some creativity, in what you have been doing. But that's because you set the level so low … a first grader who starts doing mathematics discovers commutative laws and things like that … of course at a very low level. But for this student, it's creative.

This means that the teacher placed creativity in an educational context as dependent on the background knowledge of the learner.

How can creativity be promoted?

The teachers perceived creativity as something that can be developed in individuals. For example, one teacher stated the following:

> T1: I think creativity can be trained. A hypothesis ... I think it can be trained better in collaboration. That is, ... if people discuss together and listen to each other, then new things appear, new thoughts, new ideas, which lift it to a higher level than you could manage yourself. I believe that being creative together has great value.

Here, T1 emphasizes collaboration and that new innovations can develop by sharing ideas, eliciting results at a higher level.

To foster student creativity in school, the teachers perceived it as important that students were presented with challenges that were relevant. Teacher T5 formulated this as follows:

> T5: They must feel that what they are doing is valuable, that it is a real problem, and that the result is valuable. Whether it is a small project or a large one, it must feel valuable to them ...

The teachers emphasized the need for threshold knowledge as a prerequisite for working with creativity in mathematics and science, meaning students needed some basic knowledge and skills to be creative. One teacher mentioned the parallel of playing a musical instrument: you need automated skills to be able to be creative on the instrument. He added that school subjects (especially mathematics) have traditionally overemphasized the requirement for students to have basic knowledge:

> T1: I teach music too, and when I think of creativity there ... I think that you have to be able to play the instrument ... to be creative. And those who play the instrument even better are better at being creative on the instrument. Not automatically, though. But the more you practice on it, the better music you make. And perhaps it is like that in math as well. So ... in math I think you can be creative in the way you choose which tools to use. You must have SOME knowledge! ... you do not need to have it all.

One teacher also stated that learning problem-solving strategies can enhance the persistence, creativity, and effort levels of students:

> T3: ... perhaps what we must work on [is to] find a way to give students these problem-solving tools that are ... not only linked directly to mathematics and directly to science, but are more universal. How should you approach a problem and how should you work with a problem. That is, if you've experienced it before, then perhaps it's easier that you ... try out more things, be more creative, be more persistent.

Another teacher emphasized that students should practice how to address struggles associated with increased challenges when they advance in a subject such as mathematics:

> T2: Yes, accept to hit the wall... there are many ... I have at least experienced it, that when they start lower secondary school, they have perhaps been used to achieving a lot. And then it gets a little bit more difficult, like in mathematics, algebra comes in which often cracks... tries to crack some of them at least. And the process where they meet real resistance, get stuck... what do I do then? I think that is also a skill that must lie in the foundation, in a way.

The teachers agreed that settings providing direction and support while remaining open for students' own thinking and exploration are important for fostering creativity. Further, they emphasized that tasks should be within the reach of the students:

> T2: … you [must] have a chance to solve the problem facing you. If you don't have a chance, or you feel you don't have a chance, then it will be inhibiting… and I think that interest also comes in here, [and] motivation, there are so many other factors that will play a role in this with perseverance. But I agree that without perseverance it's hard to be creative. The process will stop too early.

As a prerequisite for students working creatively, teachers underscored the need for a supportive climate in the classroom where the students feel safe and confident, enabling new ideas to be expressed and challenged. When discussing which context was favourable for promoting creativity, teacher T6 commented as follows:

> T6: I believe it depends on the class and the milieu in the classroom. If there is a milieu that allow students to challenge themselves, I think it is easier to be creative at school compared to home where you might not have the equipment necessary or you might be tempted to do something else.

Teacher T5 agreed on this and added the need for students to feel secure and confident:

> T5: Feel safe. Confident in their own thinking. Dare to express themselves.
> T5: … creating a milieu where you can be yourself … is a prerequisite for creativity. High under the ceiling.

One teacher noted that working with creativity in the classroom represents a major pedagogical challenge for teachers. When students are supposed to find their own ways to a solution, these can take very different directions, and the students may face very different problems. The teacher must balance the need for guidance (to prevent the work from stopping) with maintaining the desired openness of the task:

> T1: I think it is important for the teacher to be a bit conscious when trying to achieve some creativity … it can be challenging if many get stuck! To have time to guide them enough to move on. You need to try to find some strategies that keep students from waiting too long before getting guidance or help or hints or something.

This statement demonstrates that finding the right balance between guidance and freedom is challenging when teachers have up to 30 students in a class.

What is hindering creativity in the classroom?

The challenge pointed to above, the need to follow up many students at a time, may represent a hindrance for teachers in embarking on a teaching project allowing for students' freedom and creativity. The teachers also point to the risks of failure as a potential hindrance for creativity in the classroom. If students are to work on creative projects, the teacher must let go of control and give students freedom to find their own path. This might take time and with no guarantee that it will lead to the desired result. Therefore, teachers and students find it safer and more efficient to teach in a more traditional way:

> T1: One specific challenge is if a student has been very clever and very creative … and they have spent a lot of time on it … which negatively affects their achievement of a competence aim. That is a big dilemma, I think. So, it would be incredibly good if they dared to focus on the creative aspect here, and thought a bit innovatively, but if then they miss completely… and then they get disappointed, when they experience such a process, and it is inhibiting for the next time you have a project with an opportunity to be creative.
> T2: We run it safe, we show that we have achieved what is in the competence aim.

Accordingly, the main hindrance to creativity would appear to be the assessment system and the objectives in the curriculum. Teacher T4 formulated this as follows:

> T4: … it should be quite clear what's being assessed and how it's being assessed, that they need to achieve these competence aims, that's in a way what you really have to measure to be able to go back and say: that´s why you did it.

This demonstrates the need to justify ways of teaching in terms of curriculum requirements and to have clear criteria for assessment and methods of assessing. The fear of complaints from students to the educational authorities was also clearly expressed:

> T1: … we have to take into account not only the core value of the subject [as stated by the curriculum], but rather the competence aims, because in case of a complaint, then we must be able to justify that grade against competence aims. It seems that the county governor doesn't care about what is written in the core values of the subject. And that means that we have to spend a lot of time on the competence aims precisely, instead of spending time on core values, which could have been a very good thing.

This can result in a classroom culture which emphasises competence aims that are easy to assess, and less emphasis being placed on more generic skills such as creativity. One teacher expressed this rather clearly by claiming that "if it's not measurable and possible to assess—then it's not done". In other words, creativity must be assessed to be prioritized in the classroom.

The teachers highlighted that the ambiguity of creativity as a concept can result in challenges regarding how to implement creativity as a part of assessment criteria and how to assess creativity fairly and equally. One teacher claimed to deliberately avoid creativity in the assessment criteria since it was not clear what should be measured. This view was supported by other teachers, who argued that creativity as a concept is ambiguous and therefore difficult to implement as a stated part of student assessment. One teacher made the following comment:

> T5: No, I find it so scary to just go ahead and call it creativity without formulating what you put into it. Whether it is an aesthetic value or a functional value. Have you enriched something with a practical value… made it more functional…

The teachers also emphasized that creativity is difficult to assess since it constitutes both internal and external processes within individual students. One teacher stated that creativity takes place in the students' heads, which teachers cannot access. Although teachers argued that it should be possible to detect and track a student's creative process, they expressed concerns about the feasibility of detecting and tracking creative processes with the purpose of assessment:

> T3: … you are able to see the creativity of some students during lessons. But it is your subjective experience of the student being creative … it may well be that the student who sits two rows further back has also been creative without you being able to capture it. And that's exactly the difficult part, should one student get a top grade and the other fail because you haven't seen any creativity?

This teacher expressed concerns about the weak reliability and validity of a summative assessment that includes creativity. By comparison, teacher T2 stated that it is easier to include creativity in feedback to students in formative assessment:

> T2: There is something about assessing in the classroom, when we give feedback to the students, talk to the students and discuss with the students … The assessment that takes place then, I think it touches much more upon what has to do with creativity, the formative, along-the-way assessment. But as soon as we are to set a grade, I think, many of us at least, have like some ghost over us that here we must have evidence for the grade we set. And then it's easier to refer to the answer sheet, results, or sort of "hard data" in the totality of it.

The "ghost" teacher T2 brings into the discussion, we interpret as the unspoken "rules" for what the teachers should do and prioritize, which is closely related to the school culture they are part of.

During the discussion, the teachers also considered whether it was the result of a creative process that was being assessed, not creativity itself:

> T1: Can we rather turn it around a bit and think … what the student has learned through the creative process? What knowledge is the student left with afterwards? Which can be measured, I mean.
> T2: Then you measure the knowledge again.
>
> T1: Yes. We do that, but rather look at situations where we try to make the students more creative, and afterwards we measure what level is the knowledge on now?
>
> T2: So you think you can measure creativity by measuring the outcome of a creative process?
> T1: Both yes and no. I rather mean NOT to measure creativity, but to see that you have learned a lot through being creative. Learned other things, I mean.
>
> T2: So you facilitate, make sure that it is a creative process, so that afterwards you can measure the knowledge and say that creativity has been a helping hand in this?

The teachers' argument opens the way for viewing creativity as a means rather than an end in a creative process, thereby avoiding the problem of assessing student creativity.

DISCUSSION

Teachers' views on creativity

Although the teachers discussed creativity in the context of science and mathematics, their comments often concerned the more general sides of creativity in education. The teachers emphasized divergent thinking (the ability to generate ideas and "think outside the box") as important in creative work. Moreover, they perceived their students as creative when they thought for themselves, followed their own ideas, developed their own solutions, or modified something. While a common view in the literature is that a creative solution should be both original and useful to others in some way (Csikszentmihalyi & Wolfe, 2014; Kaufmann, 2003), the teachers had a more flexible view of the issue of novelty and usefulness. What matters is that the solution is novel and useful to the student, in accordance with how Craft et al. (2001) described "little-c" creativity as a process resulting in outcomes that are original and valuable in relation to the individual. It would appear that the teachers think of creativity as a tool for learning rather than something that should be developed for its own sake. This means that the teachers' perception of creativity in the classroom context essentially follows the "mini-c" conception of Kaufman and Beghetto (2009), which emphasizes the personal interpretation and the process of constructing personal knowledge and understanding, with the classroom as a sociocultural context.

While the teachers in this study viewed students as creative when they made new mental connections, Kaufmann (2003) views this simply as intelligent behaviour. According to him, creative thinking must include something unconventional, which does not apply in intelligent adaptation (such as combining facts and formulas in science). In the school context, the latter might cover what the teachers and the national school authorities include in the concept of *competence* in the curriculum. The Norwegian curriculum uses the following definition:

> Competence is the ability to acquire and apply knowledge and skills to master challenges and solve tasks in familiar and unfamiliar contexts and situations. Competence includes understanding and the ability to reflect and think critically.
>
> (Ministry of Education and Research, 2017)

The results in this study imply that teachers perceive creativity similarly to this definition. Traditionally, opportunities for including creativity in academic subjects have been limited (Csikszentmihalyi & Wolfe, 2014; Simonton, 2017). Hence, it is feasible that teachers view students' abilities to make their own mental connections and combine knowledge elements as the available space for including creativity in the subjects within the frames of the formal curriculum. In this, they are in agreement with how Lev-Zamir and Leikin (2011) describe creative learning in mathematics.

How can creativity be promoted?

The teachers presented three major perspectives of importance for fostering creativity in mathematics and science classrooms: (i) the nature of the task and how it is presented and organized in the classroom; (ii) the need for sufficient knowledge and skills to enable finding and using creative solutions; and (iii) the importance of having a supportive and generous climate for creativity in the classroom.

Regarding the nature of the task, the teachers emphasized the importance of relevance and appropriate levels of difficulty, both of which are regarded as important for student motivation and perseverance (Davies et al., 2013; Lev-Zamir & Leikin, 2011). Further, they noted that creativity is supported by collaborative work and they perceived collaboration as an important skill to develop, in accordance with Nielsen (2015), Davies et al. (2013), and Baruah and Paulus (2019). With regard to pedagogical challenges, the teachers addressed the delicate balance between guiding too little (resulting in student work stopping) and guiding too much (which could eliminate student creativity). Further, they thought that providing this support for up to 30 students would be a major challenge. This is in agreement with Davies et al. (2013), who indicated that constraints and support have to be balanced against student freedom to facilitate confidence and a willingness to take risks. The teachers were also aware of other challenges they must face, including relinquishing control in the classroom, being open to different solutions from those expected, and daring to use time on something that might end in a failure or at least take longer than planned. The concerns that teachers expressed to justify tasks in relation to the competence aims indicate that the school culture and the curriculum have major effects on the teacher's choice of task. This is in agreement with how Davies et al. (2018) demonstrated the impact of national education policies.

The second perspective was the need for sufficient threshold knowledge and skills, which were perceived as essential by the teachers. Threshold knowledge includes relevant subject content in addition to knowledge and experience of problem-solving strategies. This is related to the ability to perform necessary divergent and convergent thinking to generate and follow ideas and evaluate different solutions (Cropley, 2006; Meyer & Lederman, 2013). The teachers connected this with the task being in reach for students. While the teachers in general agree on the need for basic knowledge for solving problems in science or mathematics, they also question if the need for threshold knowledge in mathematics might be overrated. In addition, the teachers noted that problem-solving skills and experience may increase students' abilities and willingness to challenge new ideas, which could support creativity and perseverance.

The third perspective was a safe and supportive classroom climate, which was perceived as being essential for fostering creativity. In a creative process, divergent thinking is a prerequisite, and it is important that many ideas and suggestions are brought into discussion. Therefore, students must feel safe enough to follow their own ideas without being hampered by the risk of failure. Hence, the second and third perspectives are in agreement with Cropley (2006), who argued that creative processes require both convergent and divergent thinking.

All these three perspectives are in accordance with Amabile's (1983) componential model of creativity, in which four components are identified as influencing creativity: domain-relevant skills, creativity-relevant skills, task motivation, and the social environment. All these factors were covered in the way the teachers described creativity in the classroom. However, while Amabile is explicit about the important link between social environments and intrinsic task motivation, the teachers viewed intrinsic motivation more as a result of a relevant and interesting task. By comparison, they perceived that

the social environment (the climate in the classroom) could ensure support and contribute to student self-confidence in their creative work.

What is hindering creativity?

In agreement with several other studies, the teachers in this study perceived creativity as an ambiguous concept that did not fit neatly into one unique definition (Aljughaiman & Mowrer-Reynolds, 2005; Davies et al., 2018; Plucker et al., 2004). This ambiguity raised concerns with regards to assessment. The teachers emphasized the importance of students being aware of what is being assessed and expressed doubts related to successful incorporation of creativity in assessment criteria, especially when the content of the concept is hard to grasp for both teachers and students. They also expressed a reluctance toward using summative assessment of creativity, which is in agreement with the findings of Lucas et al. (2012). Creativity was described by the teachers as an internal process, and they expressed doubts about the reliability and validity of summatively assessing creativity. One teacher suggested that the knowledge resulting from a creative process should be assessed, not creativity itself. This raises an interesting point; if creativity in itself is a goal, and assessment is hindering creativity from being fostered in the classroom, it might be expedient to consider new criteria and methods for assessment. For example, the criteria proposed in Nielsen's (2015) work on the assessment of innovation competency could be employed. Alternatively, teachers could find creativity a fruitful way for students to meet learning requirements that are unrelated to creativity; hence, assessing creativity is unnecessary.

Although there might be numerous factors that hinder creativity, assessment was the focal point in discussions between the teachers in this study. The question always returned to whether it is possible to assess creativity in a fair and equal manner. The teachers' doubts and their discussions on the challenges of assessing creativity resonate with both Binkley et al. (2012) and Lucas et al. (2012). It would appear that assessment may hinder creativity from being prioritized in teaching. A teacher's job is to educate students based on a curriculum. Therefore, the content of the curriculum is of major importance with regard to fostering creativity in the classroom. With the new curricula introduced in Norway more attention is paid to process competencies and generic skills. It will be interesting to see if this leads to assessment practices that favor the incorporation of creativity, or if the current school culture that places great emphasis on documenting student achievement will remain and make incorporating creativity a challenge.

CONCLUSION

This study has investigated teachers' views of how creativity can be incorporated into science and mathematics. Overall, they expressed positive attitudes towards the incorporation of creativity in science and mathematics. However, some teachers perceived creativity more as a tool for learning, where both novelty and value were relative to the student. The teachers also highlighted dilemmas over assessment. They expressed a reluctance towards summative assessment of creativity due to the ambiguities of its concept and doubted that it could be assessed fairly and equally. This could be due to school cultures that emphasize objectivity and documentability. The core values and principles for learning stated in the new curriculum suggest that students should experience the joys of creating, engagement, and the urge to explore. The results of this study indicate that dilemmas of assessment are the main hindrances to the realization of these intentions. Accordingly, further work should be carried out in order to support teachers in realizing the curriculum by establishing assessment practices that provide for students to develop their creativity.

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