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Fostering Scientific Creativity in Teaching and Learning Science in Schools: A Systematic Review

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Abstract

Fostering creativity among the students will result in the production of a skillful workforce and human capital in the future. Creativity is a concept that has its roots in specific knowledge domains or disciplines including scientific creativity that is specific to science. This article attempts to fill the gap in understanding and identifying the factors and pedagogical approaches that influence and facilitate the effort to foster scientific creativity in science teaching and learning in schools. Thus, the questions arise of what pedagogical approaches and factors that foster students' scientific creativity as well as support the teaching and learning in science classrooms. A systematic review of 30 studies was conducted to investigate effective interventions and variables that influence scientific creativity among students in school science classrooms. Pedagogical approaches and strategies such as teaching creative thinking techniques, problem-based, project-based, model-based, ICT-based, integrated STEM-based, and collaborative learning were found to improve scientific creativity among students. Meanwhile, students' factors, teachers' factors, and environmental factors were identified to facilitate the inculcation of creativity in science teaching and learning. This review suggests that the role of teachers is crucial in fostering scientific creativity in the science classrooms and there is a need to study teachers' beliefs and practices in real settings. Also, future studies could also focus on identifying constraining factors that may hinder the fostering of scientific creativity by teachers in the classrooms.

Keywords: Scientific Creativity, Science Education, Fostering Creativity, Creative Thinking Methods, School Science

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INTRODUCTION

Students nowadays have to be prepared to face and overcome future challenges. One of the key aims of modern educational system is to foster their creativity. Dikici and Soh (2015) as well as Cropley (2018) highlighted that students will be able to solve unexpected problems in the future by honing their potentials during their school years. Researchers and educational policy makers around the world share a similar view and belief that fostering creativity among the students will result in the production of skilful workforce and human capital in the future. In this era where no one can escape from technology, many countries have established shaping critical and creative citizens as the main agenda in their educational policy to produce innovative producers and makers as opposed to being the end users of technology.

Scientific creativity

In science, creative thinking skills are referred to as scientific creativity. Previously, scientists had successfully created useful ideas, theories and products that promote and advance human civilisation. Scientific creativity can be defined as the ability to produce new ideas and products that are relevant to scientific contexts. It is also an ability to discover and solve scientific problems by applying scientific knowledge and skills. Researches on scientific creativity have been done focusing on identifying and investigating the criteria for creativity among individuals working in scientific fields, researches and those who are science graduate students. The criteria are based on product elements such as patents, publications, research products, instruments, ideas and methods. It is also based on behaviours including sensitivity to problems, flexibility, technology competency, communication and interpersonal relationship (Sprecher, 1975). Paul E. Torrance pioneered creativity research in education especially at the school level. Torrance (1965) defines creativity in education as the ability to be sensitive to problems (Starko, 2013)

Aspects of scientific creativity

According to researches, creativity is an intellectual trait that contributes to individuals' achievement in whatever domain they are working in. However, creativity is a concept that has its root in specific knowledge domains or disciplines. For instance, scientific creativity is creativity that is specific to science. It is stand-alone and separated from general creativity (Lin *et al.*, 2003; Mukhopadhyay, 2012). In other words, creativity in individuals consists of creativity traits and domain-specific knowledge or skills. Thus, in scientific creativity, scientific knowledge and skills are necessary besides creativity itself.

According to Mohtar & Halim (2015), among the scientific creativity models commonly referred to by educational researchers are Hu and Adey's Scientific Structural Creativity Model (SSCM) (2002), Son's Scientific Creativity Model (2009) and Park's Model of Scientific Creativity (2010). These models of scientific creativity are illustrated as in Table 1.

Table 1 Models of scientific creativity

	SSCM by Hu dan Adey	Scientific Creativity Model by Son	Model of Scientific Creativity (MSC) by Park
Aspect	Cognitive	Cognitive and non-cognitive	Cognitive
Constructs	Product	Scientific proficiency	Creative thinking
	Traits (Divergent thinking)	Creative competency	Scientific knowledge
		Intrinsic motivation	Scientific inquiry skills
	Process (Thinking, imagination)	Context that support creativity	
		Scientific creativity	

SSCM by Hu and Adey is built based on the Guilford Intellectual Model. This three-dimensional model consists of 24 cells designed to show the connections between dimensions (products, process and traits). In this model, scientific creativity is described as the intellectual ability to produce relevant scientific products by thinking and imagination. Similarly, Park's model also presents the cognitive aspects of scientific creativity. It, however, goes a step further by positing that creative thinking skills are needed to complement scientific domain knowledge (biology, physics, chemistry) and inquiry skills to develop scientific creativity. This model makes it clear that the combination of these three components will produce individuals with scientific creativity. Meanwhile, the Scientific Creativity Model by Son adapted from the Amabile Creativity Model (1996) highlights that scientific creativity depends on scientific knowledge, skills and attitude. The attitude component, which sets this model apart from the other two models, refers to the tendency in learning science including the motivation to complete science tasks or experiments and interest in pursuing tertiary education or career in the sciences.

Systematic review on fostering scientific creativity in school

Systematic review is a study of selected researches identified by a systematic method. These relevant researches are then critically reviewed to answer prior formulated questions. To summarise the results of the included studies, statistical method may or may not be conducted (Higgins et al., 2011). The rigorous study can be claimed by the authors of systematic review as the systematic methods applied including screening and analysis. It also allows the study to fulfil the gaps of previous researches and give directions for future researches (Shaffril, Abu Samah and D'Silva, 2017).

Despite the abundance of studies on scientific creativity in science education at school level, there is still lack of systematic review on these studies. This article was aimed at filling the gap in understanding the factors and identifying pedagogical approaches influencing and facilitating the effort to foster scientific creativity in science teaching and learning in schools. This peer reviewed literature report provides a general and baseline overview on fostering scientific creativity in science teaching and learning in schools. This review aims to fill an important gap in the literature, which is the lack of systematic review on scientific creativity. Previous studies on creativity in school include a systematic review on environment in creativity (Davies *et al.*, 2013), teachers' belief, conception, perception and roles in promoting creativity in the classroom (Andiliou and Murphy, 2010; Davies *et al.*, 2014; Mullet *et al.*, 2016; Bereczki and Kárpáti, 2018), support system in school creativity (Wang and Nickerson, 2017) and measuring creativity (Said-metwaly, 2017). Meanwhile, literature reviews on scientific creativity in school have been done to measure and assess scientific creativity (Mukhopadhyay, 2013; Nur Erwani and Lilia, 2018) and the constructs of scientific creativity (Mohtar and Halim, 2015). Furthermore, a meta-analysis has been done to study creative personality differences between artistic and scientific individuals (Feist, 1998). Thus, this study is important to provide an understanding on the issues in fostering scientific creativity at school.

To construct a relevant systematic review, the current article was guided by two main research questions –

1. What are the possible and suggested approaches that foster students' scientific creativity in the science classroom, and
2. What are the facilitating factors that support teaching for scientific creativity?

This study attempts to analyse existing literature on facilitating factors, pedagogical approaches and practices to foster scientific creativity in science lessons. This section elaborates the purpose of a systematic review, while the next section explains the methodology and the PRISMA Statement (Preferred Reporting Items Systematic Reviews and Meta-Analysis) conducted in this study. Available scientific literature that are relevant to the aspects related to the issue of fostering scientific creativity in science teaching and learning are appraised and critically reviewed in the following section. The last section identifies possible directions for future research.

METHOD

In this section, the method used to retrieve articles related to scientific creativity in science classroom is discussed. This study used the PRISMA method, which includes resources from databases Scopus and Web of Science. The systematic review included the processes of screening, eligibility and exclusion criteria, steps of the review process (identification, screening, eligibility) as well as data abstraction and analysis.

PRISMA

This study was guided by the PRISMA Statement (Preferred Reporting Items for Systematic Reviews and Meta-Analyses). Conducting PRISMA Statement allows clear research questions that permit a systematic research to be defined, while inclusion and exclusion criteria can be identified and large database of scientific literature in a defined time can be examined (Sierra-Correa and Cantera Kintz, 2015). The PRISMA Statement enables a rigorous investigation of terms related to scientific creativity in school and their impact.

Databases/Resources

Two main journal databases – Scopus and Web of Science (WoS) were used in this study. WoS is a database consisting peer reviews and high influence journals. It covers over 256 disciplines and various subjects including physical sciences, health sciences, life sciences and social sciences. Scopus, on the other hand, is one of abstract and citation databases. It consists of peer-reviewed literature including journals from many publishers worldwide. Scopus covers subject areas such as environmental sciences, social sciences and biological sciences. As of January 2019, the WoS has at least 13100 journals and 10.5 million proceedings articles while Scopus covers 19150 journals and 8 million proceeding articles. Both databases update their resources daily.

Systematic Review Process

The review process was carried out in four stages. The initial review process was carried out in August 2019. The process consisted of several phases namely identification, screening and eligibility

Identification

The first phase involved identifying keywords for the search process. By referring to previous studies, a thesaurus and suggestions from experts, keywords similar and related to scientific creativity in school science education were used (Table 2). The keywords used have been validated by the experts before proceeding to searching process. At this stage, five duplicated articles were removed.

Screening

The second stage was the screening stage. At this stage, a total of 102 of 162 articles eligible to be reviewed were removed due to inclusion and exclusion criteria (Table 3). Firstly, with regard to literature type, only journal articles or conference proceedings with empirical data and book chapters were selected. This indicates that article reviews, book series and books were excluded. Secondly, to avoid any confusion and difficulty in translating, the selection excluded non-English publication. Thirdly, with regard to timeline, a period of 10 years was selected (between 2009 and 2019) as it is considered an adequate period to focus on contemporary pedagogical approaches in fostering scientific creativity in science classroom. Besides, this systematic review focused on science subjects taught in school including biology, chemistry, and physics. Articles that focused on other domains or subject-specific creativity such as arts, Mathematics and computer science were effectively excluded.

Eligibility

The third stage was eligibility in which full articles were accessed. Several eligibility and exclusion criteria were determined for this review. After careful examination, 30 articles were further excluded due to their irrelevance in content, methodology or findings. The last stage yielded a total of 30 articles selected and used for in-depth analysis (Fig. 1). The remaining articles were assessed and analysed. Careful and concentrated effort and attention were devoted to specific studies that responded to the formulated research questions.

Data analysis

The remaining articles were assessed and analysed. Efforts were concentrated on specific studies that responded to the formulated questions. The data were extracted by reading through the abstracts first, followed by the full articles (in-depth) to identify the interventions used to enhance students' scientific creativity and variables included in the studies.

Table 2 The search string used for the systematic review process

Database	Search String
Scopus	TITLE-ABS-KEY (("scientific creativity" OR "scien* creativ*" OR "creativity in science*" OR "creativity in bio*" OR "creativity in chemistry*" OR "creativity in physics*") AND (student* OR pupil* OR child* OR kids OR teenagers OR adolescent) AND (primary* OR elementary OR middle OR secondary OR high) AND (school*))
Web of Science	TI = (("scientific creativity" OR "scien* creativ*" OR "creativity science" OR "creativity in science*" OR "creativity in science*" OR "creativity in bio*" OR "creativity in chemistry*" OR "creativity in physics*") AND (student* OR pupil* OR child* OR kids OR teenagers OR adolescent) AND (primary* OR elementary OR middle OR secondary OR high) AND (school*))

Table 3 The inclusion and exclusion criteria

Criterion	Eligibility	Exclusion
Literature type	Journal (research articles) and conference proceedings.	Journals (systematic review), book series, book, chapter in book
Language	English	Non-English
Timeline	2009 to 2019	< 2009
Subjects	Sciences (Biology, physics, chemistry)	Computer science, mathematics and arts
Research respondent	School students (pre-school, elementary, middle and high school)	University students

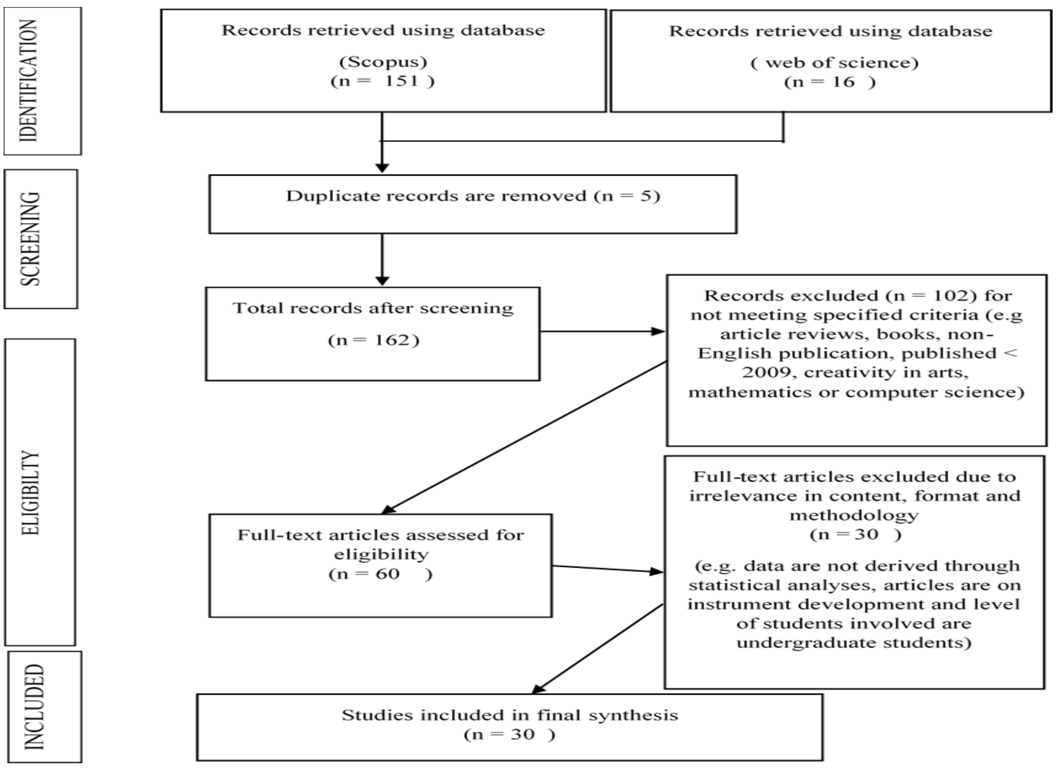

Figure 1 The flow diagram of the study (Adapted from Moher et al., 2009)

The identification of effective interventions used in the study was to answer the research questions on what pedagogical approaches can be applied in teaching and learning to foster scientific creativity. On the other hands, the variables correlated to scientific creativity were identified to answer the formulated questions on the factors that affect the process of fostering scientific creativity in students.

RESULTS AND DISCUSSION

The results of the analyses provided multiple views on the current classroom practices to foster scientific creativity. Of the 30 studies analysed for this review, 28 employed quantitative research design, while the remaining two were qualitative studies. The majority of the studies (n = 25) involved school students as the respondents or participants. Most of these studies have participants from among secondary or high school students (n = 21) and a few concentrated on elementary or primary school students (n = 4). The level of schooling was seen to vary depending on the countries the studies were conducted and their respective school systems. Among the 25 studies that involved students, three focused on gifted students while the remaining 22 look into mainstream students. In addition, only five studies involved teachers as the participants.

Pedagogical approaches, strategies and techniques in fostering scientific creativity

In this review, studies with school-based intervention were identified (n = 10). In order to establish effective pedagogical approaches to foster scientific creativity in school, this type of studies is useful as it involves implemented intervention plans and its effects on students' level of scientific creativity that are seen as dependant variables. The detailed contents of the studies are summarised in Table 4.

The constructs of scientific creativity measured vary between the studies. As mentioned in Table 1, the scientific creativity model presents different constructs of scientific creativity. By overlapping those three models of scientific creativity, it can be presented as input, processes and output –while motivation and contextual aspects act as moderator.

Based on the review, five aspects of scientific creativity that are mostly measured (vary according to study) are a) divergent thinking (creative traits), b) creative thinking, c) scientific imagination, d) scientific products and e) inquiry skills (scientific skills). These aspects were incorporated in the tests of scientific creativity in the studies. However, there were no studies that measured all five aspects of scientific creativity as a whole. Nevertheless, out of 11 studies, two studies assigned creativity as independent variable as it was embedded within the intervention, while the effects were measured in terms

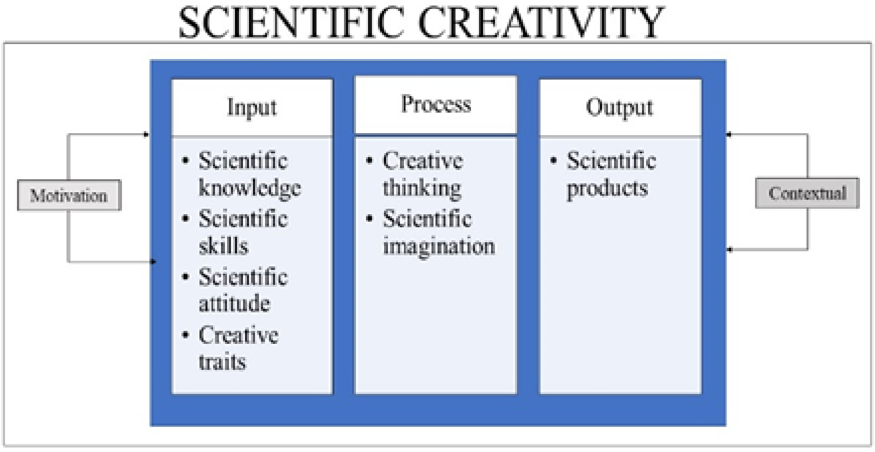

Figure 2. Scientific creativity aspects based on models by Hu and Adey (2002), Son (2009) and Park (2010)

of science process skills and motivation in learning science.

Based on Table 4, almost all of the studies measuring the effects of approaches and strategies have used experimental research designs between groups, with some comparing with control groups (n=3) or treatment groups (n=5). Only one qualitative study was found to examine the effects obtained through qualitative instruments such as interview, online data, video tape recordings and journals (Jang, 2009). In most studies, the interventions were carried out on students with only one attempted them on teachers (Laius and Rannikmae, 2011). There were two studies that attempted to embed creative thinking techniques in science and measure their effects on other variables (Astutik *et al.*, 2019; Moote, 2019). Overall, the participants of school-based intervention studies were ranged from primary 5th graders to high school seniors in several Asian countries such as Indonesia, Malaysia, China and Taiwan and other countries such as the UK, Germany and Estonia.

Based on the reviews, all the interventions showed positive effects on students' level of scientific creativity. However, no studies have measured the whole aspects of scientific creativity. Also, there were still lack of studies that measure the effectiveness of the interventions on non-cognitive aspects of scientific creativity such as attitude, motivation and contextual aspects. Therefore, in the future, researchers who wish to measure the effectiveness of their interventions should consider all aspects involved in scientific creativity (cognitive and non-cognitive aspects) to be able to claim that the interventions have positive effects on scientific creativity.

Pedagogical approaches is vital in fostering creativity in the science classroom as they assist learners to recognise thoughts and view ideas from original angles (Alsahou, 2015). This review showed various effective strategies to foster scientific creativity among students in science classroom in schools. The pedagogical approaches in the interventions that can foster scientific creativity can be classified as follow:

Teaching creative thinking techniques

Creative thinking is a key to developing creativity on top of sufficient domain knowledge and motivation. Creative thinking skills, as listed by Hu et al. (2013), include analogy, reorganization, brainstorming, breaking the set and transference. Teaching creative thinking techniques promotes the development of scientific creativity. Improvement in students' creative thinking skills denotes better comprehension on the concept of creativity, increased knowledge, heightened interest and confidence as well as reflection on creativity. Creative thinking is also a crucial part in finding and solving problems. Participating in problem-based learning requires students to maximize the use of their creative thinking techniques. The step-by-step approach proposed by Astutik et al. (2019) and Iwan Wicaksono et al. (2017) in their teaching and learning models shows that learning starts by identifying problems, followed by the application of creative thinking techniques in formulating hypotheses, discussing alternatives and designing to solve the problems. The development of thinking and knowledge of innovation should begin at the school level and students have to be trained to involve in solving 'real-world' problems as it can inculcate the creativity skills among them (Rahman et al., 2014).

Problem-based learning

Teaching and learning that are based on problems, projects and modelling allows students to learn by themselves and construct their own knowledge, which is the core of the constructivism approach to learning. Constructivism has long been considered a dominant paradigm in the field of science education. In addition to constructivism, constructionism is also an important approach in science education. Constructionism promotes student-centred discovery learning, in which students make use of prior information to acquire more knowledge. Learners typically have more autonomy over what they learn and could customize their projects to fit their own interests and abilities. Studies in this review indicate that by applying these approaches, students are able to express their diversity including scientific creativity.

Table 4 Articles included in the review: effects of intervention on scientific creativity

Author/ Year/ Country	Inter-vention label	Target students (number, level)	Scientific creativity aspects measured					Effect
			Divergent thinking	Creative thinking	Scientific imagination	Scientific products	Inquiry skills	
Zulkarnaen, Supardi, & Jatmiko, 2017, Indonesia	(C3PDR) teaching model	Secon-dary (n = 96, 8th grade)	/		/	/	/	+
Astutik & Prahani, 2018, Indonesia	Collaborative Creativity Learning (CCL) Model	High school (n = 144, juniors)	/			/	/	+
Mierdel & Bogner, 2019, Germany	Hands-on Modelling Module	Secondary (n = 115, 9th grade)	/			/		+
Sattar, et al 2018, Malaysia	The Science of Smart Communities (SoSC) Programme	Secondary (n = 330, multilevel)	/	/			/	+
Siew & Ambo, 2010, Malaysia	PjBL-STEM Module	Primary (n = 60, 5th grade)	/	/				
Hu et al., 2013, China	Learn To Think Intervention Programme	Secondary (n = 107, multi levels)		/	/	/	/	+
Laius & Rannikmae, 2011, Estonia	Teacher's professional training	Middle school (n = 248, 9th grade)	/					+
Wicaksono, Wasis, & Madlazim, 2017, Indonesia	Virtual Science Teaching Model	High school (n = 318, seniors)	/					+
Jang, 2009, Taiwan	Web-based technology	Secondary school (n = 31, 7th grade)	/	/			/	+

They have shown interest, and strived to produce the best designs and creations, thus increase their productive skills.

ICT-based learning

In this technology-driven era, the teaching and learning process should also be tailored to meet current demands and trends. By using information and communication technology (ICT), teachers are able to enrich their teaching with more innovative techniques and approaches. Two of the studies in the review have shown that the use of ICT in the teaching and learning of science can foster scientific creativity in students. Both studies agreed that the use of ICT teaching media contributes greatly to students' creativity as they facilitate the development of ideas by providing access to up-to-date data and a plethora of knowledge, which in turn stimulates brainstorming. Students can also make and create with the aid of technology. Using ICT as a tool in the classroom has been proven to increase scientific literacy, scientific attitude and students' motivation as the students said that the learning was fun and interactive (Rubini, Permanasari and Yuningsih, 2018). Furthermore, the use of ICT can help to solve the problems created by constraints in manpower and resources. Creativity in the science domain has contributed to the invention of various useful innovations and the incorporation of technology elements to it has resulted in extraordinary extension such as invention in biotechnology (Osman, Hamid and Hassan, 2009)

Integrated STEM-based learning

STEM education is an interdisciplinary approach that integrates the studies of science, technology, engineering and mathematics. Through this approach, students are challenged to make connections between learning and the real world. This integration of multiple disciplines will affect learners' inquiry skills as it involves active learning and problem-solving skills (Syukri et al., 2018). Students participating in the STEM program have the advantage and tendency to further their studies in the STEM field at a higher level and have also been proven more creative, scientific and confident in doing hands-on activities compared to those who are not exposed to STEM in school.

Collaborative learning

Collaborative learning is able to improve students' creativity since students are afforded equal opportunities and access to the same tasks and could therefore mutually teach and complement each other. In activities that necessitate teamwork, students realise that producing a good quality product requires cooperation among team members. Furthermore, group members strive to help each other, which will foster team spirit and satisfaction. Each student contributes a new idea to the experimental results.

Teacher development programme

When discussing creativity in science education, the role of teachers should also be considered. Teachers themselves must be creative as well to achieve instructional goals. Teachers who are able to perform their duties as a good facilitator, mentor and mediator in the classroom will bring about improvement of scientific creativity among their students. Laius & Rannikmae (2011) claimed that the construction of scientific knowledge is increasingly reflexive, interdisciplinary and rapidly developing in contemporary learning, and this, consequently, places a greater demand on teachers' professionalism. This has been proven in their study, which revealed that the level of teachers' professional training has a significant impact on their students' improvement in skills associated with socio-scientific reasoning and scientific creativity.

In conclusion, the approaches can be classified into six categories as discussed previously. All the approaches suggested by the studies showed some similar characteristics such as more to student-centred where students can actively learn and have more autonomy in their learning processes. These approaches give the chance to the students to build their own knowledge and understanding, and then make connection to the real world. In addition, these suggested pedagogical approaches mostly incorporate brainstorming and reasoning skills in their activities such as in problem-based or project-based learning. Brainstorming and reasoning are thinking techniques that have been frequently mentioned in many studies as the techniques that can develop creativity.

Facilitating factors that influence teaching for scientific creativity

This review found several studies that focused on variables that influence scientific creativity traits in students as summarised in Table 4. Thirteen studies were of quantitative descriptive studies, two were qualitative descriptive and four were mixed method. Only four studies involved teachers as the participants while the others involved students including gifted students (N = 4). Researches that studied gifted students mostly aim to relate scientific creativity skills to their respective talent. These studies were also found to investigate their motivation, emotional and parental support on top of intellectual capabilities (Cevher, Ertekin and Koksal, 2014; Ruiz *et al.*, 2014; Kang, Park and Hong, 2015a; Usta and Akkanat, 2015; Şahin, 2016). For studies that focused on students as participants, some were found to relate scientific creativity with demographic aspects including gender (Mierdel & Bogner, 2019; Yu, 2010a) and age (Yu, 2010a).

These studies revealed no significant differences in the level of scientific creativity among male and female students as well as those of different schooling levels (Yu, 2010a). However, Mierdel and Bogner (2019) reported that girls can produce better models than boys in model-based learning.

Studies on the relationship of scientific creativity with cognitive achievement have been done by correlating students' scientific creativity with their intellectual abilities, often in the form of academic achievements (Cevher, Ertekin and Koksal, 2014; Ruiz *et al.*, 2014; Şahin, 2016). Two such studies reported a positive correlation between scientific creative abilities and cognitive achievement, which in turn indicates that both variables can significantly influence each other. However, as emphasised by Cevher *et al*. (2014), the level of scientific creativity of gifted students is only average, even though they are above-average in intelligence tests. Researchers have also focused on specific skills to relate to scientific creativity such as thinking and inquiry skills. Studies on thinking skills look into convergent and divergent thinking skills (de Vries & Lubart, 2018), critical thinking and scientific reasoning skills (Mustika, Maknun and Feranie, 2019) and modelling skills (Mierdel and Bogner, 2019). Overall, the results of the studies showed a significant positive correlation between thinking skills and scientific creative abilities.

Some affective factors related to the students have also been examined. The factors included some personality traits including well-being and self-control (Şahin, 2016), risk- taking and curiosity (Yu, 2010b; Qian and Yu, 2012). The results reported are consistent with previous studies that indicate a generally positive correlation between personality traits and scientific creative performance. One study also focused on learners' motivation (Xue et al., 2018) and concluded that motivation must be fully considered when cultivating adolescents' scientific creativity. Another study by Usta and Akkanat (2015) on views on the nature of science (NOS) and attitude towards science classes reported a significant relationship between scientific creativity and attitude towards science. The study also revealed a significant difference between students' level of scientific creativity and their view of NOS.

Meanwhile, studies on teachers were more focused on their perspectives, conceptions and beliefs regarding scientific creativity and ways to inculcate it in science lessons (Newton and Newton, 2009; Liu and Lin, 2014; Hetherington *et al.*, 2019). The participants among teacher were reported to hold positive views and perspectives in relating creativity with science subjects. The findings indicated a broad agreement internationally that science is a creative endeavour. Meanwhile, even though the teachers have captured the central features of scientific creativity and able to distinguish between creative and reproductive activities, they still have a narrow conception and a tendency to overlook some aspects related to scientific creativity. Three studies were conducted involving in-service teachers while another study involved pre-service teachers in the university. The said studies attempted to correlate scientific creativity with their alma mater, level of study and behaviour. However, the studies reported no significant difference in the ability to foster creativity in pre-service science teachers based on the variables of university attended, major studied, year of study and gender.

Of the studies reviewed, there were two studies that focused on other contextual factors such as family background, number of language spoken, school climate as well as the support from parents and teachers (Akkanat & Gökdere, 2018; de Vries & Lubart, 2018). A study by De Vries & Lubart (2018) reported that the more languages are spoken and the more the family has foreign background, the fewer ideas are synthesised by the students. Meanwhile, Akkanat and Gökdere (2018) reported that perceived involvement of parents and teachers, as well as the school climate also contributed significantly to the creativity levels in science classrooms.

The studies reviewed in this article focused on factors associated with students, teachers and environment or contexts. These factors are illustrated in Figure 2. Based on the figure, it can be identified that most researches were done to study students' factors. These may be due to the assumption that scientific creativity is seen as an innate quality, whereby the individuals are born with it. However, creativity can happen in daily life or sometimes known as Little c creativity that can be fostered (Craft, 2002). Thus, there are also other factors in the classroom that could contribute to students' scientific creativity.

In addition, in teaching and learning process, teacher plays an important role to achieve effective learning. Based on the reviews, the factors associated with teachers were only on their belief, conception and perception on scientific creativity. These factors can be considered as the essential prerequisite factors in fostering scientific creativity as they can help the teachers to make decisions in the science classroom (Liu & Lin, 2014; Mullet et al., 2016; Newton & Newton, 2016). However, it is also important to study other factors such as teachers' intellectual traits, their pedagogical content knowledge as well as their practices in the classroom, which can be the factors in developing students' scientific creativity.

Table 5 Articles included in the review: studies focusing on variables that influence scientific creativity

Author/ Year	Method	Respondent (N, level)	Aspects studied on scientific creativity
(Hur and Lee, 2015)	Quantitative	Teachers (75, prospective)	- University attended - Major studied - Year of study - Gender - Behaviour
(de Vries & Lubart, 2018a)	Mixed	Students (118, 7- 10 year olds)	- Divergent thinking - Convergent thinking - Nationality - Number of languages spoken
(Yu, 2010b)	Quantitative	Students (495, middle school)	- Affective factors
(Mierdel & Bogner, 2019)	Quantitative	Students (115, 9th graders)	- Model quality scores - Gender
(Mustika, et al 2019)	Mixed	Students (42, 11th graders)	- Critical thinking skills - Scientific reasoning skills
(Ruiz et al, 2014)	Quantitative	Students (98, 2nd & 4th year of secondary)	- Academic achievement in mathematics and linguistic domains - Intellectual abilities
(Akkanat & Gökdere, 2018)	Quantitative	Gifted Students (698)	- Academic involvement - School climate - Parents and teacher support
(Xue et al, 2018)	Quantitative	Students (120, 7th & 8th graders)	- Extrinsic motivation
(Kang et al 2015b)	Quantitative	Students (gifted and ordinary)	- Time-based fluency
(Cevher, et al, 2014)	Quantitative	Gifted Students (20, 8th grade)	- Intellectual abilities
(Şahin, 2016)	Quantitative	Gifted Students (178)	- Academic achievement - Emotional (self-control) - Intellectual abilities

Author/ Year	Method	Respondent (N, level)	Aspects studied on scientific creativity
(Yu, 2010a)	Quantitative	Students (400, middle school)	- Age - Gender
(Qian & Yu, 2012)	Quantitative	Students (400, middle school)	- Affective factors
(Yang *et al.*, 2016)	Quantitative	Students (321, 3^{rd} - 6^{th} grade	- Scientific inquiry skills
(Usta & Akkanat, 2015)	Quantitative	Students (300, 7^{th} grade)	- Attitude towards science - View of nature of science
(Newton & Newton, 2009)	Qualitative	Teachers	- Conceptions of scientific creativity
(Hetherington *et al.*, 2019)	Mixed	Educators (270)	- Perceptions on the relationship between science and creativity
(Liu & Lin, 2014)	Qualitative	Primary teachers	- View on creativity in science classroom
(Santi, 2018)	Mixed	Students (112, primary and secondary)	- Interest in Responsible Research and Innovation (RRI) activities.

CONCLUSION

There are many approaches and techniques that can be applied by teachers to achieve effective teaching and learning in science. Nevertheless, certain approaches can be applied to have more effect in fostering students' scientific creativity.

Based on this systematic review, some pedagogical approaches were identified as effective practices that can foster scientific creativity. Instructional practices that have been proved in encouraging creativity are more on cognitive skills related to analyses, syntheses, making inferences and critical conclusion (Dehaan, 2011).

Even though existing studies have designed and provided possible activities and interventions to be applied, the responsibility of making decisions about what should or should not be applied to foster students' creativity lies on the teachers. Therefore, to foster students' scientific creativity, teachers also have to be more proactive in taking initiatives and always willing to learn for the enhancement of their professionalism in teaching.

Focusing solely on pedagogical approaches is not enough. They must be combined with contextual factors that may facilitate students' creative endeavours and can be very helpful for science educators as well as teachers (Alsahou, 2015). The factors identified by this systematic review are mostly similar to the factors that can facilitate teaching and learning, which involve teachers', students' and environmental factors. The reason being is that the process of fostering scientific creativity is not isolated. It is embedded in the teaching and learning in the classroom. There are many educational factors that can influence teaching and learning, but the most important role lies on the teachers (Halim, Meerah & Syed, 2013).Thus, it can be suggested that more researches should focus on science teachers' creative competency, intellectual traits, their content knowledge, perceptions and practices in the real setting. Furthermore, in addition to highlighting the facilitating factors, it is also essential to review the constraints that would hinder and limit the emergence of scientific creative abilities among students.

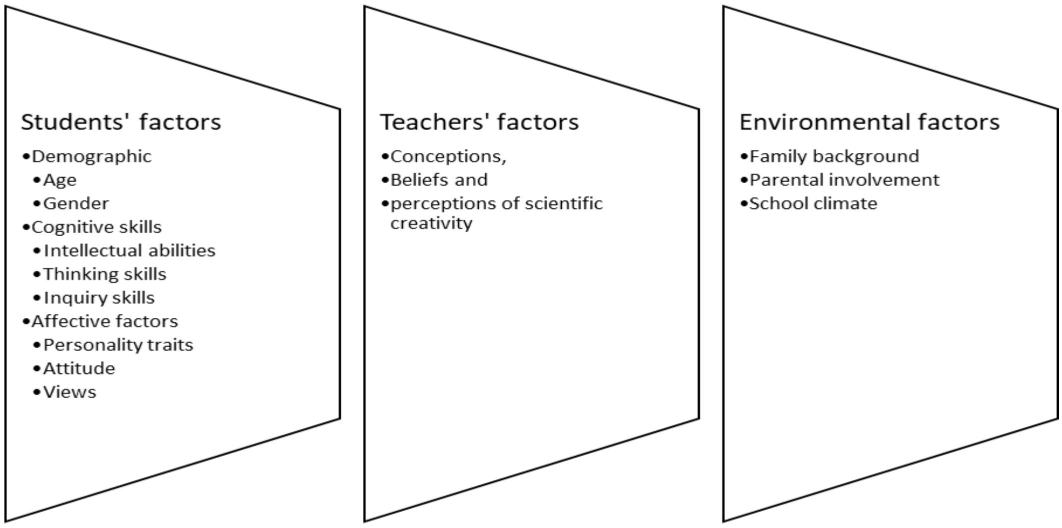

Figure 2: Facilitating factors that influence teaching for scientific creativity

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REFERENCES

Akkanat, Ç. and Gökdere, M 2018, 'The effect of academic involvement and school climate as perceived by gifted students in terms of talent , creativity , and motivation in science ', *Universal Journal of Educational Research*, vol. 6, no. 6, pp. 1167–74.

Alsahou, H 2015, Teachers ' beliefs about creativity and practices for fostering creativity in science classrooms in the State of Kuwait, PhD Thesis, University of Exeter, London.

Andiliou, A. and Murphy, P. K 2010, 'Examining variations among researchers' and teachers' conceptualizations of creativity: A review and synthesis of contemporary research', *Educational Research Review*, vol. 5 no. 3, pp. 201–19.

Anna Craft 2002, *Creativity and early years education: A Lifewide foundation*. Continuum studies in lifelong learning. London, United Kingdom.

Astutik, S., Mahdiannur, Suliyanah, and B K Prahani, BK. 2019, 'Improving science process skills of junior high school students through the implementation of collaborative creativity learning (CCL) model in physics learning', *Journal of Physics: Conference Series*, vol 1171 no. 1.

Astutik, S. and Prahani, B. K 2018, 'The practicality and effectiveness of collaborative creativity learning (ccl) model by using phet simulation to increase students' scientific creativity', *International Journal of Instruction*, vol. 11 no. 4, pp. 409–24.

Bereczki, O. and Karpati, A 2018, 'Teachers ' beliefs about creativity and its nurture : A systematic review of the recent research literature', *Educational Research Review* vol. no. 23, pp 25-56.

Cevher, A. H., Ertekin, P. and Koksal, M. S 2014, 'Investigation of scientific creativity of eighth grade gifted students', *International Journal of Innovation, Creativity and Change*, vol. 1 no. 4 pp. 1-6.

Davies, D., Snape, D.J, Collier, C., Digby, R., Hay, P., Howe, A 2013, 'Creative learning environments in education-A systematic literature review', *Thinking Skills and Creativity*. Elsevier Ltd, vol. 8 no. 1, pp. 80–91.

Davies, D. Snape, D.J, Collier, C., Digby, R., Hay, P., Howe, A 2014, 'The roles and development needs of teachers to promote creativity: A systematic review of literature', *Teaching and Teacher Education*, vol. 41, pp. 34-41.

Dehaan, R. L. 2011, 'Teaching Creative Science Thinking', *Education Forum*, vol. 334 (December), pp. 1499–500.

Dikici, A. and Soh, K. 2015, 'Indexing creativity fostering teacher behaviour : Replication and modification', *Higher Education of Social Science*, vol. 9, no. 3, pp. 1–10.

Feist, G. J 1998, 'A Meta-Analysis of Personality in Scientific and Artistic Creativity', *Pers Soc Psychol Rev*, vol. 2 no. 4, pp. 290–309.

Gardner, H 1983, *Frames of mind: The theory of multiple intelligences.* Basic Books, New York.

Halim, L., Abdullah, S.I.S.S. & Meerah, T.S.M 2014, 'Students' perceptions of their science teachers' Pedagogical Content Knowledge', *Journal of Science Education and Technology*, vol. 23, no 2, pp. 227-37.

Hetherington, L., Chappell, K., Keene, H.R., Wren,H., Cukurova, M., Hathaway, C., Sotiriou, S., Bogner, F 2019, 'International educators' perspectives on the purpose of science education and the relationship between school science and creativity', *Research in Science and Technological Education*, pp. 1–23.

Hu, W. and Adey, P 2002, 'A scientific creativity test for secondary school students', *International Journal of Science Education*, vol. 24, no. 4, pp. 389–403.

Hu, W.Wu, B., Jia, X., Yi, X., Duan,C., Meyer, W., Kaufman, J.C 2013, 'Increasing students' scientific creativity: The "Learn to Think" Intervention Program', *Journal of Creative Behavior*, vol. 47 no. 1, pp. 3–21.

Hur, Y. J. and Lee, S. Y 2015, 'Analysis of instruction fostering creativity in prospective natural sciences and engineering teachers', *Information (Japan)*, vol. 18 no. 3, pp. 867–72.

Wicaksono, I, Wasis and Madlazim 2017, 'The effectiveness of virtual science teaching model (vs-tm) to improve student's scientific creativity and concept mastery on senior high school physics subject', *Journal of Baltic Science Education*, vol. 16 no. 4, p. 13.

Jang, S. J 2009, 'Exploration of secondary students' creativity by integrating web-based technology into an innovative science curriculum', *Computers and Education*. Elsevier Ltd, vol. 52 no. 1, pp. 247–55.

Kang, D., Park, J. and Hong, H 2015, 'Changes in the number of ideas depending on time when conducting scientific creativity activities', *Journal of Baltic Science Education*, vol. 14, no. 4, pp. 448–59.

Laius, A. and Rannikmae, M 2011, 'Impact on student change in scientific creativity and socio-scientific reasoning skills from teacher collaboration and gains from professional in-service', *Journal of Baltic Science Education*, vol. 10, no. 2, pp. 127–38.

Lin, C.Hu, W., Adey,P., Shen, J. 2003, 'The influence of cultural factors on scientific production', *Research in Science Education*, vol. 33, no. 33, pp. 137–46.

Liu, S. C. and Lin, H. shyang 2014, 'Primary teachers' beliefs about scientific creativity in the classroom context', *International Journal of Science Education*, vol. 36, no.10, pp 1551–67.

Mierdel, J. and Bogner, F. X 2019, 'Is creativity, hands-on modeling and cognitive learning gender-dependent?', *Thinking Skills and Creativity*. Elsevier Ltd, vol. 31, pp. 91–102.

Mohamad Sattar, R., Nosrsalehan, Z., Lilia, H., Roseamnah, A.R 2018 'Impact of integrated stem smart communities program on students scientific creativity', *Journal of Engineering Science and Technology*, Special issue November, pp. 80–9.

Moher, D., Liberati, A., Tetzlaff, J., Altman, D.G., The PRISMA Group, 2009, ' Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement', *PLoS Med*. vol. 6, no. 7.

Mohtar, L. E. and Halim, L 2015, 'Konstruk Kreativiti Saintifik Bagi Kajian Dalam Pendidikan Fizik Sekolah Menengah : Satu Sorotan Literatur', in *Sixth International Conference on Science and Mathematics Education*. CoSMEd 2015 16 – 19 November 2015, Penang, Malaysia.

Moote, J 2019, 'Investigating the Longer-Term Impact of the CREST Inquiry-Based Learning Programme on Student Self-regulated Processes and Related Motivations: Views of Students and Teachers', *Research in Science Education*, vol. 49, no.1, pp. 265–94.

Mukhopadhyay, R 2012, 'Whether aptitude in physics, scientific attitude, and deep approach to study explain achievement in physics significantly – An investigation', *International Journal of Humanities and Social Science Invention*, vol. 2, no. 1, pp. 57–63.

Mukhopadhyay, R 2013 'Measurement of creativity in physics - A brief review on related tools', *IOSR Journal Of Humanities And Social Science (IOSR-JHSS)*, vol. 6, no. 5, pp. 45–50.

Mullet, D. R., Willerson, A., Lamb, K., Kettler, T 2016, 'Examining teacher perceptions of creativity: A systematic review of the literature', *Thinking Skills and Creativity*. Elsevier Ltd, vol. 21, pp. 9–30.

Mustika, M., Maknun, J. and Feranie, S. 2019, 'Case study : analysis of senior high school students scientific creative, critical thinking and its correlation with their scientific reasoning skills on the sound concept', *Journal of Physics: Conference Series*, vol. 1157, no. 3.

Newton, D. P. and Newton, L. D 2009, 'Some student teachers' conceptions of creativity in school science', *Research in Science and Technological Education*, vol. 27, no. 1, pp. 45-60.

Newton, L. & Newton, D 2016, 'Elementary school science creative thinking and teaching for creativity in elementary school science', Gifted and Talented International, vol. 25, no.2, pp. 111-24 .

Osman. K, Hamid A, S.H, Hassan, A 2009, 'Standard setting: inserting domain of the 21st century thinking skills into the existing science curriculum in Malaysia', *Procedia Social and Behavioral Sciences*, no.1 (2009), pp. 2573–77.

Park, J 2010, 'Practical ways for teaching and evaluation scientific creativity', *XIV IOSTE Symposium: Socio-cultural and Human Values in Science and Technology Education*. Bled, Slovenia.

Qian, J. and Yu, J 2012, 'Students creativity modeling with gene expression programming', *International Conference on Computer Science and Electronics Engineering, ICCSEE 2012*, vol. 3, pp. 582–85.

Rahman, S 2014, 'Using Problem-focused Approach to Nurture Creativity and Entrepreneurship among Students', *Procedia - Social and Behavioral Sciences*, no. 191 (2015), pp 2782 – 6

Rozi, N.E,. and Halim, L 2018, 'Sorotan literatur: Instrumen pengukuran kreativiti saintifik dalam sains', *International Conference on Global Education Vi*, (May), pp. 163–79.

Rubini, B., Permanasari, A. and Yuningsih, W. 2018, 'Learning Multimedia Based on Science Literacy on the Lightning Theme', *Jurnal Penelitian dan Pembelajaran IPA*, vol. 4, no. 2, p. 89.

Ruiz, M. J., Bermejo, R., Ferrando, M., Prieto, M.D., Sainz, M 2014, 'Intelligence and scientific-Creative thinking: Their convergence in the explanation of students' academic performance', *Electronic Journal of Research in Educational Psychology*, vol. 12, no. 2, pp. 283–302.

Şahin, F 2016, 'General intelligence, emotional intelligence and academic knowledge as predictors of creativity domains: A study of gifted students', *Cogent Education*. Cogent, vol. 3, no. 1, pp. 1–16.

Said-metwaly, S 2017, 'Approaches to measuring creativity : A systematic literature review ', vol. 4, no. 2, pp. 238–75.

Santi, E. A 2018, 'Scientific Creativity Related To Rri - Psychological And Practical Implications For Students', *The European Proceedings of Social & Behavioural Sciences* (March), pp. 619–26.

Shaffril, H. A. M., Abu Samah, A. and D'Silva, J. L 2017 'Adapting towards climate change impacts: Strategies for small-scale fishermen in Malaysia', *Marine Policy*, 81(December 2016), pp. 196–201.

Sierra-Correa, P.C., Cantera Kintz, J.R 2015. 'Ecosystem-based adaptation for improving coastal planning for sea-level rise: A systematic review for mangrove coasts', *Mar. Policy* vol. 51, pp. 385–93.

Siew, N. M. and Ambo, N 2010, 'Development and evaluation of an integrated project- based and stem teaching and learning module on enhancing scientific creativity among fifth graders', *Journal of Baltic Science Education*, vol. 17, no. 6, pp. 1017–33.

Son Mi Jo 2009, '*A Study of Korean Students' Creativity in Science Using Structural Equation Modeling', PhD Thesis,* University of Arizona, Tucson.

Sprecher, T. B 1975, '*A Proposal for identifying Meaning of Creativity', in Scientific Creativity: Recognition and Development*. Robert E. Kreiger Publishing Company, New York.

Starko, A. J 2013, '*Creativity in the Classroom : Schools of Curious Delight*', Taylor & Francis Ltd, London.

Syukri, M., Soewarno, S., Lilia, H., Lilia, E.M 2018, 'The impact of engineering design process in teaching and learning to enhance students' science problem-solving skills', *Jurnal Pendidikan IPA Indonesia*, vol. 1, pp. 66-75

Torrance, E. P 1965 'Scientific views of creativity and factors affecting its growth', *Daedalus*, vol. 94, no. 3, pp. 663–81.

Usta, E. and Akkanat, C 2015, 'Investigating scientific creativity level of seventh grade students', *Procedia Social and Behavioral Sciences*, vol. 191, pp. 1408–15.

de Vries, H. B. and Lubart, T. I 2018 'Scientific creativity: divergent and convergent thinking and the impact of culture', *Journal of Creative Behavior*, pp. 1–11.

Wang, K. and Nickerson, J. V 2017, ‘A literature review on individual creativity support systems’, *Computers in Human Behavior*, vol. 74, pp. 139-51.

Xue, Y., Gu, C., Wu, J., Dai, D.Y., Mu, X., Zhou, Z. 2018, ‘The Effects of Extrinsic Motivation on Scientific and Artistic Creativity among Middle School Students’, *Journal of Creative Behavior*, pp. 1–14.

Yang, K. K., Lin, S. F., Hong, Z., Lin, H. S. 2016, ‘Exploring the assessment of and relationship between elementary students’ scientific creativity and science inquiry’, *Creativity Research Journal*, vol. 28, no. 1, pp. 16–23.

Yu, J. 2010a, ‘The application of GA-based clustering analysis for the student scientific creativity’, *Proceedings - International Conference on Artificial Intelligence and Computational Intelligence, AICI 2010,* vol. 2, pp. 574–76.

Yu, J 2010b, ‘The application of neural networks and rough set in creativity measurement’, *2010 International Conference on Computational Intelligence and Software Engineering, CiSE 2010*, pp. 1–3.

Zulkarnaen, Supardi, I. and Jatmiko, B 2017, ‘Feasibility of creative exploration, creative elaboration, creative modeling, practice scientific creativity, discussion, reflection (C3PDR) teaching model to improve students’ scientific creativity of junior high school’, *Journal of Baltic Science Education,* vol. 16, no. 6, pp. 1020–34.