International Journal of Academic Research and Development
ISSN: 2455-4197
www.newresearchjournal.com/academic
Volume 1; Issue 2; February 2016; Page No. 15-20

What is scientific literacy: A review paper

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Abstract
In recent years scientific literacy is considered as one of the major aim of science education and it is the most popular phrase among science educators, teachers and various education reform documents. Though there exist numerous definitions of scientific literacy but there exists no consensus over any definition. For some it is merepossession of scientific knowledge, for some it is the scientific attitude and skills and application of the knowledge, while some see it as just the capacity for reading and comprehending scientific articles. Others consider it the different abilities of an individual for example making decisions in socio-scientific issues and/ or capacity to evaluate the quality of scientific information. Due to this ambiguity in definitions and meaningsmany authors consider it as an ill-defined phrase and suggest stopping the generic use of scientific literacy. Despite of this ambiguity, the importance of scientific literacy could not be lessened because now-a-days, with advancement of science and technologyevery country and government desire for scientific literate citizenry, but it again, raises the questionwhat is scientific literacy? The authors in this paper is tried to answer this question.

Keywords: Science, Scientific literacy, science and technology.

Introduction

This term is said to be first used by Hurd in 1958 (Laugksch, 2000) [20] or probably by James Bryant Conant in 1952 (Bybee, 1997 b cited in Wenning, 2006a) [7, 43]. Whoever used the term but there is no controversy that this term has been become very popular and it is frequently said that achieving scientific literacy is one of the major aim of science education (AAAS, 1989 & 1993; NRC, 1996; Millar & Osborne, 1998; Laugksch, 2000; Sadler, 2004; Wenning, 2006a; Holbrook & Rannikmae, 2009; NSTA, 2010; UNESCO, 2010). [1-2, 25, 22, 20, 37, 43, 18, 26, 16] Though this term has become a buzzword and has been used in literature for more than four decades (Gallagher & Harsch, 1997 cited in Holbrook & Rannikmae, 2009) [15, 18] still its meaning and definition remains vague (DeBoer, 2000) [11]. A precise definition of scientific literacy has been an objective for many scientists, educators, and philosophers (Wenning, 2006a) [43] but this term has defied precise definition since its introduction in 1950s (DeBoer, 2000) [11] because of multiple definitions and meanings. Anelli (2011) [4] has aptly remarked that *to preclude confusion, any serious discourse on scientific literacy should be framed within a clear and precise definition of the term because its meaning has evolved over time and, as will be discussed, it means different things to different stakeholders, including education scholars*. Besides, multiple definitions, this term is being used as synonyms to several other terms. Robert (2007) [35] in an exhaustive review abbreviated the two terms scientific literacy and science literacy as SL. He further identified two other closely related terms that are used and popular in several countries. These terms are *scientific culture* or *la culture scientifique*and *public understanding of science* that are popular in Canada and England respectively. He also mentions the use of the term *public engagement with science*. Laugksch (2000) [20] in his historical overview viewed the scientific literacy as what general public should know about science. Nonetheless, like many authors he believed that differences in meanings and interpretations have made it an ill-defined and diffuse concept. Fensham (2007) [13] though connected the term scientific literacy with science education, and science education for all students but said it lacks an operational definition. Feinstein (2011) [14] address the lack of clarity as*it has come to mean everything and nothing—an idea of usefulness that is taken for granted but is too vague to make a difference.* Due to this fact, it has become extremely difficult to assign it a clear meaning or to define it precisely. Therefore, researchers, educators and policy makers conceptualize it in the way it support their goals of research, education or policies (Sadler, 2004) [37].

However, there are numerous definitions given by authors, educators, and reform documents, some very popular definitions are discussed in this paper.

Meaning and definitions

Pella, O'Hare & Gale in 1966 [32] made one of the earliest efforts to define scientific literacy (cited in Wenning, 2006a) [43]. After reviewing hundreds of articles they come up with six defining elements of scientific literacy. These elements are:

- interrelations between science and society
- ethics of science
- nature of science
- conceptual knowledge
- science and technology
- science in the humanities

Pella (1967) [33] by using the results of the review, defined scientific literacy in terms of what scientifically literates do. In his view, a scientifically literate individual understands relationships between science and society, understand the methods and processes of science, possess the knowledge of

fundamental science concepts, and know the interaction between science and the humanities.

Shen (1975) [39] defined scientific literacy as the understanding and application of science so that its benefits could be utilized and pitfalls could be avoided. He further illustrated that scientific literacy can be many things from knowing about nutritious meal to the laws of physics. He proposed three categories (practical, cultural and civic scientific literacy) of scientific literacy to put these different activities into perspective.

- Practical scientific literacy refers to the application of scientific knowledge that improves the living standards. It is the knowledge that finds the solution of the most basic human needs like food, health and shelter.
- Cultural scientific literacyis related to the appreciation of and desire to know about the scientific achievements by those people who are not involved with science directly like artists, and poets.
- Civic scientific literacy is related to participation and awareness of citizen in science and science based public issues.

Laugksch (2000) [20] suggested that though these three categories are not mutually exclusive, but still different in objective, audience, contents, format, and means of delivery. Though, all the three types of scientific literacy mentioned by him require basic knowledge of scientific concepts, but they are applied in nature.

Miller (1983) [23] contended scientific literacy as an understanding of key scientific terms and concepts (science content knowledge) as *these two dimension together- an understanding of the norms of science and knowledge of major scientific constructs* (nature of science)- *constitute the traditional meaning of scientific literacy as applied to broader populations.* But he further adds that *if scientific literacy is to become truly relevant to our contemporary situation, awareness of the impact of science and technology on society* must be added to it. Thus, like Shen he also took the social context of scientific literacy as being relevant and important over the traditional meaning, of understanding scientific terms and content.

The concept of scientific literacy was also used by the American Association for the Advancement of Science (AAAS, 1989) [2] in Project 2061. It advocates scientific literacy in order for the *life-enhancing potential for science and technology* so that people could make decisions at personal, social or national levels. It offered a broad definition of scientific literacy as *science literacy which encompasses mathematics and technology as well as the natural and social sciences has many facets.* Moreover, it suggests what a person needs to know, understand and do for being scientifically literate.

- *familiarity with the natural world and respecting its unity;*
- *being aware interdependence between mathematics, technology;*
- *understanding some of the key concepts and principles of science;*
- *having a capacity for scientific ways of thinking; knowing that science, mathematics, and technology are human enterprises, and knowing what that implies about their strengths and limitations;*
- *Using the scientific knowledge and ways of thinking for personal and social purposes.*

This definition describes the interconnection between science, mathematics, technology and social sciences, indicating that a person for being scientifically literate should know basic principles of the mentioned disciplines. It also emphasises scientific way of thinking and most importantly social usefulness of science.

Hazen & Trefil (1991) [17] defined it as *scientific literacy constitutes the knowledge you need to understand public issues. It is a mix of facts, vocabulary, concepts, history, and philosophy. It is not the specialized stuff of the experts, but the more general, less precise knowledge used in political discourse*. Having known the facts, vocabulary and the concepts of science enables an individual to understand the scientific news with the same ease as he understands the other news of sports or politics. This definition seems similar to the 'traditional' meaning of Miller. So, we may think that this definition is very narrow or inadequate but they very clearly differentiated doing science and using science, for them doing science is scientist's stuff whereas using science is concerned with common people and is related to scientific literacy. Later, they suggested eighteen principles from physics, chemistry and biology which a person needs to know in order to be scientifically literate. They viewed the importance of scientific literacy through three perspectives, civics; aesthetics and intellectual connectedness. Every citizen required to have some basic scientific knowledge to deal with the public issues, this point argues the importance of scientific literacy from civics point of view, but this is not enough, they argued that the world where we live is operated by laws of nature and only a scientifically literate person could be able to appreciate the beauty and presence of science in daily life. The argument of intellectual coherence is related to the acceptance and appreciation of new discoveries, ideas and theories in science.

Durant (1993) [12] specifies scientific literacy as *what the general public ought to know about science.* So, it could be that scientific knowledge which is useful for everybody in their daily life.

Project 2000+ (1993) advocated scientific literacy as well as technological literacy for all and interpreted both the term as *the ability to read and write scientific and technological prose and understand technical terms.* This definition focuses on reading, writing and understanding the text, however, it further remarked that the meaning of these phrases go beyond to this restricted interpretation. In addition to this, it has assigned operational meanings to the terms as *the capability to function with understanding and confidence, and at appropriate levels, in ways that bring out empowerment in the made world and in the world of scientific and technological ideas.* Hence, it also takes the account of society as one of the aspect of scientific literacy like the other authors mentioned above.

In addition, Jenkins (1994) [19] stated scientific literacy *commonly implies an appreciation of the nature, aims, and general limitations of science, coupled with some understanding of the more important scientific ideas.* This definition primarily includes nature of science and scientific inquiry as the component of scientific literacy but social aspect has not been considered.

Shamos (1995) [38] in the book *The Myth of Scientific Literacy* problematized the achievement of general scientific literacy in his *words we will never get the mass of our population to*

understand science in detail, but we may be able to instill some understanding of how the enterprise works and how scientists practice their discipline enough, one hopes, to serve the societal purpose of scientific literacy. From the definition it becomes clear that though scientific literacy is required by all, it is hard to achieve. Social purpose of scientific literacy is important aspect in this definition. He further proposed three forms of scientific literacy. Each level moves to higher level of scientific literacy.

- Cultural scientific literacy: it refers to basic factual information and vocabulary that requires to read newspaper and magazines etc. without understanding the scientific terms. As this level of scientific literacy is achieved by most of the adults so they believe they are reasonably scientifically literate.
- Functional scientific literacy: it is not only the use of scientific terms, vocabulary but also the ability to converse and write coherently.
- True scientific literacy: this level is hard to achieve and involves the attainment of the previous two levels as well as scientific process. More than that it also includes the basic understanding of history, values and assumptions of science. At this level the individual knows about the scientific enterprises and the theories that formed the foundations of science. He also discussed the mental abilities that an individual possesses at this level and called it scientific habits of the mind or critical thinking. He called it the ultimate level of literacy.

National Science Education Standards (NSES) in 1996 [25] not only attempted to define the term but explained its meaning in very comprehensive manner. NSES defined it as *scientific literacy is the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity. It also includes specific types of abilities* This definition describes scientific knowledge and concepts as the components of scientific literacy but it goes a step ahead and includes application of knowledge and understanding of scientific concepts in decision making, participation in civic and cultural affairs, economic productivity. It means it is not just the ability of reading and understanding scientific news in the popular press but it enables the individuals to satisfy their curiosity, to engage in scientific discussion and arriving on some valid conclusions. Furthermore, it operationally defines what scientifically literate people can do.

- One can ask, find, or determine answers to questions derived from curiosity about everyday experiences.
- One has ability to describe, explain, and predict natural phenomena.
- One is being able to read with understanding articles about science in the popular press and engage in social conversation about the validity of the conclusions.
- One can identify scientific issues underlying national and local decisions and express positions that are scientifically and technologically informed.
- One can evaluate the quality of scientific information on the basis of its source and the methods used to generate it.
- One has capacity to pose and evaluate arguments based on evidence and apply conclusions fromsucharguments appropriately.

These abilities could be categorized into four, scientific inquiry, nature of science, scientific knowledge and decision making in socio-scientific issues.

Further, Millar & Osborne (1998) [22] have expressedviewssimilar to NSES, in a report 'Beyond 2000 [22]: Science Education for the Future' they stated that *science deals with major themes in which most people are already interested, or can readily be interested: life and living things, matter, the universe, information, the 'made-world'.* They emphasize the role of curriculum in providing a course which can enhance scientific literacy. In this report, scientific literacy described to include:

- appreciation of the scientific ideas and the value of science and its contribution to the culture;
- appreciation of the basic rationale for decisions about daily life problems (for example about diet, or medical treatment, or energy use) which the students may wish, or be advised, to take in everyday contexts, both now and in later life;
- ability to understand, and respond critically to the science component of issues with scientific component;
- ability to actively participate in and expression of a personal point of view on, issues with a science component;
- Ability to acquire further knowledge when required, either for interest or for vocational purposes.

Various definitions are given by OECD's Programme for International Student Assessment (PISA) surveys that describe scientific literacy time to time.

In PISA 2000 and 2003 scientific literacy has been defined as *the capacity to use scientific knowledge, to identify questions and to draw evidence-based conclusions in order to understand and help make decisions about the natural world and the changes made to it through human activity (OECD 2000, 2003).*

Scientific knowledge in this definition encompasses knowledge of science and understanding about science (OECD, 2013) [31]. In other words we can say that scientific knowledge is not just the knowledge of facts, terms and vocabulary but it also includes the understanding of scientific concepts and nature of science (NOS). Likewise the previous definitions noted above, it also emphasizes the application of scientific knowledge in making informed decisions about self, family, community and global issues (OECD 1999) [27]. The context of application of scientific knowledge is very comprehensively described in OECD (2000) [28] and it is considered as the ability to solve the problems confronted in real life situations *which can affect us as individuals (e.g., food and energy use) or as members of a local community (e.g., treatment of the water supply or siting of a power station) or as world citizens (e.g., global warming, diminution of biodiversity).*

In PISA 2006 and 2013 the definition of scientific literacy is like that

an individual's scientific knowledge and use of that knowledge to identify questions, to acquire new knowledge, to explain scientific phenomena, and to draw evidence-based conclusions about science related issues, understanding of the characteristic features of science as a form of human knowledge and enquiry, awareness of how science and technology shape our material, intellectual, and cultural

environments, and willingness to engage in science-related issues, and with the ideas of science, as a reflective citizen (OECD 2006, 2013) [30, 31].

This definition comprises three competencies, explaining phenomena scientifically; evaluating and design scientific inquiry; and interpreting data and evidence scientifically (OECD, 2013) [31] that require scientific knowledge and its application. In this definition scientific knowledge stands for knowledge of science or content knowledge (i.e. *concept and ideas of science*) and knowledge about science. The latter could be more specified by dividing it into two, the procedural knowledge (i.e. *the procedures and strategies used in all forms of scientific enquiry*) and the epistemic knowledge (i.e. *the manner in which ideas are justified and warranted in science*) (OECD, 2013) [31]. So there are three kinds of knowledge required to achieve these competencies.

In an extensive review Roberts (2007) [35] specifies the definitions and meanings from the literature into two competing visions to form a continuum of scientific literacy, Vision I and Vision II. At one extreme Vision I looks within science and focuses on *the canon of orthodox natural science, that is, the products and processes of science itself*. This vision visualizes the literacy or 'thorough knowledge ability' within science. On the other hand Vision II is dedicated to the *situations with a scientific component, situations that students are likely to encounter as citizens.* So it has become clear that Vision I is mainly concerned with the knowledge aspect, that is *what must people know or be able to do to be science literate?* (Feinstein 2011) [14] and how this knowledge is attained. Vision II encompasses Vision I and *seeks to enhance student's capacities to function as life-long, responsible, savvy participants in their everyday lives* (Aikenhead, 2008, cited in Sarkar, 2012) [3, 36].

For Gregario (2010) [16] scientific literacy is *usually taken to mean developing the ability to use science knowledge creatively in everyday life and to solve problems, make decisions and hence improve the quality of life. This ability is based on acquiring educational skills at the intellectual, attitudinal, societal and interdisciplinary levels.*

This definition seems to be consistent with the above mentioned definitions as it herein refers to the application of scientific knowledge in day-to-day life to make it easier, comfortable and better by solving the problems or by making informed decisions. However, he suggested the necessity acquisition of educational skills for the application of scientific knowledge in everyday life.

Brickhouse (2007) [5] in the article '*Scientific Literates: What do they do? Who are they?'* has specified three types of scientific literacy from the popular literature and proposed one more form.

- Civic scientific literacy: Likewise the Shen's classification, civic scientific literacy refers to the application of science in society. It also includes informed decision making about the public issues which are scientific in nature.
- Personal scientific literacy: It includes the application of scientific knowledge for making personal decisions, like health. It is quite similar to the practical scientific literacy of Shen.
- Cultural scientific literacy: It is the appreciation of scientific knowledge it also seems to be similar to the cultural scientific literacy described by Shen.
- Critical scientific literacy: This form of scientific literacy has added by the author because she thinks that only reading, understanding or applying the scientific knowledge in day to day life are not sufficient rather it is equally important to know why the text has been written, what the authors want to do with the text, what is the place of science in the text and how the readers are being positioned by the text. In simple words we may say it involves the critical evaluation of content of scientific texts.

Since always science education is considered as the means to enhance scientific literacy, Holbrook & Rannikmae (2009) [18] focuses on this aspect and put forward a new definition of scientific literacy as *developing an ability, to creatively utilize appropriate evidence-based scientific knowledge and skills, particularly with relevance for everyday life and a career, in solving personally challenging yet meaningful scientific problems as well as making, responsible socio-scientific decisions*. Application of scientific knowledge in everyday life is the main aspect of this definition. They further argued the importance of interaction skills, personal development and suitable communication approaches in enhancing the scientific literacy.

Bybee (2012) [9] clarified the meaning of scientific literacy in very simple words. He defined it as *an understanding of science and its applications to social experiences.* This definition seems to be very close to the definition given by Hurd in 1958 and cited in Bybee *et al*. (2009) [8].In 1997 in a chapter '*Towards an understanding of scientific literacy*' he proposed four levels of scientific literacy.

- Nominal scientific literacy: At this level a person is able to recognize the scientific terms but does not have much understanding of science concepts.
- Functional scientific literacy: At this level a person is able to read and write about science matters i.e. one can work with vocabulary but does not have much understanding of associations.
- Conceptual and procedural scientific literacy: at this level one can associate the concepts as well as understands the structure of science and its use for gaining new knowledge.
- Multidimensional scientific literacy: This level includes understanding the nature of science and the role of science in society.

So, these levels also include knowledge, nature of science and social aspect of science similar to the previous definitions.

Conclusion

After discussing a number of definitions it has become even clearer that this term is used metamorphic ally (Holbrook & Rannikmaeb 2009) [18]. In addition they broadly classified these definitions of scientific literacy into two points of view:

- The first view gives prime importance to the knowledge of science;
- The second view values the utility of science in social context.

Some of the definitions discussed here fall in the first category, some in the second, while in some both of this views seem to complement each other. Besides this, some other components for example process of science; nature of science, etcalso forms the component of some definitions. Nearly all visions of scientific literacy involve at least some scientific knowledge (McEneaney, 2003 cited in Carlson, 2008) [21, 10] though scientific knowledge is essential but it could not be enough to be regarded as scientific literacy till it is applied in social context. Besides, processes through which we get the new knowledge and then translation of this knowledge into action should also be included in the components of scientific literacy.

From the above definitions four main components of scientific literacy seems to appear:

Content Knowledge

Nature of Science (NOS)

Scientific Inquiry

Implication in Socio-Scientific Issues (SSI)

Content Knowledge: It is the factual knowledge. Such knowledge helps in understanding the natural world and also required for making sense of experiences in personal, local, national, and global contexts (OECD, 2013) [31]. State Board of Education (2007) [40] (cited in Carlson, 2008) [10] defines it as the practices of identifying and using. Identifying requires the student to recall, define, relate, and represent basic science principles so that they understand how principles of science work. The practices of using focuses on usefulness of scientific knowledge in making exact predictions about phenomena and in explaining observations of the natural world in rational manner.

Nature of science (NOS): It is a complex concept that involves philosophy, sociology and history of science (Wenning, 2006b) [44]. Ministry of Education, New Zealand (2011) [24] described the characteristics of NOS as:

- Scientific knowledge is tentative (subject to change).
- Science is based on or derived from observation of the natural world.
- Science is inferential, imaginative and creative.
- Science is subjective and theory laden.
- Science is socially and culturally embedded.

In other words NOS is an understanding of what science is about and how it proceeds (Wenning, 2006b) [44].

Scientific Inquiry: It has been defined by AAAS (1993) [2] as *making a great many careful observations and then organizing them.* For NRC (1996) [25] scientific inquiry is *the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world.* Wenning (2007) [45] operationally defined scientific inquiry at a level appropriate for secondary schools. He further provided a list of fundamental scientific inquiry skills as:

- Identify a problem to be investigated.
- Using induction, formulate a hypothesis or model incorporating logic and evidence.
- Using deduction, generate a prediction from the hypothesis or model.
- Design experimental procedures to test the prediction.
- Conduct a scientific experiment, observation or simulation to test the hypothesis or model.
- Collect meaningful data, organize, and analyze data accurately and precisely.
- Apply numerical and statistical methods to numerical data to reach and support conclusions.
- Explain any unexpected results.
- Using available technology, report, displays, and defends the results of an investigation to audiences that might include professionals and technical experts.

Implication in Socio-Scientific Issues (SSI): Radcliffe & Grace (2003) [34] defined SSI *one which has a basis in science and has a potentially large impact on society.* They further described the nature of these issues as:

- have a basis in science, frequently that at the frontiers of scientific knowledge;
- involve forming opinions, making choices at personal or societal level;
- are frequently media-reported, with attendant issues of presentation based on the purposes of the communicator;
- deal with incomplete information because of conflicting/incomplete scientific evidence, and inevitably incomplete reporting;
- address local, national and global dimensions with attendant political and societal frameworks;
- involve some cost-benefit analysis in which risk interacts with values;
- may involve consideration of sustainable development;
- Involve values and ethical reasoning.

Finally it could be said that being scientifically literate means a person is able to solve the real life problems by executing the knowledge of science, he/she understands the nature of science and possesses the skills of scientific inquiry.Such people could betermed as *reflective citizen*.

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