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Scientific Creativity- A New Emerging Field of Research: Some Considerations

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Abstract: Knowledge of science and creative vision of an individual have become two important quality parameters of him/her in the contemporary society- which is highly technical, as well as complex. In this context, fostering creativity in science education is also becoming more and more important. As a consequence, investigation of creativity in science education, to be called precisely as 'scientific creativity' is also receiving increasing attention of science educators. This area has been selected as the focal theme of the present study. The study was designed to identify whether science learning has scope to nurture creative vision, to examine the construct of scientific creativity, to review different considerations of science educators regarding various dimensions of the construct.

Science learning has some of its intrinsic features. It enables an individual to acquire various information in science and also to apply different steps of scientific method in each step of daily life leading to improvement of the standard of living, at the same time. Present study has explained this feature of science learning with reference to the philosophical perspective of science and also shows its similarity with the construct of creativity.

Emergence of scientific creativity as a new area of research has also been discussed with adequate no of references. The discussion reveals that scientific creativity needs to be considered as an independent field of study. Operational construct of scientific creativity has also been explained. Different operational dimensions considered by different researchers have been reviewed in details. Though divergent thinking is considered as the essential element to explain the construct of creativity (general), discussion reveals that convergent thinking also is considered by some of the researchers to explain the construct of scientific creativity.

Discussion also indicates that available studies are inadequate, and scope is there to investigate creativity in physics which is a potential area of scientific creativity, though remains mostly unexplored. The study has its psychometric importance, and is relevant in the contemporary context of revolution of science and technology in the modern society.
Keywords : Science Education, Creativity, Scientific Creativity, Operational Dimensions, Creativity in Physics.

I. Introduction

Due to progress of civilization, modern world has become highly complex and needs a large no of creative persons to meet multidimensional challenges emerging in the society. Not only the survival, but also future prosperity of the society depends upon creative vision and its implementation. The complex society, being technical and scientific, also needs a good number of scientifically tempered and skilled persons who may effectively contribute to its development. These two prime requirements of the society obviously suggest the importance of fostering creative thinking in the field of science, in general. Students are the future citizens and potentiality of this important resource influences the progress of the nation significantly. Therefore, the suggestion, as referred, also implies the necessity of encouraging students' creativity in the context of learning science, in particular. Under this circumstance, investigation of creativity in students' science learning has become an important area of research.

Creativity has the scope to be investigated in the context of learning [32]. Even Guilford, one of the pioneers in the field of scientific research on creativity, also emphasized on cultivation of creativity among school children [21] and therefore supports the view. In spite of emphasis given by Guilford on the relationship between creativity and learning, much of the researches of the past half century have studied creativity of eminent persons; far less have investigated the role that creativity plays in students' learning [33].

In the context of learning, in institution particularly, creativity is considered in relation to a specific domain (domain of specific task, content knowledge etc.). Therefore, though most of the earlier researches on creativity recognized it as domain independent, but learning related creativity is domain specific by nature; its functioning in one domain is unique and psychologically differs from that of in other [12, and 10]. Alexander [7] and Amabile [5] hence emphasized the need for specific domain or discipline- based knowledge and skills for fostering creative thinking in learning. Albert [4], Baer [6], Filho and Alencar [9] etc. also have recognized the importance of context (or domain) specific study on creativity and therefore support the view. Morten and Vanesa [31] pointed out that each individual subject should emphasize creativity within an agenda reflecting characteristics of each, indicating also the domain specific nature of learning based creativity. This is why domain-specific creativity is gradually receiving more and more attention of researchers, working in the field of creativity in the context of school education.

Scientific creativity is such a domain specific creativity which is the focal theme of the present investigation. Questions arise in the mind of researcher in this context are - Whether science education has the scope to nurture creative thinking? Whether scientific creativity has emerged as a consequence of this? Whether it is an independent field of research or mere a branch of the research on creativity, in general? How do different science educators explain the nature of the construct? What are various dimensions associated with this? Is there any unexplored area of scientific creativity? Present study is an attempt to search for the solution of these questions. The study particularly aims at : explaining emergence of the concept (scientific creativity) in the contemporary social context, describing nature of the construct as viewed by different researchers along with different operational dimensions as identified by them, and, to identify any unexplored area of scientific creativity, if any, which needs an in depth investigation. These are discussed step by step as follows.

II. SCIENTIFIC CREATIVITY- EMERGENCE OF THE CONCEPT

Science is a specialized body of knowledge; knowledge of several facts, phenomenon, laws, theories and their applications etc. – which, a learner is to acquire accepting the truth established already, recognizing 'science as a product'. At the same time, science is also 'a process', a way of establishing the truth exploring new areas of knowledge. Hence, truth is the major concern of science and science recognizes truth as a product, as well as a process.

According to Karl Popper's 'Philosophy of Science', there is no absolute scientific truth. A person only perceives a relative scientific truth, which is tentative. It is 'testifiable' [34], as well.

Scientists always search for exploring the underlying truth of the natural world. For doing this, they are guided very much by their perception of relative truth, which they develop on the basis of their background knowledge of scientific principles, concepts and theories. If their perception of truth fails to explain reality of natural world, discrepancy between theory and fact appears resulting in problems. In search of the solutions of those problems, scientists formulate multiple hypotheses and testify them stepwise. Scientific investigation thus begins. This ultimately leads to 'falsification' [34], establishing failure of inappropriate hypotheses. Hypotheses, which are not falsified, are retained and considered as the solutions of the problem. Popper [34] called this approach as 'error elimination', which helps scientists to realize the truth of higher probability. The solutions thus emerge, though are tentative also and subject to further testification for realizing the truth of more and more higher degree of probability. This is why science is dynamic and an ongoing activity resulting in newer and newer theories to emerge.

Therefore, 'problem' plays a major role in advancement of science, as is revealed. In 'poppererian error elimination approach', a problem leads to the scientific growth. Even a problem has major role in encouraging scientific enquiry of students. When a student faces a problem in the context of his science learning; he recognizes and investigates it following various steps as: identifying the problem, analyzing it, developing a number of hypotheses, formulating them using proper scientific language, conducting suitable experiments to verify those etc, leading to the solution ultimately. These are 'scientific process skills' and are similar to 'error elimination approach', considered by Popper [34], which a scientist follows for exploring the reality of the universe.

Learner searches for the solution of the problem first within his existing body of scientific knowledge. If the existing knowledge fails to provide the solution, conflict results in his mind. He makes continuous attempts for resolution of the arouse conflict, recognizes the gaps sensitively which ultimately challenges his existing knowledge structure, resulting in a change in it, constructing a new scientific knowledge. This helps him in finding new relationships among the known variables, in generating wide variety of scientific ideas in relation to a concept and a number of solutions of a particular problem, which are novel, as well as of high social value, encouraging his diversity, and creativity, as well.

Therefore, scientific investigation of a learner and that of a scientist have close association. Both originate from an emerging problem. Various scientific process skills used by the science learner in search of the solution of a scientific problem are essentially the steps of error elimination, as followed by a scientist in search of the underlying truth of universe. These steps are similar to the steps of a creative process. Hence close association of science learning with creativity might be the consequence. In fact, creativity has a supplementary role in science learning [1]. Saxena [35] has considered science as a process containing creative components in each step, in addition of being a product. In order to develop a fundamental understanding in science, individual needs to think creatively [27]. Das [8] also considered that scientific process is similar to creativity; both of them result from the necessity of eliminating a problem in daily life, leading to the solution ultimately.

For creativity and science learning being closely associated, there is enough scope in science education to foster and encourage creativity [27].

Kothari Commission, [11] also has recommended that one of the important objectives of science education is to develop creative thinking. Several reports on science education published by the Government of India have recognized the importance of the same [32]. Realization of this objective is also essential in the context of the present society, which is complex as well as scientific, and technical.

Therefore, the emerging trend of the context specific research on creativity, and the felt need of studying creativity particularly in science education lead science educators consider studying creativity in scientific context separately, where the knowledge of creativity, in general, is inadequate [10]. Creativity in science education, to be called precisely as 'scientific creativity', thus has emerged as an independent field of creativity research, rather being considered only as a mere application of creativity in scientific endeavor, and is drawing increasing attention of science educators.

III. SCIENTIFIC CREATIVITY- NATURE OF THE CONSTRUCT AND OPERATIONAL DIMENSIONS CONSIDERED BY DIFFERENT RESEARCHERS

First scientific explanation of creativity is given by Guilford [14]. He explained the construct of creativity, in general, in relation to the model of Structure of Intellect (SI-Model). According to Guilford [14], creativity is mostly associated with 'divergent production' leading to a number of solutions of a particular problem, unlike 'convergent production', where information leads to one single appropriate answer. Guilford related divergent thinking to certain well-known ability factors, namely: fluency (ability to produce a number of valid responses), flexibility (ability of producing a wide variety of responses), originality (ability to generate rare and uncommon responses), and elaboration (ability to construct complex object on the basis of simple construct). Though later on, Guilford [15] included two other abilities – 'redefinition' and 'sensitivity to problem' belonging to 'convergent production' and 'evaluation' category of intellectual operation respectively.

Therefore, though divergent production was the key concept of Guilford to describe the operational construct of creativity, convergent production was also considered as one of the components of the construct. Sternberg [39] also recognized the importance of convergent thinking in addition to divergent thinking in the same relation.

Idea of Guilford [14] on creativity also influenced the research works on scientific creativity a lot. Studies on scientific creativity by Majumdar [26], Singh [38], Misra [29], Shukla and Sharma [37], Hu and Adey [18] etc. are conducted in this light. Majumdar [26] and Singh [38] explained scientific creativity in relation to the SI model proposed by Guilford [14]. Divergent production, along with some other intellectual operations as convergent production, cognition and evaluation are considered to explain the construct of scientific creativity by these researchers. Few SI factors considered by both Majumdar and Singh are : Divergent Figural Transformation (DFT), Cognition of Semantic Transformation (CMT), Convergent Semantic Relations (NMR), Evaluation of Semantic Implication (EMI) etc. Misra [29] explained scientific creativity in the light of Guilford [14]; considered it in relation to divergent thinking and defined the concept in the way as Torrance [40] defined creativity (general). Misra [29] defined scientific creativity as- "a process of becoming sensitive to problems related to science; deficiencies, gaps, missing elements, disharmonies and so on scientific knowledge; identifying the difficulty; searching for solutions; making guesses or formulating hypotheses about deficiencies; testing and retesting of these hypotheses and possibly modifying and retesting them, and finally communicating the result" (pp. 17). Misra [29] explained scientific creativity in relation to divergent thinking only; scientific creativity was considered by Shukla and Sharma [37] also in the same light. Fluency, Flexibility, and Originality were the common dimensions of divergent thinking considered by these researchers. Though in addition, Majumdar [26] considered 'elaboration' and Misra [29] considered 'scientific inquisitiveness' as the criterion. Convergent and Divergent thinking both were considered by Majumdar and Singh, whereas only divergent thinking were considered by Shukla and Sharma, and by Misra. Different abilities considered by these researchers in this relation are as follows:

1. Majumdar [26], Singh [38] : guess consequence, alternate uses, problem sensitivity, remote association, apparatus improvement, finding conceptual correlates etc.
2. Misra [29] : redefinition, elaboration, product improvement, guess causes, guess consequences
3. Shukla and Sharma [37] : guess consequences, predict unusual uses, finding new relationships, finding out causes etc.

In relation to scientific creativity, Lee and Lee [22] considered few new dimensions namely openness, and, precession and entitling- in addition to fluency, flexibility, and originality. These dimensions are also considered in William's idea of creative thought [in 3].

Jang [20] considered the criterion : sensitivity, fluency, flexibility, and elaboration in relation to scientific creativity in web-based technology.

Whereas, Moravesik [30] has explained scientific creativity by saying – "it can explain itself in comprehending the new ideas and concepts added to scientific knowledge, in formulating new theories in science, finding new experiments, preventing the natural laws, in recognizing new regulatory properties of scientific research and scientific group, in giving the scientific activity plans and projects originality and many other ideas" (pp.-222).

Hu and Adey [18], being influenced by Guilford [14], explained scientific creativity in relation to a three dimensional model named– 'Scientific Structure Creativity Model' (SSCM), having the dimensions: Scientific Process (Scientific thinking and scientific imagination), Personality trait (fluency, flexibility, originality), and Scientific product (technical product, scientific knowledge, scientific phenomenon, scientific problem). Scientific creativity, according to Hu and Adey [18] is "a kind of intellectual trait or ability producing a certain product that is original and has social or personal value, designed with a certain purpose in mind, using given information" (pp.- 391). Attempt of Hu and Adey [18] is comprehensive as it considered scientific creativity as a process, person, and also a product. Only Divergent thinking was considered as the criterion by these researchers, therefore the attempt differs from that of Majumdar [26], and Singh [38]; and is in accordance with Misra [29], and, Shukla and Sharma [37].

McCormack and Yages [28] introduced a new taxonomy in 'imagine and creative domain'. They have considered the abilities i.e. visualizing or producing mental image, combining objects and ideas in new ways, producing alternate and unusual uses of objects, solving problems and puzzles, fantasizing, pretending, dreaming, designing devices and machines etc. to describe the operational construct of scientific creativity.

Innamorato [19], Liang [23], Meador [27] etc. considered different scientific process skills i.e. sensing problem, formulating problem, analyzing problem, generating hypotheses etc. as important abilities of a scientifically creative person. Hoover and Feldhusen [16] and Hoover [17] considered 'finding problem' , and 'formulating hypotheses'; Lin, Hu, and Zhen [24] considered the abilities i.e. formulating creative hypotheses, devising experiments and technical innovations, and problem solving in relation to scientific creativity.

Problem solving in science is accepted as a common measure of scientific creativity. Lubart [25] pointed out that problem solving can lead to creativity, because if a problem exists there is only a creative solution. But Erdner [in 3] indicated that 'recognizing the problem in diverse ways' and 'analyzing' it are also essential for scientific creativity. Infield [in 13], Ochac [in 3] even considered that 'sensitivity to problem' and 'formulating the problem' are more important than 'finding solution'.

Therefore, the review of scientific creativity indicates the following points:

i) All the studies are found to be influenced by Guilford and Torrance significantly

ii) Researchers have considered divergent as well as convergent thinking in relation to scientific creativity (Majumder [26]; Singh [38]).

iii) A number of common abilities are found which are as follows :

(a) Formulation of hypotheses : considered by Hoover and Feldhusen [16]; Hoover [17]; and; Lin Hu, and Zhen [24].

(b) To see new relationship : considered by Sharma and Shukla [38] ; and Singh [38].

(c) To add new knowledge to a given situation: considered by Majumder [26]; and Singh [38] (named as elaboration).
(d) Finding a problem: considered by Majumdar [26], and Singh [38]
(e) Guess what would happen: considered by Majumder [26]; Singh [38]; Misra [29]; and, Sharma and Shukla [38]
(f) Problem solving: considered by Majumder [26]; Hu and Adey [18], and Singh [38]

iv) In most of the attempts, the criterion i.e. fluency, flexibility, and originality are found to be the common in relation to divergent thinking.

IV. AREA OF SCIENTIFIC CREATIVITY WHICH REMAINS MOSTLY UNEXPLORED

Discussion reveals that though some research investigations are on scientific creativity, but the number is extremely inadequate, in general. Review also identifies another area where there is scope of in depth investigation, in particular. Discussion is as follows.

Among several disciplines of science, physics particularly has immense potentialities of encouraging and nurturing creativity in its own domain. Its axiomatic nature, scope of applying abstract thinking, inductive approach and analytical reasoning in particular, deductive approach and synthetic reasoning in general in understanding physics etc. provides a physics learner greater opportunity in constructing knowledge actively. Not only this, each individual discipline is characterized by some of its intrinsic features, which influences the nature of its learning as perceived by a learner [2]. Physics is characterized by its well organized nature of content. Several concepts in physics are strongly interrelated with one another following a particular hierarchy. In view of this, students may perceive physics learning as an active search of those interrelationships, finding out the integrated whole, exploration of newer and newer constructs by combining those concepts differently, which might encourage their diversity, leading to creativity. Hence, study of scientific creativity in the context of learning physics is important, in particular.

In India and abroad, few works have been conducted on scientific creativity ([26], [35], [29], [37], [18]) as already mentioned. But study on creativity in physics, in particular, is extremely inadequate. Study of Diakidoy and Constantenou [10], Sen and Mukhopadhyay [36], and, Mukhopadhyay [32] are few among those researches where creativity in physics is considered as the focal theme. The construct of creativity in physics is explained by these researchers in the following way.

Overall features of scientific creativity (discussed already) are also the basic features of creativity in physics, for creativity in physics being a subject specific domain of scientific creativity. But at the same time, it also has some special features which are related to knowledge and understanding of various concepts in physics particularly [32]. The operational construct of creativity in physics is explained by Sen and Mukhopadhyay [36] mostly in relation to divergent thinking. At the same time, adequate and proportionate convergent thinking leading to an appropriate and unique solution of a problem in physics is also considered to explain the same. Fluency, flexibility, originality, planning and foresight, conceptual correlates, and correct vocabulary were the criterion considered by Sen and Mukhopadhyay [36], and also by Mukhopadhyay [32]. Three among these are related to divergent thinking, and the remaining to convergent thinking. The approach is similar to the considerations of Majumdar [26] and Singh [38] - in relation to scientific creativity. Whereas Diakidoy and Constantenou [10] considered creativity in physics in relation to divergent thinking only. They have identified open-ended tasks and ill-defined problems emerging multiple solutions as the ways of measuring the construct. Three types of problems were selected for this purpose. The problem were intended to measure students' ability of explaining possible mechanism behind a physical phenomenon, their ability of predicting consequences, and ability of multiple use of a device. Fluency, appropriateness, and originality were selected as criterion. All the studies, as mentioned were found to be influenced strongly by the idea of Guilford.

No other complete study on creativity in physics is found. Therefore, in spite of having enough scope of encouraging creative thinking within its own domain, creativity in physics remains mostly as an unexplored area of scientific creativity. So study on creativity in physics is demanding also. Particularly in the context of physics learning in institution, scope of such study is more leading to human resource development in a long run.

V. CONCLUSION

Present study therefore has highlighted relevance of the concept 'scientific creativity' in the modern context and explained the construct in details with reference to the view of different other researchers. Understanding the nature of construct of a variable is important for a number of reasons, particularly from the psychometric point of view. The discussion has also identified a particular area of scientific creativity (i.e. creativity in physics) which needs special attention of the researchers. The study, therefore might have its significance to the researchers in conducting their investigation in view of this, which may extend frontiers of knowledge opening a new horizon in the field of scientific creativity.

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