Demystifying Scientific Literacy: Charting the Path for the 21st Century

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Abstract

Scientific literacy is an attribute deemed desirable by many developed and developing nations worldwide. However, there has been much contention regarding its definition and the likelihood of its acquisition. This paper critically evaluates existing literature on the topic of scientific literacy by analyzing conceptions of it over the past thirty years. It further distills the literature and yields a simplified operational definition of scientific literacy. Finally, implications for science teaching based on the basic definition posited namely the use of strategies such as questioning, problem-solving, inquiry and experimentation are explored.

Keywords: *scientific literacy, scientific concepts, nature of science, science and society, critical thinking,*

1. Introduction

The term "scientific literacy" has been used widely to describe the range of abilities that the majority of a country's population should posses in an effort to facilitate national, social and economic success. It was first coined by Paul DeHart Hurd in 1958 in an article entitled "Science Literacy: Its Meaning for American Schools" (DeBoer, 1991) and has been extensively used in science and educational journals ever since as seen in Figure 1.

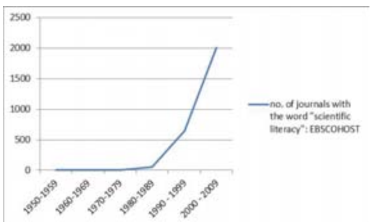

Figure 1. The growth of the use of the term "scientific literacy".

The figure illustrates the number of articles published with the word "scientific literacy" over a 50 year period using the EBSCOHOST database (August, 2011).

While the term 'scientific literacy' is synonymous with the "public understanding of science" (Shamos, 1995, p. xii) in Britain, "la culture scientifique" is used in France (Durant, 1993; Roberts, 2007). As the terms for scientific literacy vary from place to place, the definitions of scientific literacy vary from author to author (Fensham, 2007; Laugksch, 2000; Osborne, 2007; Roberts, 2007; Shamos, 1995). Due to the lack of a universally accepted definition of the concept, it is sometimes referred to as ill-defined and diffuse (Laugksch, 2000). Nevertheless, an in-depth analysis of the literature reveals basic components that constitute scientific literacy. The following section provides the basis for the definition of the term 'scientific literacy' as it is used in this paper.

2. Conceptions of Scientific Literacy

In 1963, a survey conducted by the National Science Teachers Association (NSTA) revealed that many scientists and educators defined scientific literacy in terms of content knowledge in a wide range of science fields while few of them described it as having a connection with the relationship between science and society (DeBoer, 1991). These two viewpoints represent two major camps; one perspective where knowledge of science plays a central role and the other encompassing the usefulness of science to society (Holbrook & Rannikmae, 2009). From the inception of its use until now, conceptions of scientific literacy fall along the aforementioned continuum.

Pella, O'Hearn, & Gale (1966), in one of the earliest attempts to arrive at a definition of scientific literacy, deduced that scientific literacy was based on six characteristics. They stated that a scientifically literate person should have an understanding of basic concepts in science, nature of science, interrelationships of science and society, ethics that control the scientist in his work; difference between science and technology and interrelationships of science and the humanities.

Building upon the work of Pella and his colleagues, Showalter (1974) and his colleagues combined 15 years of relevant literature in order to produce a definition of scientific literacy with seven dimensions (Rubba & Andersen, 1978). That is, the scientifically literate person:

1. Understands and accurately applies appropriate concepts in science as they interact with the universe.
2. Understands the nature of scientific knowledge.
3. Understands the values that permeate science and consciously chooses to apply them or not in interacting with their universe.
4. Has developed numerous manipulative skills associated with science and technology.
5. Uses the processes of science appropriately in solving problems, making decisions, and furthering their own understanding of the universe.
6. Has developed a richer, more satisfying and more stimulating view of the universe as a consequence with their education in science and seeks to extend this education throughout his life.
7. Understands and appreciates the joint enterprise of science and technology and the interaction of these with each other and with other aspects of the society.

The feature that made this particular work unique was that it was the only known explicit definition of scientific literacy at the time (Rubba & Andersen, 1978).

Like Showalter, Miller (1983) contended that scientific literacy is a multidimensional construct. However, he described it using three related dimensions. Miller forwarded that scientific literacy consists of (1) an understanding of the key concepts in science, (2) an understanding of the norms and methods in science (nature of science) and (3) an awareness of the impact of science and technology on society.

Six years later, the American Association for the Advancement of Science (AAAS) (1989) offered a similar definition for scientific literacy but expanded it to encompass mathematics. They opined that a scientifically literate individual is:

One who is aware that science, mathematics, and technology are interdependent human enterprises with strengths and limitations; understands key concepts and principles of science; is familiar with the natural world and recognizes both its diversity and unity; and uses scientific knowledge and scientific ways of thinking for individual and social purposes (xvii).

While the nature of science is not specifically mentioned in this conception of scientific literacy, understanding of human enterprises and the strengths and limitations thereof are viewed as facets of that dimension (e.g Abd-El-Khalick and Lederman, 2000).

The NRC (1996) in their National Science Education Standards (NSES) proposed that 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. Consequently, a scientifically literate population not only benefits the individual but serves the needs of society. It is for this reason that Laugksch (2000) asserted the micro and macro views. According to him, the more knowledgeable the citizen in science, the better he/she is able to negotiate their way through society. Furthermore, he reasoned that scientific knowledge empowers individuals to participate intelligently in the productive sector of the economy. An explanation for the reasoning of Laugksch can be found in the definition of scientific literacy as posited by OECD (2007). They forwarded that scientific literacy is the extent to which an individual possesses scientific knowledge and uses the knowledge to identify questions, acquire new knowledge, explain scientific phenomena and draw evidence-based conclusions about science-related issues; understands the characteristic features of science as a form of human knowledge and enquiry; shows awareness of how science and technology shape our material, intellectual and cultural environments; and engages in science-related issues with the ideas of science as a reflective citizen. Simply put, scientific literacy is the ability to understand science and its role in society, and make informed decisions as citizens based on scientific evidence and knowledge (Cavanagh, 2008).

The definition of scientific literacy posited by Murcia (2007) is consistent with that of Miller (1983). Murcia conceived scientific literacy as the ability of an individual to blend the knowledge of important scientific terms and concepts, the knowledge of the nature of science and the knowledge of the interaction of science and society; however, she stressed that the blending must occur within a contextual framework.

Generally, definitions proffered for scientific literacy cite qualities that embody critical thinking. It is the thread that ties knowledge of scientific content, nature of science and the society together. This type of thinking reverberates as one of the main characteristics of scientific literacy and is even more evident in the elaborative list of characteristics that Hurd (1998) has developed to describe a scientifically literate person. According to him, a scientifically literate person must exhibit 26 traits. He stated that a scientifically literate person is one who:

1. Distinguishes experts from the uninformed.
2. Distinguishes theory from dogma, and data from myth and folklore.
3. Recognizes that almost every facet of one's life has been influenced in one way or another by science/technology.
4. Knows that science in social contexts often has dimensions in political, judicial, ethical, and sometimes moral interpretations.
5. Senses the ways in which scientific research is done and how the findings are validated.
6. Uses science knowledge where appropriate in making life and social decisions, forming judgments, resolving problems, and taking action.
7. Distinguishes science from pseudo-science such as astrology, quackery, the occult, and superstition.
8. Recognizes the cumulative nature of science as an "endless frontier."
9. Recognizes scientific researchers as *producers* of knowledge and citizens as *users* of science knowledge.
10. Recognizes gaps, risks, limits, and probabilities in making decisions involving knowledge of science or technology.
11. Knows how to analyze and process information to generate knowledge that extends beyond facts.
12. Recognizes that science concepts, laws, and theories are not rigid but essentially have an organic quality; they grow and develop; what is taught today may not have the same meaning tomorrow.
13. Knows that science problems in personal and social contexts may have more than one "right" answer, especially problems that involve ethical, judicial, and political actions.
14. Recognizes when a cause and effect relationship cannot be drawn. Understands the importance of research for its own sake as a product of a scientist's curiosity.
15. Recognizes that our global economy is largely influenced by advancements in science and technology.
16. Recognizes when cultural, ethical, and moral issues are involved in resolving science–social problems.
17. Recognizes when one does not have enough data to make a rational decision or form a reliable judgment.
18. Distinguishes evidence from propaganda, fact from fiction, sense from nonsense, and knowledge from opinion.
19. Views science–social and personal–civic problems as requiring a synthesis of knowledge from different fields including natural and social sciences.
20. Recognizes there is much not known in a science field and that the most significant discovery may be announced tomorrow.
21. Recognizes that scientific literacy is a process of acquiring, analyzing, synthesizing, coding, evaluating, and utilizing achievements in science and technology in human and social contexts.
22. Recognizes the symbiotic relationships between science and technology and between science, technology, and human affairs.
23. Recognizes the everyday reality of ways in which science and technology serve human adaptive capacities, and enriches one's capital.
24. Recognizes that science–social problems are generally resolved by collaborative rather than individual action.
25. Recognizes that the immediate solution of a science–social problem may create a related problem later.
26. Recognizes that short- and long-term solutions to a problem may not have the same answer.

Although the aforementioned characteristics exemplify scientific literacy, it is an oversimplification to categorise a person as literate or illiterate in science. Consequently, Shamos (1995) proposed that there are three levels of scientific literacy. They are cultural scientific literacy - the kind of literacy that manifests itself in the person's ability to grasp background information that communicators believe that their audiences already have; functional scientific literacy – the kind of literacy that is contingent on the person's ability to converse, read and write coherently by using scientific terms in context; and true scientific literacy – the kind of literacy that requires the person to have knowledge of major conceptual schemes or theories that are the foundation of science, how and why these theories are accepted, how these theories achieve order out of a random universe, and the role of experiments in science. While Shamos (1995) indicated progression in using the term 'levels of scientific literacy', Shen (1975) alluded to forms of scientific literacy (Dillon, 2009; Laugksch, 2000; Shamos, 1995). He postulated three forms - practical scientific literacy, cultural scientific literacy and civic scientific literacy. Shen described practical scientific literacy as the knowledge used in the solution of practical problems (food, health and shelter) while cultural scientific literacy referred to an individual's desire for knowledge in human achievement. He explained that civic scientific literacy, the cornerstone of informed public policy, directly relates science to science-related issues so that citizens can use their knowledge in science to deal with real-life problems.

One major difference between the types of scientific literacy as proposed by Shen and Shamos, is that Shen (1975) focused on situations in which critical thinking could be used while Shamos (1995) referred to degrees of it. For example, Shen highlighted the use of scientific knowledge for the solution to problems such as survival and civic debate while Shamos mainly focused on knowledge gains. For Shamos, critical thinking increased as an individual approached true scientific literacy and, even though the ability to problem-solve was implied in the highest level of scientific literacy, no level of literacy was directly linked to the solution of practical or societal issues.

The views of scientific literacy that are held by Shen and Shamos may be explained in view of two schools of thought as proposed by Roberts (2007). Roberts postulated that the two schools of thought are based on two visions which he called Vision I and Vision II. According to him, Vision I is inward looking and is concerned with science and its products and processes such as laws and theories in the first instance and hypotheses and experimentation in the second instance. On the other hand, Vision II is outward looking and focuses on the science and its role such as critical thinking and decision making about socio-scientific issues (Roberts, 2007). The major difference between Vision I and Vision II is the relevance of science to everyday life.

Erickson (2007) postulated that there is a desire to shift away from the strong emphasis on the traditional delivery of the disciplinary science content as seen in Vision I to the Vision II perspective. This view is especially applicable today since the present era requires students to apply the concepts learnt, the hypotheses and the experimentation to advance humankind and to make informed decisions in everyday life. Subsequently, Erickson (2007) questions the presence of an unnecessary dichotomy between the two visions and posits that there may be some kind of integrative approach that would address most of the concerns and values represented in both perspectives. While Dillon (2009) does not necessarily share the same view, he believes that by breaking down the term "scientific literacy" into "scientific literacies, we might have the ability to tackle the "philosophical tensions" that are present between the two Visions (p. 211).

3. A Simplified View of Scientific Literacy

An appraisal of the aforementioned literature reveals that scientific literacy comprises three main dimensions. These dimensions undergird the reviewed definitions of scientific literacy.

3.1 Dimension 1: Knowledge of Key Concepts

The first dimension that is common among the reviewed definitions of scientific literacy is the individual's knowledge or acquisition of organized knowledge in science. Many authors refer to individuals possessing knowledge of basic/key/appropriate concepts in science. This knowledge serves as building blocks for further understanding in science and is relied upon for action in problem-solving. The problem here is that the concepts that individuals are required to know vary based on culture and social setting. For example, a young boy in small Amerindian village may not necessarily need to know about stem cell research as this knowledge may not be relevant to his everyday life experiences; however, he may find it more useful to have an understanding of the refraction of light to be effective in his everyday spearing of fish. Therefore, basic/key/appropriate concepts are contextual as they are dependent on the usefulness of that knowledge to individuals as they function in everyday life.

3.2 Dimension 2: Knowledge of the Nature of Science

This dimension embodies the broad domain of nature of science. Like scientific literacy, there is generally no consensus on the definition of nature of science (Abd-El-Khalick & Lederman, 2000). Lederman (1992) referred to "nature of science" as the epistemology of science, science as a way of knowing, or the values and beliefs inherent in the development of scientific knowledge. While Lederman's definition of the nature of science seems to refer specifically to scientists and the way in which they widen knowledge, Millar and Osborne (1998) explain that the nature of science is equally important citizens. They argue that the products of science and technology permeate our everyday lives and it is necessary to inculcate values in students regarding the beneficial applications of these products. They further that knowledge of nature of science allows students to recognize that evidence and argument help to establish reliable knowledge and that they themselves can develop their own arguments. Subsequently, it empowers them to hold and express views to enable them to become actively involved in civic debates.

As alluded to by Millar and Osborne, the nature of science is not only guided by the building up of knowledge for its own sake but is driven by the benefits that science can have to humanity. It encompasses humanistic dimensions such as ethics, history, philosophy and culture. This point is bolstered by United Nations Educational Scientific and Cultural Organisation (UNESCO) (1999) who advanced that scientific research and the use of knowledge from that research should always (i) aim at the welfare of humankind, including the reduction of poverty, (ii) be respectful of the dignity and rights of human beings, and of the global environment, and (iii) take fully into account our responsibility towards present and future generations. Additionally, UNESCO (1999) forwarded that the ethical standards of scientists must be high and the science curricula should include the history and philosophy of science and its cultural impact.

While Lederman (1992) broadly described the nature of science, National Science Teachers' Association (NSTA) (2009) specifically identified its features. They explained that the nature of science is based on premises such as the reliability and tentativeness of scientific knowledge; shared values; creativity; naturalistic methods; the socio-cultural impact on science; the history of science and; understanding the natural world for its own sake. These features are rather different to early conceptions of the nature of science. Rubba (1977) based his model of the nature of science on that of the Showalter and condensed the original nine features into six. Rubba posited that science is amoral, creative, developmental, parsimonious, testable and unified.

Although views of the nature of science seem to vary among authors, the literature on this topic shows some level of generality. After distillation of literature on nature of science, Abd-El-Khalick and Lederman (2000) purported that scientific knowledge is generally (i) tentative, (ii) empirically-based, (iii) subjective, (iv) partially based on human imagination, creativity, and inference; (v) socially and culturally embedded, (vi) the distinction between observation and inference and (vii) the functions of, and relationship between scientific theories and laws. Examples of knowledge of these characteristics are seen in the conceptions of scientific literacy of Pella (1975), AAAS (1989), Shamos (1995), NRC (1996), Hurd (1998) and OECD (2007) among others. These works allude to the scientifically literate having the ability to appreciate elements of scientific investigation, understand the nature of scientific knowledge and evaluate the quality of scientific information on the basis of the source and methods used to generate it.

3.3 Dimension 3: Knowledge of the Interaction between Science and Society

The last dimension of scientific literacy encompasses characteristics that identify the relationship between science and society. Millar and Osborne (1998) believed that an understanding of science can help students in their decision-making about diet, health, lifestyle etc. The goal of educating students to this end can only be reached as students are taught science from a social perspective. Hence, there is a need for students to learn science in a way that is applicable to their everyday life. Fensham (1985) and Ziman (1980) bolstered this argument by stating that instead of teaching science in the classroom as though it were unconnected to the world, the scientific knowledge purported in schools must be relevant to the students' lives outside of school. Much like the knowledge of key/basic/appropriate concepts in science, the knowledge of the relationship of science and society is dependent on an individual's environment. Because of individual differences in this dimension, Miller (1998) did not consider it in his measurement of sceintific literacy in his cross-national studies. This view is bolstered in the definiton of Hurd (1998) who put forward that the scientifically literate must demonstrate the traits of recognizing the everyday reality of ways in which science and technology serve human adaptive capacities and enriches one's capital. Generally, persons are expected to apply their knowledge in science effectively to various situations that they experience in their everyday living.

The condensation of the characteristics of scientific literacy into three dimensions is supported by Miller (1983). Furthermore, Laugksch and Spargo (1996) reiterate that the acknowledgement of these three dimensions of scientific literacy is common. Table 1 shows the disaggregated definitions scientific literacy and how they can be categorised under the proposed three dimensions of scientific literacy.

It is parsimonious to state that knowledge in the three dimensions posited will cause scientific literacy. Though knowledge in the three dimensions is important, the type of thinking that binds the three dimensions together is equally necessary. It is this type of thinking that Shamos (1995) believed prevented persons from reaching the highest level of literacy. According to him, persons may be functionally literate but be unable to extrapolate their skills to issues in society. Showalter (1974) also recognised this important trait and stated that individuals who are sceintifically literate must demonstrate an ability to think on the formal operations level as described by Piaget and others.

Table 1: Table Showing the Disaggregated Definitions of Scientific Literacy as They Relate to the Three Dimensions Posited

AUTHOR	Knowledge of Scientific Concepts	Knowledge of Nature of Science	Knowledge of the Interrelationship between Science and Society
Pella et al. (1966)	-Understands basic concepts in science	-Understands nature of science -Understands ethics that control the scientists' work	-Interrelationships of science and society
Showalter (1974)	-Understands and accurately applies appropriate concepts in science as they interact with the universe	-Understands the nature of scientific knowledge -Understands the values that permeate science and consciously chooses to apply them or not in interacting with the universe. -Uses processes of science appropriately in solving problems, making decisions and furthering their own understanding of the universe.	-Understands and appreciates the joint enterprise of science and technology and the interaction of these with each other and with other aspects of society.
Shen (1975)	-Understands and applies knowledge to solve practical and public issues.	-Develops an appreciation for humanistic science.	-Uses knowledge to solve practical and public issues
Miller (1983)	-Understands key concepts in science.	-Understands the nature of science.	-Understands the interrelationship between science and society.
AAAS (1989)	-Understands key concepts and principles in science.	-Is familiar with the natural world and respects its unity. -knows that science, technology and mathematics are social enterprises -Develops a capacity for scientific thinking.	-Uses scientific knowledge and ways of thinking for personal and social purposes.
Shamos (1995)	–Understands major conceptual schemes or theories that are the foundation of science.	-Understands how and why theories are accepted, how theories achieve order out of a random universe, and the role of experiments in science.	
NRC (1996)	-Understanding of scientific concepts and processes required for decision making.		-Participation in civic and cultural affairs -Economic productivity
Hurd (1998)	-Uses science knowledge where appropriate in making life and social decisions, forming judgments, resolving problems, and taking action.	-Senses the ways in which scientific research is done and how the findings are validated. -Distinguishes science from pseudo-science such as astrology, quackery, the occult, and superstition. -Recognizes the cumulative nature of science as an "endless frontier." -Recognizes scientific researchers as *producers* of knowledge. -Recognizes gaps, risks, limits, and probabilities in making decisions involving knowledge of science or technology. -Knows how to analyze and process information to generate knowledge that extends beyond facts. -Recognizes that science concepts, laws, and theories are not rigid but essentially have an organic quality; they grow and develop; what is taught today may not have the same meaning tomorrow. -Knows that science problems in personal and social contexts may have more than one "right" answer, especially problems that involve ethical, judicial, and political actions. -Recognizes when a cause and effect relationship cannot be drawn. Understands the importance of research for its own sake as a product of a scientist's curiosity. -Recognizes when cultural, ethical, and moral issues are involved in resolving science–social problems. - Recognizes when one does not have enough data to make a rational decision or form a reliable judgment. -Distinguishes evidence from propaganda, fact from fiction, sense from nonsense, and knowledge from opinion.	-Knows that science in social contexts often has dimensions in political, judicial, ethical, and sometimes moral interpretations. -Recognizes citizens as *users* of science knowledge. -Recognizes that our global economy is largely influenced by advancements in science and technology. -Views science–social and personal–civic problems as requiring a synthesis of knowledge from different fields including natural and social sciences. -Recognizes the symbiotic relationships between science and technology and between science, technology, and human affairs. - Recognizes the everyday reality of ways in which science and technology serve human adaptive capacities, and enriches one's capital. - Recognizes that science–social problems are generally resolved by collaborative rather than individual action. - Recognizes that the immediate solution of a science–social problem may create a related problem later. -Recognizes that short- and long-term solutions to a problem may not have the same answer.
Murcia (2007)	-Ability to blend the knowledge of important scientific terms and concepts, the knowledge of the nature of science and the knowledge of the interaction of science and society within a contextual framework.		
OECD (2007)	-Possesses knowledge and skills.	-Uses knowledge to identify questions, acquire new knowledge, explain scientific phenomena and draw evidence-based conclusions about science related issues. -Understands the characteristic features of science as a form of human knowledge and enquiry.	- Shows awareness of how science and technology shape our material, intellectual and cultural environments. -Engages in science-related issues with the ideas of science as a reflective citizen.
Cavanagh (2008)	Understands science and its role in society, and make informed decisions as citizens based on scientific evidence and knowledge		

4. Implications for Science Teaching

The research implies that there is a need to expose students to scientific content that is meaningful and relevant to their everyday experiences. Science must be taught in a contextual manner so that students are able to transfer the learning gained in the classroom to situations outside of the classroom. For example, a student in a country that experiences sunshine all year round may find it more beneficial to learn about the harnessing of solar energy for his everyday needs as opposed to learning about another topic that bears no relevance to him and that has no direct application.

Moreover, students need to be exposed to germane topics in ways that involve scientific investigation. They should be allowed to read scientific articles, question, inquire, problem-solve and experiment in an effort to develop to critical thinking skills and form an understanding of the way that science progresses. Teachers should focus on the development of basic and integrated science process skills in a manner that produces meaningful outcomes for students. The nature of science should be taught explicitly to ensure that students understand the nacre of scientific thinking.

Finally, scientific content and nature of science should be taught in light of socio-cultural issues. Students should be made aware of the interrelationship between science and society. An approach such as this could dispel students' views about the abstract nature of science. As students are made aware of the relationship that exists through seeking solutions to everyday problems, it is likely that a greater appreciation of science could occur.

5. Concluding Remarks

Teachers are critical in the production of scientifically literate individuals in our society. There is a need for teachers to create and deliver lessons that are meaningful and relevant to today's youth while focusing on preparing them for the future. Where possible, all should be done to ensure that students benefit from a sound science education that enables them to navigate effectively in a rapidly changing society.

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