Nurturing Scientific Creativity in Science Classroom*

Priya Gupta and Yukti Sharma

The present article attempts to understand the interrelationship between the processes of science and scientific creativity and its relevance to a science classroom. We explore how these processes can be incorporated as pedagogical practices in the classroom to foster students' scientific creativity. Few activities based on these processes are also suggested that can offer enabling experiences to students and may nurture their scientific creativity.

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Fostering scientific creativity, creativity in science, science education.

1. Introduction

Science education in India, even at its best develops competence but does not encourage inventiveness and creativity [1]. This is one of the most pertinent and crucial issues demanding the immediate attention of science teachers, teacher educators, science educationists, and researchers working in the area of creativity. The issue indicates that there is a need for a paradigm shift in the pedagogical practices followed in science education; specifically aiming towards encouraging investigative ability, inventiveness, and creativity. National Curriculum Framework (NCF) 2005 too reiterates that the aim of science education should be to nurture the natural curiosity, aesthetic sense, and creativity of the child in the field of science and technology and that the curriculum should engage the learners in acquiring the methods and processes that lead to the generation and validation of scientific knowledge [1]. Considering science as a creative process as well as creativity as an integral component for science learning, it is imperative that the students are engaged in this process to nurture their potentials in scientific creativity. Students' creativity in learning sci-

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ence is important as they are future scientists and potential resource of any nation. Moreover, at a more mundane level, scientific creativity helps individuals deal with their everyday problems logically. Science involves experimentation, testing hypothesis, building evidences, and theoretical discussions as it undergoes a constant process of reviewing and renewal. Thus, engagement with science requires a great deal of knowledge, imagination, and creative insight on the part of the learners, and there are also significant factors for major inventions, breakthroughs and scientific discoveries. This depicts the importance of nurturing scientific creativity amongst students. However, there are many questions that require deliberation; particularly the meaning and nature of scientific creativity in the context of students and education. It explicitly attempts to understand the interrelationship between the processes of science and scientific creativity and its relevance to a science classroom for providing a theoretical basis for specific pedagogical practices.

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2. Scientific Creativity Amongst Students: Indian Context

Scientific creativity is often attributed to eminent scientists and is referred to as Big-C creativity. But in the context of secondary school students and in tandem with the small-c creativity perspective, scientific creativity is defined as, "a kind of intellectual trait or ability producing or potentially producing a certain product that is original and has social or personal value, designed with a certain purpose in mind, using given information" [2]. This definition reflects the person, process, and product aspects of scientific creativity and also focuses on the creative potential, everyday creativity, and personal creativity of students. In India, there is no dearth of creative potential, but lots need to be done towards nurturing it. NCF 2005 explicitly states in its position paper on science that science education in India does not promote inventiveness and creativity. The answer probably lies in the way science education is pursued and implemented in the Indian schools and universities. Focusing upon science education at the school level, amidst various factors such as lack of proper infrastructure in schools, especially in rural areas and government schools, unavailability of science laboratories, higher student teacher ratio, lack of quality education, greater emphasis on preparation for examinations through rote learning, etc., most of the pedagogical practices followed in science classrooms are conventional. There are programs and projects that aims to train teachers in innovative science practices especially for teaching in rural or under-resourced areas. One such nationally acclaimed program that has been successful against all odds for thirty years is the Hoshangabad Science Teaching Program (1972–2002) which was a collaborative effort of the State Education Department of Madhya Pradesh, a voluntary NGO called Eklavya, and many scientists and academicians from the best Indian universities and research institutions. The program focused on innovative science teaching at middle school level (classes VI to VIII) in both rural and urban schools. Learning through discovery based approach was encouraged wherein students engaged with science through observations, developed apparatus from low cost materials, conducted experiments and hands on activities, and analysed their data. In 1991, MHRD, Government of India, strongly recommended this program for the whole state and to develop it as a model to be emulated in the entire country.

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Another example is the Science Program that was started in 2006 by the NGO Pratham in the slums and under-resourced areas of Mumbai and other cities of Maharashtra. Under this program, 2000 government teachers in Aurangabad district were trained in the 'learning by doing' method, and they collaborated with the Homi Bhabha Centre of Science Education for developing reading cards. The current model of the program conducts workshops and science fairs, and is also involved in the formation of science clubs in various schools and communities. The intervention aims at stimulating the innate curiosity and developing scientific temper amongst children and encouraging them to explore and carry out experiments by building different models, tools and apparatus on their own [3]. Another organization that aims at fostering innovation and creativity in rural India is the Agastya International

Foundation (1999). It runs one of the largest hands-on science education programs for children and teachers in the world and aims at sparking curiosity and nurturing creativity; specifically in rural India with economically disadvantaged children. With 55 science centres, 144 mobile science labs, 172 acres creativity campus, 77 lab-on-a bike, lab-in-a-box, and peer-teaching facilities, it has benefited 10 million children and 250,000 teachers in experiencing creativity while teaching and learning science. Jyothsna and Bhargavi (13 years old), two students of the Foundation from a small rural village in Andhra Pradesh represented India as international delegates at the International Science Fair held in Pittsburgh in 2012 with their project 'Growing Oxygen on Highways' which determined the best trees to grow on the road dividers on the Indian highways. Such examples reflect providing proper opportunities at the primary and middle school level is crucial to foster creative potential of students. These initiatives prove that the negative effects of lack of resources and infrastructure, or high student-teacher ratio can be overcome if the teachers are motivated enough to look at science teaching from an unconventional perspective. Thus, what is important is the science teachers' belief and engagement in the pedagogical practices that can provide opportunities to learners for creative thinking. This requires that the teacher education programs should include the literature on scientific creativity that provides the theoretical basis of embedding certain activities based on cognitive processes and creative thinking within science pedagogy.

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3. Nurturing Scientific Creativity: A Look into the Cognitive Processes Involved

Certain thinking abilities/cognitive processes with respect to scientific creativity as identified by various researchers are: divergent thinking abilities i.e. fluency, flexibility, originality and elaboration [2, 4–8]; convergent thinking [4, 5, 9]; Janusian thinking/process [10]; creative problem finding [2, 4, 5, 11, 12]; creative problem solving [4–6, 13–21]; application of science process skills [22]; scientific inquisitiveness [6]; openness, precession and entitling [8]; hypotheses formulation [21, 23]; finding new relationships or connections [4, 7]; elaboration: adding new knowledge to a given situation [4, 5]; guess consequences [4–7]; visualizing or producing mental images; combining objects and ideas in new ways, fantasizing, pretending, dreaming, designing devices and machines, etc. [17, 18]; devising experiments and technical innovations [21]; finding alternate/unusual uses [2–5]; problem sensitivity; remote associations; apparatus improvement; finding conceptual correlates [4, 5] redefinition; product improvement; guess causes [2, 6], etc.

Few of these processes are discussed in detail and some activities based on them are suggested in the following sections.

4. Scientific Process Skills

Scientific process skills are an important aspect of any scientific endeavour. These skills when used in a particular order, constitute the scientific method used by scientists to plan and follow any investigation. Considering creativity as an integral process of science, science process skills have been interlinked to various components of creativity [22]. The relationship of problem solving ability, science process skills and their connection with scientific creativity of secondary school students was examined in a study [24]. 158 students of class IX and X (CBSE) (62 males, 96 females) of Punjab were the participants of this study. Majumdar scientific creativity test (MSCT) by S K Majumdar (1982), problem solving test (PSAT–D) by L N Dubey, and science process skills test (TSP–MK) by Karuna Shankar Misra were used to collect the data. The study showed that both problem solving ability and science process skills have meaningful influence on the scientific creativity of secondary school students.

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Thus, students, when engaged in activities that involve science process skills in a meaningful way, giving them opportunity to work with openness and to explore on their own without foreclosing the experience, nurtures their scientific creativity (see *Box* 1 for example).

Box 1. Activity 1

Observe how plants grow in the Sun, and shade or in any other context. Frame different hypothesis on the basis of how different factors like air, water, sunlight, types of soil, etc., effect the growth of plants, and plan your own scientific investigation or experiments in groups to test your hypothesis. Collect and interpret the 'data' and discuss the findings with your peers and mentor. You can question each other's findings and interpretations, and try to arrive at some common conclusions.

These kind of activities (as mentioned in *Box* 1) may encourage the use of various science process skills by the students as they model the way scientists work and investigate. It also helps in developing the ability to think scientifically and may also lead to creative ideas and outcomes.

5. Divergent Thinking

Guilford [25] associated creativity with divergent thinking, i.e., the ability to think of many different solutions to a given situation. Divergent thinking encompasses several forms of creative thoughts including – fluency (ability to produce number of valid ideas); flexibility (ability to produce a wide variety of ideas from different perspectives); originality (ability to generate rare and uncommon ideas), and elaboration (adding on ideas to improve them/ability to construct complex ideas on the basis of simple construct). Many researchers [4–6, 11–27] supported this premise that increase in students' divergent thinking enhance their creative performance. A variety of research is often cited indicating that if clear directions are provided to generate more fluent and more original ideas, then the possibility of occurrence of such ideas increase [28]. However, divergent thinking does not guarantee actual creative achievement, but tests of divergent thinking are reliably and reasonably valid predictors of certain performance criteria [29]. Thus, divergent thinking tests can be taken as predictors of the potential for creative thought. Divergent thinking has little relationship with the highest level of creativity which

Box 2. Activity 2

Imagine an object of your choice that you use frequently in your daily life and list its maximum possible uses. Think of certain changes you would like to make in the object to increase its utility.

is generally referred to in the context of adults [30]. Divergent thinking is thus more relevant for children's creativity rather than eminent creativity. It is important to note that though predicting creative potential is a complex process including many predictors, divergent thinking is amongst one of the most important indicators of creative potential and not actual creativity per se. Research on scientific creativity by many scientists [2, 4–7] are highly influenced by Guilford's ideas on creativity, and they consider divergent thinking to be one of the major components of scientific creativity. Scientific inquiry through an imaginative and divergent thinking process aids the development of learners' creativity in science [31].

The activity mentioned in *Box* 2 provides an opportunity to think divergently as well as critically to list out the possibilities of using any material/object found commonly. A familiar context helps learners relate better, and hence think efficiently.

6. Brainstorming

One of the strategies that has been identified in the literature and provides an opportunity to develop divergent thinking abilities is 'brainstorming' (*Box* 3). Brainstorming has been closely associated with the creative problem-solving movement, where it is widely acknowledged as one of the best-known creative problem-solving techniques [13–20]. Brainstorming is a creative-thinking strategy using free association in a group or team environment to stimulate inspiration. It may be used to help students generate a wide variety of ideas instead of focusing upon one correct method or unique solution to a problem. However, the purpose should not be just the generation of many ideas but also upon the quality of

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Box 3. Activity 3

Brainstorm in groups over open-ended content specific topics such as:
a) Alternate sources of energy
b) Innovative ways to deal with waste in a sustainable manner (bio-degradable, non-degradable and nuclear waste).

those ideas, i.e., evaluating all the ideas and focusing more upon the original and unusual/interesting ideas.

7. Janusian Process in Scientific Creativity

Janusian process is a creative process based on actively conceiving multiple opposites simultaneously. The process is named after the Roman God – Janus – who is pictured with faces that look in the diametrically opposite directions simultaneously.

Janusian process is a creative process based on actively conceiving multiple opposites simultaneously. The process is named after the Roman God – Janus – who is pictured with faces that look in the diametrically opposite directions simultaneously [10]. Although it appears to be self-contradictory to conceptualise opposite ideas or concepts as simultaneously co-existing, but such formulation are actively constructed with a logical and rational state of mind to produce creative outcomes. These formulations may develop at any stage in the creative process and may undergo transformations in the later stage. As a mental operation, this process plays a role in the development of all types of creativity, defined as the production of both new and valuable phenomena [10]. In a major study [32], 375 outstandingly creative individuals, including 22 Noble Laureates in science, were interviewed regarding the Janusian process. The semi-structured interview was focused on the creative processes involved in the progress of arts, literature and scientific research, and yielded 2500 hours of recorded data. Examples were cited from the interview study as well as from primary sources. For instance, while elaborating upon the Janusian process in scientific creativity, example of Einstein consciously formulating the simultaneously opposite construct that a person falling from the roof of his house was both in motion as well as in a state of rest at the same time was quoted. Niel Bohr's theory of complementarity of light also involved Janusian process at a generative phase. Light that can have both wave and particle nature is a Janusian construct wherein wave nature and particle nature are simultaneously antithetical aspects. In scientific creativity, Janusian process was empirically determined in four identifiable phases that operate over different periods of time. During the first phase, 'motivation to create', an individual has a deliberate willingness to create, and the area for creation is also selected on the basis of its emotional/aesthetic importance by the individual. The second phase is the 'conceptual deviation or separation' in which both antithesis are developed. In the next phase, 'simultaneous opposition or antithesis', the formulated antithesis are conceived as operating simultaneously. This stage could be surprising even for the creative individual themselves wherein diametrically opposite ideas or contradictory theories appear valid simultaneously. The final phase is the 'construction of the theory, and discovery or experiment' in which scientific intellect is critically important to observe and make use of the observations, deduction and frame a logical and unifying mental process in order to develop a full theory or discovery [32]. It is evident that the Janusian process plays an integral role in scientific creativity at various levels of scientific investigation, and it may not necessarily be directly implied in the final product. Many researchers have emphasised the importance of conceiving together remote ideas or opposite ideas to stimulate a new perspective or a new synthesis [32–34]. Hence, engagement of learners in activities that are based on the Janusian process may involve looking for instances that coexist but contradict each other conceptually. An example of of this is mentioned in *Box* 4.

In scientific creativity, Janusian process was empirically determined in four identifiable phases that operate over different periods of time.

Janusian thinking involves a lot of complexity, and students may get confused while actively conceiving two opposite phenomena simultaneously. Hence, it's important that the students understand one concept completely, before forming or exploring an opposite idea/construct. This would require providing the students some facts in favour of the opposite idea and encouraging them

Box 4. Activity 4

The topic 'Nature of light as a wave' can be taken from the curriculum of the students. Students will frame/construct an opposite idea of the presented idea by studying examples wherein light do not behave as a wave. Student will have to reason out if both the opposite ideas could simultaneously coexist and determine the nature of light.

to think of various reasons in favour of the opposite idea. After students understand both the opposite ideas, they may be asked to analyse the situation and come up with theories considering the coexistence of the opposite ideas. Instances from history of science that explain how scientists used the Janusian process to make major scientific breakthroughs, for example dual nature of light with both wave and particle nature, should also be shared with the students. This will help students understand the creative nature, of scientific process, how real science works, and the fact that opposite ideas can also complement each other well. Though this may appear a very daunting task, it is totally worth it if the ultimate objective is to foster students' scientific creativity.

8. Conclusion: Implications for Science Education

While planning science lessons, attempts should be made to integrate and internalise science process skills and cognitive processes related to science within the regular pedagogy rather than mechanically applying them in a segregate manner as a mere technique.

Science education should aim at cultivating students' curiosity and enhancing their scientific thinking by providing active science learning environment through progressive learning activities involving the implementation of scientific knowledge and scientific processes. The activities presented in this paper are simply representative of the kind of activities that should become a part of the science teaching-learning process so that learners can engage in the application of various science process skills and get ample opportunities to think creatively. Hence, while planning science lessons, attempts should be made to integrate and internalise science process skills and cognitive processes related to science within the regular pedagogy rather than mechanically applying them in a segregate manner as a mere technique. The use of various strategies in a science classroom has to be thoughtfully and meaningfully planned keeping in view the developmental level of the students as well as their scientific knowledge. One single strategy may not help all the students alike. Thus, cognitive level of students need to be considered before planning the activities. For example, basic science process skills and divergent thinking process can be used at any level, but the use of Janusian process requires higher levels of abstract thinking abilities. Thus, teachers should aim at developing scientific thinking amongst students starting from a very basic level providing opportunities to develop creative potential of all students and gradually advance to more complex and abstract levels of thinking processes. For instance, during a creative problem-solving activity, science process skills, brainstorming, divergent thinking and convergent thinking abilities of students can be exercised simultaneously. Students are themselves very curious by nature, and their curiosity should be used as a potential resource to develop their interest in the subject matter. Finkelstein [35] said, "I was struck by how much children are like scientists. They seem to have an insatiable curiosity, they love to investigate unfamiliar concepts and objects, and they analyse what they observe." This is all the more important in scientific domain than any other domain because science is about observations, asking questions, planning and carrying out scientific investigations, experimentations, making hypotheses, finding and solving problems, constructing explanations, analysis and interpretation of data, and arriving at meaningful conclusions. Thus, students should be involved in these processes of science so that they can question the validity of their previous knowledge and experiences about scientific phenomenon they observe in their surroundings, find logical explanations, and bring conceptual changes while they try to understand newer concepts.

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– Finkelstein

Familiarity with these cognitive processes and applying them in different contexts will equip students with a set of strategies that they can use to explore different ideas or to find creative solutions to real-life problems. These strategies tend to stimulate the cognitive processes that underlie creativity and use them in different classroom exercises by applying them to different circumstances enhancing the students' potential to transfer creativity to real-life situations. Practising these processes will help students to deliberately channelize their thoughts in new directions and explore things from multiple perspectives. However, application of these creative thinking processes in just one situation is not enough and does not lead to automatic transfer to other situations. Hence, teachers should provide multiple opportunities to students so that they can internalise how to use these processes and be able to decide when to use it under different situations. Engaging students in these activities while learning science will provide a start-up for evolving a creative process. Hence, these should be used as pedagogical practices in classrooms to assist students in thinking scientifically and engaging with original and novel ideas. Activities based on these strategies will also help develop students' interest in science and will also motivate them to become thinking learners.

Suggested Reading

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