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The development of an analytical model for science classroom creativity in China

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ABSTRACT

Background: Fostering students' creativity is a key feature of education. While Chinese students score well on international measures of science attainment, their performance on measures of science creativity is less impressive.

Purpose: To develop an analytical model for science classroom creativity in China and examine its likely applicability, given Chinese culture and other factors. With suitable modifications, our model may apply elsewhere, too.

Design and methods: We critically evaluated three established creativity models and developed a new analytical model for science classroom creativity in China by synthesising components from the three models and additional development in light of a literature review on science education practices.

Results: Our model for science classroom creativity in China has four components: 'creative students' (who possess or are developing creative characteristics, including scientific knowledge, divergent thinking, and intrinsic motivation); the 'creative process' (students' engagement in scientific inquiry activities within classrooms, facilitated by the guidance of science teachers); 'teachers' attitudes to creativity' (teachers' perceptions of creative students and teachers' feedback on creative ideas); a 'creative environment' (the physical and the socio-cultural environments within which teaching and learning take place).

Conclusion: In Chinese science classrooms, some students typically have adequate but not challenging scientific knowledge and a lack of divergent thinking and intrinsic motivation. Additionally, the inappropriate understanding and practice of scientific inquiry among some Chinese science teachers, coupled with their limited pedagogical content knowledge, can impede the creative process. This challenge might be further compounded by teachers' partial understanding of creative students and negative feedback towards creative ideas. Moreover, the lack of a suitable physical environment and sufficient time prevent students from engaging in authentic scientific inquiry. Finally, the socio-cultural environment in which harmony, encouraged by collectivism and Confucianism, may not encourage difference, and cultural factors concerning 'Face' may discourage students from developing their creativity.

KEYWORDS
Creativity; science classrooms; China; modelling

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Introduction

In the 21st century, many countries are increasingly emphasising creativity, recognising it as a significant contributor to national economic growth and a crucial ability that empowers individuals to excel in the ever-evolving labour market (OECD 2015; Vincent-Lancrin et al. 2019). This heightened focus on creativity has extended to the field of education, where nurturing students' creative abilities is deemed a fundamental objective (Kupers et al. 2019). As defined by Sternberg (1999, 3), 'creativity is the ability to produce work that is both novel (i.e. original, unexpected) and appropriate (i.e. useful, adaptive, concerning task constraints)'. Furthermore, Sternberg stated that creativity necessitates not only the ability to develop original ideas but also the analytical ability to evaluate the quality of the ideas, as well as the practical ability to implement the ideas or persuade others of their effectiveness (Sternberg 2020).

The cultivation of creativity is not limited to specialised educational activities such as the visual arts, music or fiction writing; it can also be found in school science, particularly when students conduct scientific research like 'real scientists' (Kind and Kind 2007). With support from teachers or researchers, science students could pursue their own ideas, experience the process of scientific inquiry, and be motivated further to study science (Bennett et al. 2018). Hetherington's et al. (2020) study on the intersection of science and creativity revealed a consensus among educators, including teacher educators, secondary science teachers, and scientists, that science education should actively promote students' creativity. Various features of creative pedagogy, such as praising students' original thinking, encouraging personal reflection, and engaging students in hands-on tasks, could effectively improve students' creativity in science classrooms (Bell and McGregor 2021). However, current educational policies and systems that place an excessive emphasis on knowledge, testing and standardisation may not support some innovative practices (Kupers et al. 2019). Hetherington's research revealed a small number of secondary science teachers who placed a higher value on imparting scientific knowledge and did not tend to see science as creative (Hetherington et al. 2020).

In recent years, China has attached great importance to cultivating students' creativity, as evidenced both by the official report of the Chinese government (Xi 2022), and also the fact that many schools have been carrying out innovative educational practices (Zheng, Yang, et al. 2022). However, Chinese students' level of creativity remains a subject of controversy. On the one hand, some have criticised Chinese students for their low creativity (Allen-Ebrahimian 2015; Qian 2020), and some studies have indeed confirmed that Chinese students score lower on creativity tests than their Western counterparts (Niu and Sternberg 2001; Park et al. 2021; W. Hu et al. 2004, Wong and Niu 2013). On the other hand, there are studies suggesting that Chinese students perform well in some creativity tests (Rudowicz, Lok, and Kitto 1995; Shen and Lin 2007; L. Zhou, Cha, and Shi 1995), and, as a result, there is no conclusive evidence to prove that the overall creativity level of Chinese students is lower than that of students in other countries.

China's education system, known for its exam-centric focus, may trigger this controversy (Ke and Liang 2023). In many schools, the main goal of education is to prepare students for success in 'The National College Entrance Examination' (also known as 'Gaokao'), which significantly affects teachers' evaluations, school quality, and students' future (Tan 2016). In such an exam-centric environment, the focus is on standardisation and correctness, and students are expected to provide correct answers rather than novel but unexpected ones in examinations (Wang and Greenwood 2013). Multiple factors, including teachers, students, and families, operating within the embedded structure of classrooms, schools and social environments, create challenges and pressures for developing creativity in China.

In summary, China, as a quintessential example of an exam-centric education system, faces challenges in promoting creativity in science education. This article has two main objectives: first, to develop an analytical creativity model that encompasses students, teachers, the teaching process, and the various environmental factors, serving as a comprehensive tool for further exploration of creativity in science education; secondly, to employ this newly developed analytical creativity model within the Chinese educational context to illuminate the challenges present in Chinese science classrooms. By comprehending these challenges, Chinese educators and others who encounter similar circumstances in other countries can develop strategies to foster scientific creativity in their students.

Theoretical background

Creativity in science education

The definition of creativity has still not generated an academic consensus, with diverse interpretations among educational practitioners, scientists, and policymakers (McGregor and Frodsham 2019). This diversity of definitions spans the domains of both art and science (Bell and McGregor 2021; Kind and Kind 2007), as well as different aspects of school classrooms (Starko 2022). As highlighted above, a commonly accepted definition of creativity can be summarised as the generation of a novel and appropriate idea (Sternberg 1999; Sternberg and Chowkase 2021). Novelty and appropriateness are fundamental aspects of creativity (Nijstad et al. 2010). These characteristics are also crucial when discussing creativity within the science context (Hadzigeorgiou, Fokialis, and Kabouropoulou 2012). Science is a creative endeavour based on novel ideas, where novelty either means something new to humanity in general (i.e. a new theory or a discovery is entirely new) or something new to particular individuals (i.e. a new idea is new in a personal sense, for instance to learners but not to others) (Hadzigeorgiou, Fokialis, and Kabouropoulou 2012).

A particular feature that helps distinguish scientific creativity from other types of creativity (excepting that in mathematics) is the strict requirement for 'logic' in science (Simonton 2004). For scientific advancements, ideas need to be internally consistent (logical), established on prior scientific knowledge, and via a problem-solving process (Hetherington et al. 2020; Kind and Kind 2007; Simonton 2004). More specifically, logical thinking is an important prerequisite for scientific discovery (Taber 2012), and new knowledge claims need to be backed up by an argument chain (Toulmin 1972). Furthermore, scientific knowledge, comprising domain-specific and general knowledge, enables scientists to grasp the fundamental terminology, structures, and frameworks within their discipline and apply this knowledge flexibly to generate creative ideas (Heller 2007). Additionally, when scientists push against the knowledge boundary, they need different scientific problem-solving procedures to test these creative ideas (McGregor and Frodsham 2023). Therefore, scientific creativity involves logic, requiring rich scientific knowledge and a strict empirical testing (cf. Kind and Kind 2007). When novel ideas withstand experimental verification or are not refuted, they become factually sound and logically acceptable, thus proving their worth to both the scientific community and society . As defined by Xu, Reiss, and Lodge (2024, 2), 'Scientific creativity is not only the manifestation of inspiration and imagination, but also the process of transforming creative ideas into scientific knowledge by logical reasoning within the existing intellectual framework for the scientific discipline in question'.

Creativity in science education differs from creativity in scientific research, in ways that are manifested at different levels, participants and settings. Kaufman and Beghetto (2009) proposed a 'Four C model' to conceptualise four different levels of creativity:

Mini-creativity

Mini-creativity is inherent to the personal learning process, characterised by the generation of novel and personally meaningful interpretations of experiences, actions, and events. For example, a fourth-grade student might offer what are for them unique and personally significant insights into the question of whether Pluto should or should not be considered a planet.

Little creativity

Little creativity necessitates individuals possessing domain-relevant skills, such as knowledge and technical expertise. For instance, when faced with a question about whether Pluto in a planet, the teacher or some students may not consider it creative if a fourth-grade student already knows the answer. However, if the student can collect scientific information to substantiate their view and create a poster or a PowerPoint presentation detailing the scientific exploration within the science classroom, this can be referred to as 'little creativity', both for the student and for others in the science classroom.

Pro-creativity

Pro-creativity signifies a level of expertise at a professional scale, demanding extensive preparation and formal training within a specific domain to attain world-class expert status. Publications, such as research articles, serve as a means to showcase pro-creativity.

Big-creativity

Big-creativity encompasses outstanding creative contributions that could bring about significant changes within a specific domain. This level of creativity is exemplified by clear-cut, eminent creative contributions like Albert Einstein's theory of special relativity in the field of science.

The first two levels, Mini-Creativity and Little Creativity, are accessible to and exhibited by most individuals in their daily lives, while the latter two levels, Pro-Creativity and Big-Creativity, pertain to professional and domain-specific excellence, often extending beyond the capabilities of the general population. In school science education, creativity can be expressed as potentially every student's ideas and actions being novel and valuable to the individual (mini-creativity), or it can be found in everyday educational activities (little creativity). This understanding helps give creativity educational meaning and practical value, as it suggests that not only does every student have creative potential, but that science teachers can foster creativity in their daily classroom activities.

Science classroom creativity

The development of scientific creativity in science classrooms and the factors influencing the process are described and explained by different models.

One example is Amabile's componential model of creativity, in which she defined creativity as 'the production of novel and useful ideas by an individual or small group' (Amabile 1988, 126). Amabile and her group have developed the model several times and finally reached the 'Dynamic Componential Model of Creativity' (Amabile 1988; Amabile and Pratt 2016). In this model, individuals' creativity comprises three major components: task motivation, specifically, people can be intrinsically motivated by interest or challenge of the work itself, or extrinsically motivated by pressures or recognition; skills in the task domain, including factual knowledge, technical skills, and special talents in the domain; and creativity-relevant skills, such as a cognitive style favourable to taking new perspectives on problems (Amabile and Pratt 2016).

Amabile introduced a concise five-stage model for individual creativity (Amabile and Pratt 2016). It begins with Stage 1, Task Presentation, where an individual's strong intrinsic motivation or an external source, such as an assignment, triggers the creative process. Stage 2, Preparation, is a phase dedicated to acquiring the knowledge, skills, and specific information needed to address the problem effectively. In Stage 3, Idea Generation, individuals brainstorm and develop one or more potential solutions. Stage 4, Idea Validation, involves assessing the utility and appropriateness of these creative ideas. Finally, in Stage 5, Outcome Assessment, decisions are made based on the results (Amabile and Pratt 2016).

This model emphasises the essential components and the creative process needed for individual creativity, offering valuable insights into the factors that characterise creative students and providing guidance on nurturing the creative process within science classrooms. However, it does not examine the intricate impact of the external environment on creative individuals nor the creative process, particularly in science classrooms where multi-level socio-cultural factors come into play, such as the influences of students' families, communities, and broader social culture (Liang et al. 2022). Therefore, further research is needed to explore the influence of the multi-level social-cultural environment on the creative process of students in science classrooms.

The occurrence and importance of multi-level socio-cultural environments are emphasised in Chinese culture; Fei pointed out that 'it looks like the ripples form from a stone thrown in a lake, each circle spreading out from the centre becomes more distant and at the same time more insignificant' (Fei 1992, 65). This analogy of order within water ripples signifies the complex, multi-level interactions between individuals and their surroundings. For instance, students transition from their homes to the classroom, school, and eventually into broader society, with external environments enveloping them like concentric ripples in water. Within these contexts, students grapple with the expectations linked to key human relationships, including those they have with parents and teachers.

These expectations, referred to as '*renlun*' in Chinese culture, akin to 'the order existing in ripples of water' (Fei 1992, 65), mean that numerous demands are placed on students by these interpersonal relationships across multiple environments.

Yi (2008) captured this characteristic of Chinese culture and proposed the 'Cultural Pyramid Model of Creativity' (CPMC), which was used to compare artistic creativity between German and Chinese students, and discuss the creative organisational climates of Chinese secondary schools. Figure 1 shows that CPMC consists of a pyramid of creativity set in a cultural or environmental globe. When focusing on the cultural or environmental globe, creativity is classified into three levels: the *individual*, also known as the self-world; *relationships*, which encapsulate interpersonal relationships in families, classes and schools; and *collectives*, which represent the whole of society, including community, any kind of organisations, or the media world (Yi 2008). Furthermore, the arrows in Figure 1 represent the tension between the three levels of the cultural globe, and this tension is dependent not only on the interaction between the individual and the group but also on the interaction between the relationship and the collective level (Yi 2008). When some creative ideas generated by individuals are inconsistent with the group's standard answers or the collective's traditional answers, it is critical for the multiple social-cultural environments to handle the tension, as the results may affect whether the individual will continue to implement the creative idea or be willing to propose more creative ideas in the future.

This multi-level cultural perspective allows creativity researchers to explore the role of the external environment more systematically, especially in specific cultural contexts. In the science classroom, students' close human relationships with their science teachers significantly impact students' creativity (Fredagsvik 2021; Kind and Kind 2007). However,

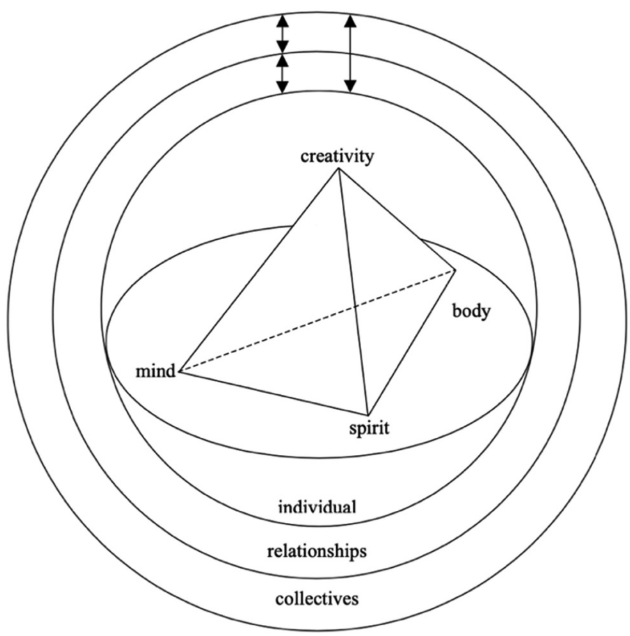

Figure 1. The cultural pyramid model of creativity (CPMC) (Yi 2008).

the CPMC model does not address how science teachers may influence students' creativity, whereas it is important to include science teachers in the analysis of science classrooms alongside creative students, creative processes, and socio-cultural environments.

The significance of science teachers in science classrooms is highlighted in the 'Science Classroom Creativity' (SCC) model, developed by Hong and Song (2020). Figure 2 shows that SCC includes five dimensions, each with two components constituting different subcomponents. Science teachers' support, as one dimension, encompasses cognitive components, like providing guidance during the inquiry process or posing appropriate questions, and emotional components, like maintaining a positive attitude and offering feedback, and it could play an important role in the development of students' creativity as the external environmental dimension in this model. Additionally, the SCC model encompasses students' characteristics, creative behaviour and engagement in science class, and these three components also align with the components of creative students and the creative process, as discussed in the 'Dynamic Componential Model of Creativity' (Amabile and Pratt 2016).

The SCC model has been validated for use in Korean science classrooms through interviews with science teachers and students, as well as classroom observations (Hong and Song 2020). The empirical validation ensures its suitability for analysing creativity in science classrooms. However, there are still some areas for improvement in this model. For instance, creative behaviour and engagement in the science class may overlap, as

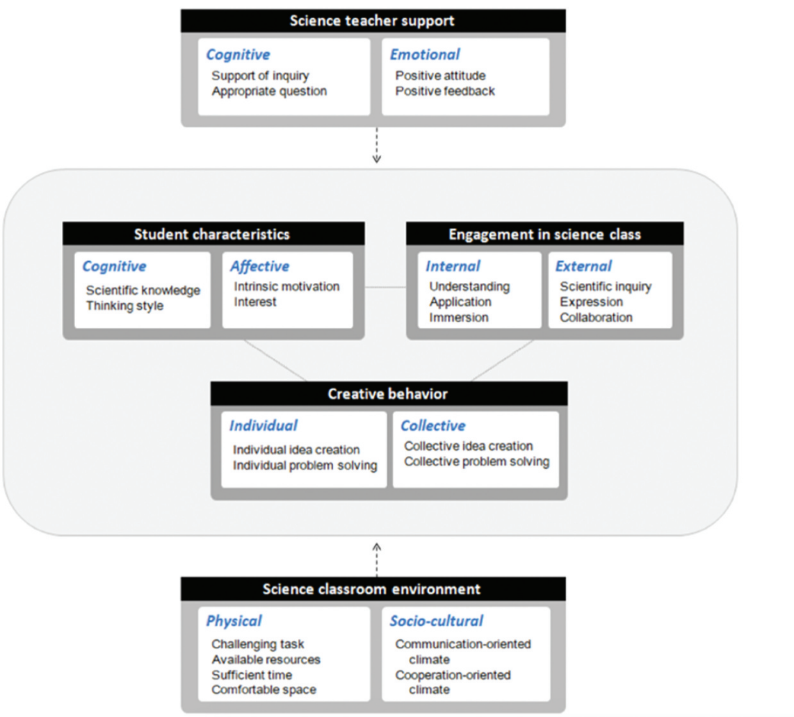

Figure 2. Componential model of science classroom creativity (SCC) (Hong and Song 2020).

students' behaviour can also reflect their engagement (Fredricks, Blumenfeld, and Paris 2004). Moreover, certain sub-dimensions in the model, such as 'individual problem solving' and 'scientific inquiry', are divided into distinct components despite sharing similar underlying processes (Cropley 2001). In addition, students' interests can be included within intrinsic motivation (Amabile 1988), and teachers' feedback can also reflect their attitudes, but the model discusses these subdimensions separately. Nevertheless, the SCC model developed in Korea provides valuable insights and inspiration for Chinese educators due to cultural similarities and a shared emphasis on the role of teachers in science classrooms.

In summary, the 'Dynamic Componential Model of Creativity' delineates the components of creative individuals and the creative process. Moreover, the 'Cultural Pyramid Model of Creativity' (CPMC) aids our understanding that within the Chinese context, creative individuals are embedded in multi-level socio-cultural environments. Notably, according to the 'Science Classroom Creativity' (SCC) model, the role of science teachers emerges as a pivotal factor in fostering creativity, working in concert with students, the creative process, and the environment. Therefore, this study proposes a new integrated analytical model which strives to offer a comprehensive depiction of science classroom creativity in China by combining components from the three models and addressing some of the previously mentioned limitations.

An analytical model of science classroom creativity

This study proposes a new analytical model that incorporates creative students, the creative process, teachers' attitudes, and a creative environment, all of which influence science classroom creativity. Our particular focus is China, though we suspect that with suitable modifications, it may apply elsewhere too.

Creative students

In the model, 'creative students' possess or develop inherent creative characteristics, including scientific knowledge, divergent thinking, and intrinsic motivation. These characteristics are vital in the science classroom, as they not only facilitate the creative process (Amabile and Pratt 2016) but also serve as specific objectives for fostering students' creativity (Hong and Song 2020). Specifically, students' existing valid scientific knowledge ensures that their creative ideas are scientifically logical (Simonton 2004), and their divergent thinking sometimes leads them to think in different directions from those that are standard, in ways that reflect the novelty of their ideas (Runco 1999). These two components align with the logical and original features of scientific creativity, leading to the generation of diverse and innovative ideas rather than fantastical and unrealistically imaginative thoughts in science classrooms.

In addition, the conversion of individuals' creative ideas into creative products requires strong intrinsic motivation (Amabile and Pratt 2016), which is regarded as 'the drive to do something for the sheer enjoyment, interest, and personal challenge of the task itself' (Hennessey and Amabile 2010, 581). When students view a scientific problem as a challenge and desire to explore the science world to satisfy their curiosity, their creative potential is more likely to be stimulated. This process could be described as a meaningful and valuable learning experience. While not all students in science classrooms are initially 'creative students', we believe that everyone has creative potential (Runco 2004), and one of the goals in science classrooms is to nurture students to become creative (Kind and Kind 2007). Therefore, these three key characteristics can aid educators in identifying creative students, assessing their creative potential, and providing clear directions for their development in becoming more creative.

Creative process

The term 'creative process' describes students' engagement in a series of inquiry activities within the science classroom, facilitated by the guidance of science teachers. Aligned with the dynamic componential model of creativity, the creative process underscores the necessity for creative ideas to undergo preparation, proposal, evaluation, and eventual expression (Amabile and Pratt 2016). This process aligns with the concept of 'inquiry', as outlined in the official teaching standards for Chinese science teachers, involving 'asking questions, making hypotheses, developing plans, gathering evidence, processing information, drawing conclusions, expression and communication, and reflective evaluation' (MOE 2022b, 119). Furthermore, scientific inquiry implies not only an ordered and prescribed scientific process, but also a rational and critical process in which students can analyse or evaluate information systematically to decide what actions to take next; it is therefore related to developing students' scientific divergent and convergent creativity in Chinese science classrooms (Yang et al. 2016).

The effective development of the creative process relies on science teachers guiding the process of scientific inquiry; without such guidance, students may not achieve satisfactory progress in the creative process (Furtak et al. 2012). Therefore, science teachers need to possess pedagogical content knowledge, including an understanding of students' scientific thinking, the science curriculum, science-specific instructional strategies, assessment of students' science learning, and teaching orientations (Schneider and Plasman 2011). For example, if science teachers can make learning content relevant to students and use imaginative approaches to make teaching interesting, students will be more engaged in the creative process and have a passion for inquiry, discovery, and experimentation in science learning, ultimately contributing to the development of students' creativity (Jeffrey and Craft 2004).

Teachers' attitudes to creativity

Teachers' attitudes to creativity include teachers' perceptions of creative students and teachers' feedback on creative ideas. Johnson's (2023) review reveals that teachers' assessment of creative students significantly impacts the recognition and subsequent development of students' creativity, influencing whether it thrives or diminishes over time. For example, Chan's and Chan (1999) study demonstrated a strong association between creativity and intellectual functioning among Chinese teachers, highlighting traits such as quick responsiveness and high intellectual ability. Moreover, Aljughaiman and Mowrer-Reynolds (2005) observed in their study involving 36 American elementary teachers that creativity might be acknowledged in students displaying likeable characteristics and achieving high academic success, while those manifesting negative behaviours or lower achievement scores may be overlooked.

This phenomenon suggests a potential belief among teachers that only academically gifted students can exhibit creativity, possibly leading to the undervaluation or dismissal of creative ideas and performances from other students (Aljughaiman and Mowrer-Reynolds 2005; Zheng, Yang, et al. 2022). Consequently, teachers may invest time in nurturing the creative ideas of academically successful students, encouraging them to bring these ideas to fruition, while creative ideas from other students perceived as disruptive might be ignored or criticised in classrooms (Aljughaiman and Mowrer-Reynolds 2005). This dismissal of ideas may discourage students from taking intellectual risks, leading them to conform to perceived expectations rather than expressing their creativity in the classroom (Fredagsvik 2021).

Creative environment

A creative environment includes both the physical and the socio-cultural environment within which teaching and learning take place. In terms of the physical environment, science laboratories can serve as crucial spaces where students engage with materials and models, mirroring the investigative practices of scientists studying the natural world (Hofstein and Lunetta 2003). According to the review by Hofstein and Lunetta (2003), laboratory experiences play a key role in advancing science education objectives, including deepening students' understanding of scientific concepts and the nature of science, developing scientific practical skills, as well as fostering students' interest and motivation for science. Kind and Kind (2007) point out that 'hands-on' activities within laboratory or outdoor settings could be deemed good 'creative teaching', creating environments conducive to openness and freedom. Thus, science laboratories can not only enable students to gain hands-on experience in scientific inquiry but also afford them a relatively open and free space to implement their creative ideas within an authentic scientific framework. As with the physical environment, Davies et al'.s (2013) systematic literature review underscores the essential role of time in cultivating students' creativity. For example, Burnard et al. (2006) discovered that young children require sufficient time for immersion in an activity in order to achieve creative outcomes.

The previous discussion highlights the crucial role of a supportive socio-cultural environment in nurturing creativity, as manifested in people's perceptions and beliefs about environmental attributes that shape expectations, contingencies, requirements, and interactions within science classrooms (Yi 2008). A significant cultural difference between Western and Eastern environments is evident in the inclination towards individualism or collectivism, with the former emphasising the healthy expression of one's thoughts and the latter prioritising the maintenance of harmony (Hofstede 2011), which is also a central value derived from Confucianism in Chinese culture (T. Chen et al. 2015). However, the essence of creativity, marked by diversity and novelty, necessitates a community that respects, cares for, and tolerates differences (Richardson and Mishra 2018).

In China's science classrooms, characterised by a typical collectivist context, cultivating an environment that respects differences becomes imperative. In addition, fostering an environment that tolerates mistakes is crucial for supporting students' creativity in classrooms (Richardson and Mishra 2018), particularly when there are large class sizes (S. Chan and Yuen 2014). The fear of making mistakes, social disapproval, and separation anxiety are powerful deterrents to creative thinking (Aljughaiman and Mowrer-Reynolds 2005). Therefore, given the large class sizes in China, science teachers should foster an environment that tolerates mistakes in science classrooms, encouraging students to share new ideas and take risks without the fear of making mistakes.

Figure 3 therefore shows the analytical model of science classroom creativity advocated in this article. Creative students, a creative process, teachers' attitudes to creativity, and a creative environment, as well as their sub-components, will all impact science classroom creativity.

Applicability of this analytical model to school science education in China

Chinese students in science classrooms

Scientific knowledge

Regarding scientific knowledge, Chinese students are usually at or close to the top of the international rankings. According to the Programme for International Student Assessment (PISA) results in 2018, 15-year-old students in Beijing, Shanghai, Jiangsu and Zhejiang (four provinces in the Chinese mainland) ranked first in science examinations among counterparts in other countries (OECD 2019). Specifically, 97.9% of these Chinese students could use scientific knowledge to identify, in simple cases, whether a conclusion was valid based on the data provided, and 32% of the Chinese students were top performers who could apply their scientific knowledge creatively and autonomously in different situations. In comparison, only 6.8% of the students across OECD countries were top performers who demonstrated this excellent ability (OECD 2019). Furthermore, in the 2022 PISA science assessment conducted in Macao (China), Chinese Taipei, and Hong Kong (China), Chinese students

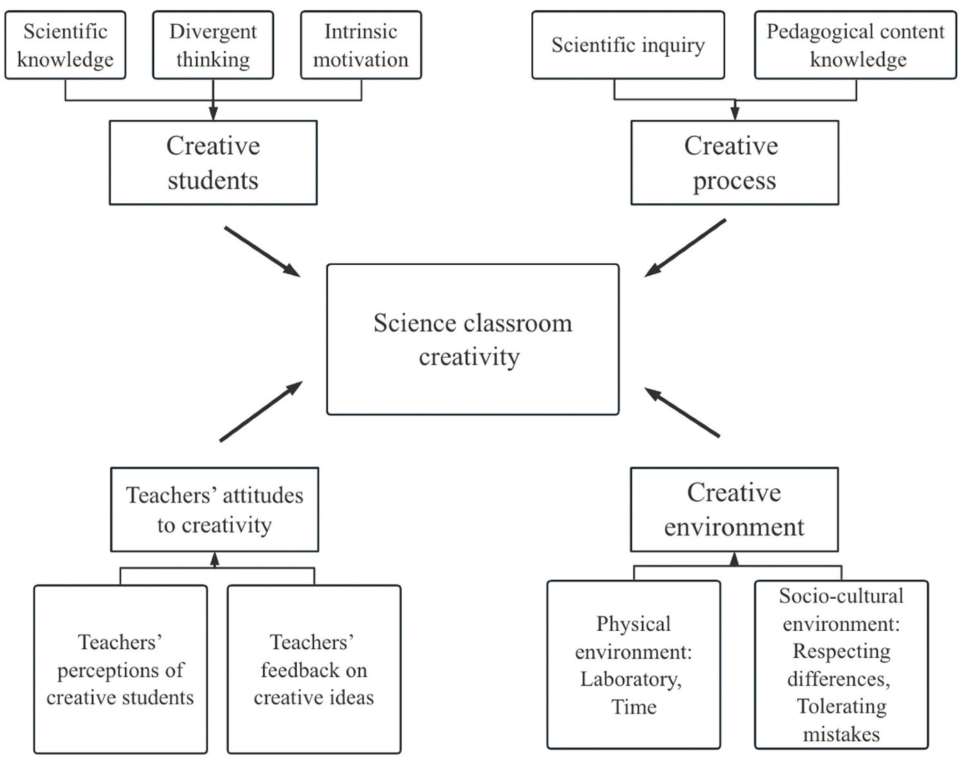

Figure 3. The analytical model of science classroom creativity.

demonstrated continued proficiency by securing commendable rankings of third, fourth, and seventh place, respectively, among all participating countries (OECD 2023).

However, even though Chinese students perform well in international tests for science achievement, the scientific knowledge they typically acquire in science classrooms often remains confined to the memory level, focusing primarily on factual and conceptual knowledge (Wei and Ou 2019). According to the revised Bloom's taxonomy, the intellectual demands of students' learning outcomes can be assessed at four knowledge levels (Factual, Conceptual, Procedural, and Meta-cognitive) and six levels of cognitive processes (Remember, Understand, Apply, Analyse, Evaluate, and Create) (Anderson et al. 2001). Wei and Ou (2019) used this taxonomy to examine science curricula in Chinese lower secondary schools in four regions (Chinese mainland, Taiwan, Hong Kong, and Macao), and the results revealed that conceptual knowledge accounted for the majority of the curricula in the four regions, with the Chinese mainland, Taiwan, and Macao emphasising factual and conceptual knowledge memory. Overall, the intellectual demands for science classrooms are modest in Chinese lower secondary schools, similar to what Wan and Lee (2021) found for the science curriculum in Chinese primary schools. As a result, even though Chinese students may perform well in various science tests, the knowledge-oriented towards test questions often lacks the depth necessary for guiding students in inquiry experiments, impeding their capacity to apply, analyse, evaluate, and create knowledge in authentic contexts, ultimately discouraging their creative thinking.

Divergent thinking

Using scientific knowledge as a basis for creativity in science requires divergent thinking; indeed, some studies have argued that divergent thinking is more important than intelligence (as measured by IQ scores) or scientific knowledge for creativity (Plucker 1999), and divergent thinking tests are very frequently used to estimate the potential for creative problem solving (Acar and Runco 2019). Participants who work on divergent thinking tasks may take an open-ended problem and move toward many different solutions (Acar, Runco, and Park 2020). Cheung et al. (2016) reviewed previous research on Chinese students' divergent thinking and found mixed results, with some studies identifying excellent divergent thinking in Chinese students while others found a paucity of divergent thinking.

The teaching model of China's exam-centric education is why it is usually believed that Chinese students are not good at divergent thinking. Expository methods and drilling for external examinations are common in Chinese classrooms. Gao and Watkins (2002) investigated the conceptions of teaching held by Chinese school science teachers, and the results showed that 'knowledge delivery' was the most commonly identified teaching concept in science classrooms; this views teaching as a process of delivering knowledge and skills, and considers students as passive receivers or containers of knowledge. Under this guidance, students' ideas might rely heavily on the views of teachers and textbooks that are officially correct and fixed, so most students are more likely to comply with their teachers' views and follow the textbook requirements rather than coming up with new and different ideas. As one teacher described her teaching in science classrooms:

> The nature of teaching, or say, the role of a teacher, is to deliver knowledge as long as the methods and skills . . . No matter how many things are involved in teaching process, it is still a delivery process. (Gao and Watkins 2002, 65)

Meanwhile, 'exam preparation' also dominates Chinese science classrooms, with a strong focus on textbook learning, didactic teaching and summative assessment. As one science teacher said:

> As a teacher, my main task in the classroom is to ensure that my students can get good marks in the matriculation examination, because this is the most important or even the only aspect by which the school authority assesses my teaching. As a result, the matriculation examination becomes the main focus of my teaching. (Gao and Watkins 2002, 65)

Achieving high examination grades is probably the ultimate educational goal of most teachers, students, parents, and even the entire education system in China, as examination results greatly affect teachers' work performance, the quality of a school, and, in the case of students, their subsequent lives (Tan 2016). As a result of this exam-centric environment, teachers are required to teach the prescribed content and learners are expected to produce the standard answers. All of these point to convergent thinking, where students are more likely to pursue the single, best, standard answer rather than the diverse, novel, and unconventional ideas encouraged by divergent thinking and affecting the development of scientific creativity (Zhu et al. 2019). Furthermore, when students educated within such a system take a divergent thinking test, they may unconsciously tackle it more carefully and slowly, seeking to provide the best standard answers, which is counterproductive to the very idea of a divergent thinking test.

Intrinsic motivation

When Chinese students enter their second year of high school, they are required to choose subjects for the National College Entrance Examination (NCEE). Most students choose science subjects (physics, chemistry, and biology) as their future learning path, which means they will enrol in specific science classrooms, specialise in the science subjects over the next two years, take the final science NCEE, and eventually pursue a science major at a university. In Anhui, a province with a medium level of economic, social and educational development in China, a total of around 471,000 students registered for the NCEE in 2022, of whom about 388,000 chose science NCEE (AEEA 2022), and this enthusiasm for science is widespread throughout China. Cheng and Wan (2016) reviewed previous surveys on the interest of Chinese students in science learning and found that on many items students scored highly, e.g. 'When I do science, I sometimes get totally absorbed' or 'I like chemistry theory lessons and laboratory work'. Students' strong intrinsic motivation makes them more curious about scientific issues and helps them to engage in the learning process, thus stimulating their creativity.

However, Chinese students' learning motivation for science may not simply be a passion for the subject. Some studies have revealed that Chinese students have a strong instrumental motivation to learn science (Cheng and Wan 2016; Tuan and Chin 2000). Tuan and Chin (2000) analysed 149 Chinese students' goals when learning physical science and found that most students' motivation was related to extrinsic considerations. One student stated in their interview:

> It is very important [to learn physical science]. In our daily life, many things [are] related to physical science. For instance, petroleum and refining of petroleum and the refining products. There are many things in daily life not petroleum products but other things [that] are very useful in our daily life. (Tuan and Chin 2000, 10)

In Chinese science classrooms, a famous proverb goes, 'Whoever has a good command of maths and science will be free from worries'. In other words, many students and teachers believe that science is a useful tool to help them overcome daily challenges (Tuan and Chin 2000) and secure good employment opportunities in the future (Cui, Wu, and Pan 2017; MyCOS Research 2022). The income disparity observed in the 2022 salary survey of Chinese university graduates further supports this perspective, revealing higher earnings for students choosing to study science (MyCOS Research 2022). Consequently, the utilitarian, performance, and achievement motivations prevalent among Chinese students may significantly shape their approach to science learning (Cheng and Wan 2016), potentially impeding enthusiasm for science and, consequently, hindering the cultivation of creativity.

In addition to instrumental reasons, other extrinsic performance motivations might influence creativity. In science classrooms, performance motives have been described as 'the students' goals are to compete with other students and get attention from the teacher' (Tuan, Chin, and Shieh 2005, 643). Given that the Chinese education training model places great value on correctness, students are more likely to seek to provide accepted, traditional answers rather than original ideas (Wang and Greenwood 2013). Furthermore, learning includes moral aspects in Confucian culture (Li 2001), so students' good performance will be viewed as a family obligation and a community and social responsibility (Liu et al. 2020). For example, Li (2002) pointed out that if Chinese students perform poorly in classrooms, they are likely to feel shame-guilt for themselves and cannot face up to their families. As a result, even if students are not interested in science, they will still typically strive to learn to fulfil their obligations by providing conventional answers to their teachers' questions and satisfying the expectations of their families, schools and society.

Creative process in Chinese science classrooms

Scientific inquiry

The poor scientific inquiry skills of teachers and students also hinder the development of creativity in science classrooms. In the PISA 2015 survey, the frequency of inquiry teaching in science classrooms in China was significantly lower than the average of OECD countries (OECD 2016). According to Zheng, Li, et al. (2022), Chinese science teachers are not skilled in problem-solving and inquiry-based methods, and the current system for training science teachers also neglects the importance of scientific inquiry. In this context, the level of scientific inquiry of Chinese students is probably unsatisfactory as well. Zheng, Yu, et al. (2022) analysed 32 physics videos to assess primary school students' inquiry skills, and the findings revealed that these students could ask scientific questions through observation and comparison, but did not explicitly state a hypothesis, could only make simple plans, and needed guidance from others when they observed the phenomena of scientific experiments. For example:

> In the 'What Blurs My eyes – Fog Generation and Elimination Inquiry Experiment' lesson, one female student started from life experience and asked, 'Why it would be foggy to wear glasses and masks outside in winter but not in summer', and then related to 'How fog is formed', but then she gained the answer through a web browser and prepared the suitable experimental tools without creating an experimental hypothesis, so the entire process was only a verification experiment. (Zheng, Yu, et al. 2022, 11)

Furthermore, in Chinese science classrooms, scientific inquiry seems more like a verification activity, with students following the teachers' predetermined inquiry steps rather than independently applying, analysing, synthesising, and evaluating information gained from observations and experiences (Pei and Liu 2018). For example, Pei and Liu (2018) analysed 16 experimental inquiry activities in Chinese lower secondary science classrooms, 14 of which tended to establish a common hypothesis and a similar design plan which targeted a correct answer. Figure 4 shows a slide of a teacher's teaching design for an 'inquiry activity' (Pei and Liu 2018). This process simplifies scientific inquiry into a procedural, manipulative, and verifiable teaching process where teachers 'impart' the knowledge and skills of inquiry rather than let students conduct more authentic, student-centred inquiry activities. When students see scientific inquiry as a way of making things by following teachers' instructions, science classrooms are transformed into a place of re-production rather than creativity (Newton and Newton 2009).

Pedagogical content knowledge

Science teachers with adequate pedagogical content knowledge in creative teaching and learning will be more likely to provide students with cognitive support to instruct them in creative activities (Jeffrey 2006). In 2020, China had 230,201 science teachers in primary schools (MOE 2020). A survey covering 131,134 primary school science teachers showed that 97.5% had a university degree or higher education background, but only 27.5% possessed a professional qualification in science, and some science teachers' professional backgrounds were even in art, music, or physical education (Zheng, Li, et al. 2022). The findings are also consistent with Tian, Xin, and Hu's (2021) survey that showed that most Chinese primary and secondary school science teachers met the legal requirements for educational level and possessed qualified teacher status, but many had not previously majored in science, and some had not even received professional training to be a science teacher. Systematic science teacher training is necessary because it allows science teachers to master not only scientific knowledge but also pedagogical content knowledge, allowing them to understand the key ideas in their subject, the most helpful forms of

Figure 4. A slide of a teacher's teaching design for an 'inquiry activity' (Pei and Liu 2018, 116).

representation, as well as strong explanations (Windschitl 2009). Furthermore, lacking pedagogical content knowledge, science teachers may struggle to implement scientific inquiry, identify and address students' science misconceptions, and challenge scientific ideas (Kanter and Konstantopoulos 2010). In Chan and Yuen's (2014) interview with 10 primary school teachers in Hong Kong, some teachers stated:

> I think the teacher mentality and the teacher training are so important for ... enhancing creativity ... I think teachers don't really take the time to think of how they want students to express it in class ... They don't really think about how they can bring it out ... because they are bound by textbooks. (S. Chan and Yuen 2014, 73)

> I have seen that ... not all teachers are sensitive to students' individual strengths and interests. I have shared this with my co-workers. It really is a pity. (S. Chan and Yuen 2014, 73)

Without pedagogical content knowledge, even if science teachers understand key concepts of science, they may struggle to impart this knowledge to their students creatively (Jeffrey 2006). Instead, they are more likely to be bound to the textbook, following cookbook-style activities, rather than supporting students to explore their own ideas (S. Chan and Yuen 2014; Kanter and Konstantopoulos 2010).

Teachers' attitudes to creativity in China

Perceptions of creative students

Compared to Western teachers, Chinese teachers' perceptions of creative students are highly associated with intellectual function (D. W. Chan and Chan 1999). Chan and Chan (1999) asked 204 Hong Kong primary and secondary school teachers to characterise creative students; 'quick in responding', 'high intellectual ability', 'high verbal ability', and 'like/willing to think' were frequently mentioned by these teachers, but were less reported in North American studies. Huang and Lin (2008) invited 255 Chinese secondary school teachers to describe creative students' characteristics and found that their descriptions were associated with achievement-related intelligence. One teacher stated:

> In terms of learning, the highly creative student loves to learn, is a good thinker, conscientious, good at identifying problems, and is always keen to make up for and rectify his shortcomings. Regarding recreation, he is also good at playing and will think of ways to have more fun, be more interesting, and be more different from others. (Huang and Lin 2008, 91)

Also, in their interviews, some teachers at a vocational secondary school stated:

> The students in our school are the ones whom good secondary schools have not chosen, and they are not creative because their academic performance is poor. (Huang and Lin 2008, 91)

There is no consensus that intelligence is highly correlated with creativity (Batey and Furnham 2006; G. Chen et al. 1996), so some Chinese teachers' biased perception of creative students may lead them to focus on the creativity of high-achieving students while ignoring the creativity of other students. In addition, 'nurturing outstanding creative talents' – a new Chinese education policy – deserves attention (MOE 2019). The 'outstanding' here means good grades, so it is akin to suggesting that only high achievers have the potential for creativity, and 'creative talents' refers to the policy's goal of developing leading scientists who can make sublime achievements in the future. Influenced by this policy, some schools have developed strategies, such as offering gifted and creative classes or inviting university professors to guide students in research activities (Zheng, Yang, et al. 2022). All of this suggests that nurturing creativity in China may require a specific environment, professional guidance, and a particular group, so teachers in classrooms and their students might come to believe that their everyday creativity is of no worth.

Feedback on creative ideas

In science classrooms, teachers' feedback on creative ideas will be impacted by their dual attitudes toward creative students (Fredagsvik 2021). On the one hand, creativity can be desirable for students who perform well in school, so when they have creative ideas and engage in creative activities, teachers will value these ideas and provide the necessary assistance. On the other hand, creativity may be a negative trait for students with poor academic performance. For these students, teachers in Chan's and Chan (1999) study described them as self-centred, arrogant, unaccepting of others' opinions, and their behaviour served only to attract the attention of teachers and students. These behaviours and traits are not welcome in the Chinese classroom, since being introverted and respectful of others are what Chinese culture promotes (Zhang, Chu, and Lin 2008). In this context, teachers might not support some innovative ideas because they would disrupt the teaching process, so these ideas are more likely to be ignored, interrupted or criticised by teachers.

Creative environment in Chinese science classrooms

Physical environment

Laboratories are places where students can carry out specialised scientific inquiry that requires dedicated scientific equipment and materials, and where they have the opportunity to experience the creative process first-hand. According to a survey of 131,134 primary school science teachers in China, 17% of the science teachers indicated that their schools did not have a laboratory, and only 56% of them had one laboratory (Zheng, Li, et al. 2022). Figure 5 shows the space (floor area) of science laboratories for each primary, lower secondary and upper secondary student in China from 2011 to 2015 (more recent data seem to be unavailable); although this figure increased during this period, it was still relatively low (NAIS 2018).

Fan (2022) interviewed 10 Chinese primary school science teachers about the use of school laboratories, and some teachers responded that:

> There are at least 12–13 science experiments in a book, but due to limited time and laboratories, it is impossible to perform all of them. Some suitable for demonstration are shown to all students by the teacher in science classrooms; some more complex ones are shown by watching videos. Most science laboratories will plan 4–6 science experiment sessions a week. If an experiment takes longer, the teacher will schedule two science lessons together to complete it. (Fan 2022, 17)

Other teachers in charge of school laboratories stated that:

> Science laboratories in our schools are prepared for official inspections, and students generally do not enter them. (Fan 2022, 17)

In part because of China's large population, its historical phase of development, and government priorities, school science laboratories are still quite scarce. Although scientific inquiry can be conducted in (non-laboratory) classrooms where students and teachers explore and discuss science within a 'narrative of enquiry' context (Hofstein and Lunetta 2003), Lee and Park found that, in comparison to teachers and parents, students prioritise 'doing experiments accurately and deliberately using machines or devices without hurrying but with concentration in their own laboratory space' (2021, 75) as more crucial for the development of scientific creativity. As a result, due to the frequent absence of a suitable physical environment, scientific inquiry activities in Chinese science classrooms are often led by science teachers rather than being independently performed by students in laboratories.

In addition to space considerations, time pressures are also significant for science classroom creativity. From the frequency and content of classroom dialogue, we can see the time distribution of a science lesson. Hu et al. (2021) analysed 17 Chinese science lessons in 2016, covering physics, chemistry, and biology in lower secondary schools. They found that in each lesson, teachers imparted knowledge, evaluated and explained students' answers, and asked additional questions, accounting for 86% of the total dialogue, while student-initiated questions and group discussions only accounted for the remaining 14%. Gao (1998) discussed the context of school science teaching and learning in China and referred to the issue of time with a teacher's remark:

> I would like to spend more time on student activities such as group discussion, but I can't because of limited time and large class size. I need to cover the syllabus, but there is so much

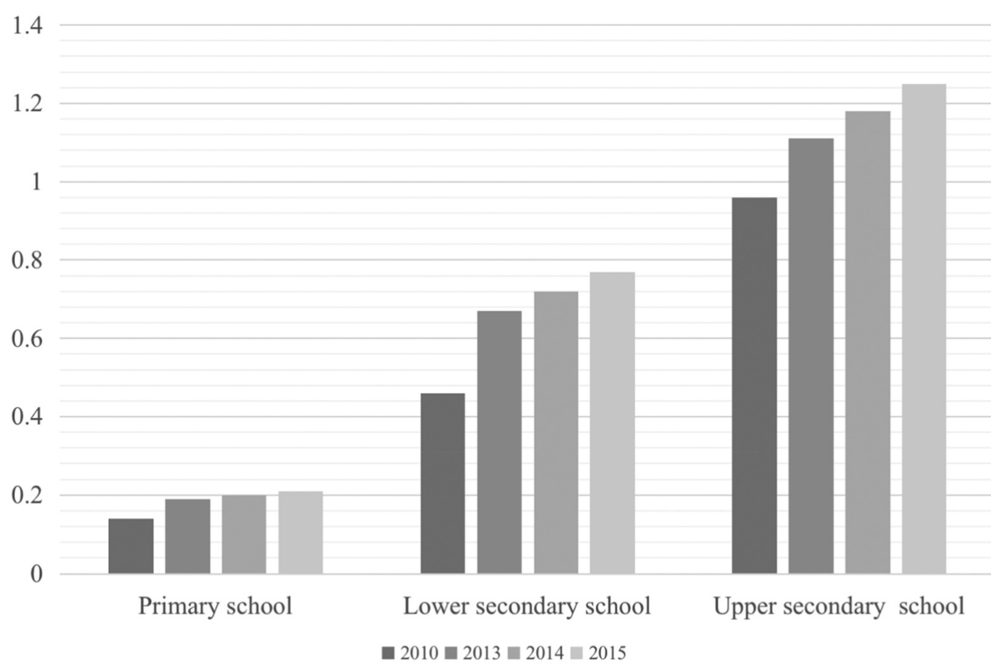

Figure 5. Laboratory space per student in primary, lower secondary, and upper secondary schools in China (Unit: m^2) (NAIS 2018, 286).

> in it. I have to face more than 50 students, and it is very difficult to keep them involved in activities and, at the same time, keep the class in order and make sure that everyone is on task. (Gao 1998, 4)

According to the Chinese National Curriculum Standards in compulsory education, primary school lessons last 40 minutes, and lower secondary school lessons last 45 minutes (MOE 2022a). Additionally, in a nationwide contest in 2021, the average number of students per class in primary school was 38, and in lower secondary school, it was 46 (Q. Zhou, Chen, and Qiu 2023). As a result, each student has only a very limited amount of time to express and discuss their opinions in every lesson in their science classrooms, if their teachers are to hear what they say. In order to comply with teachers' instructions, classmates' learning pace, and the curriculum's schedule, students may restrain their imagination and abandon their creative ideas. Otherwise, they may fall behind their teachers' requirements.

Socio-cultural environment

To some extent, the very notion of creativity suggests ideas and activities that are different, non-traditional or contrary to what authority expects; it will be challenging for Chinese students to demonstrate creativity in a science classroom dominated by Confucian culture and collectivism. First, 'harmony' is the central value in Chinese culture derived from Confucianism; it emphasises that people should maintain harmonious relationships with other social actors (T. Chen et al. 2015). Harmonious relationships expect individuals to think and behave in line with their groups and to avoid conflict and tension with others; understandably, individual interests can be sacrificed to satisfy the collective interest. The Confucian value of 'harmony' is more likely to result in students trying to avoid appearing too different from others and learning to limit the expression of their creativity (Kim 2007). Furthermore, rather than encouraging creativity, Confucius wished for each person to be able to 'control oneself and conform to rituals', which means that people should conform to authority (Fei 1992). In the classroom setting, because teachers and textbooks are the authorities, students must control their behaviour and respect authority, and those who act against authority are deemed unethical and are condemned in Confucian culture.

Finally, being creative may imply making mistakes, which many Chinese students are afraid of. In a study on fostering creativity in Chinese students, one teacher said:

> Many students, even those with high ability, are not willing to raise their hands because they are afraid of making mistakes, especially in front of the entire class. (S. Chan and Yuen 2014, 74)

Making mistakes is not negligible for Chinese students, as Chinese culture imposes a high cost on mistakes, where mistakes in classrooms might cause Chinese students to 'lose face' (Wu 2009). 'Face' is a phenomenon in Chinese interpersonal relationships, and it represents individuals' relationships and social status; losing face means that individuals feel embarrassed or humiliated, and their interpersonal and social status has been damaged (Hwang 1987). Face concern is more salient for Chinese than for many other cultures, and it has significant effects on students' classroom behaviours, such as rarely venturing any questions or opinions (Wu 2009). Consequently, the cultural factor of 'Face' may contribute to students in science classrooms being more fearful of making mistakes, even though such errors are deemed acceptable.

In summary, considering the cultural context of harmony, authority and face, some different, unconventional and potentially wrong creative ideas and behaviour may not be readily welcomed in Chinese science classrooms.

Conclusion

Fostering creativity is important for science classrooms. The study has generated and defended an analytical model that can help educators to examine and reflect on the development of creativity in science classrooms. In the context of Chinese science classrooms, our examination of the literature highlights that students typically have adequate but not challenging scientific knowledge, as well as a lack of divergent thinking and intrinsic motivation. In addition, teachers' misunderstanding of scientific inquiry methods and limited pedagogical content knowledge impact the creative process in Chinese science classrooms, and their partial understanding and negative feedback towards creativity also generally cause Chinese students' creativity to be ignored, even suppressed. We also argue that the lack of a suitable physical environment and sufficient time prevent students from engaging in authentic scientific inquiry, and that the sociocultural factors of Confucianism and collectivism may also deter students from showing their differences (being original) and making mistakes. Therefore, the factors that hinder science classroom creativity in China do not only exist within the classroom but are also significantly influenced by policies, culture and other aspects outside the classroom. It seems likely that at least some of the above issues are not unique to China but can be found in science classrooms throughout East Asia, indeed in some other places. All science teachers need to be aware that their science classrooms may have such problems, and educators and policymakers should take responsibility for creating environments that encourage creativity in school science.

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