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Public Understanding of Science 2003; 12; 183
DOI: 10.1177/09636625030122004

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SAGE Publications
http://www.sagepublications.com

Public Understand. Sci. **12** (2003) 183–202

RESEARCH PERSPECTIVE

Science communication: a contemporary definition

T.W. Burns, D.J. O'Connor, and S.M. Stocklmayer

Science communication is a growing area of practice and research. During the past two decades, the number of activities, courses, and practitioners has steadily increased. But what actually is science communication? In what ways is it different to public awareness of science, public understanding of science, scientific culture, and scientific literacy? The authors review the literature to draw together a comprehensive set of definitions for these related terms. A unifying structure is presented and a contemporary definition of science communication positioned within this framework. Science communication (SciCom) is defined as the use of appropriate skills, media, activities, and dialogue to produce one or more of the following personal responses to science (the AEIOU vowel analogy): Awareness, Enjoyment, Interest, Opinion-forming, and Understanding. The definition provides an outcomes-type view of science communication, and provides the foundations for further research and evaluation.

1. Surveying the field

The meaning of science communication and other terms used in the field of scientific literacy has been plagued by an unfortunate lack of clarity.[1]

Science communication (SciCom) is not simply encouraging scientists to talk more about their work, nor is it an offshoot of the discipline of communications. Although people may use the term "science communication" as a synonym for public awareness of science (PAS), public understanding of science (PUS), scientific culture (SC), or scientific literacy (SL)—in fact many of these terms are often used interchangeably—it should not be confused with these important and closely related terms.

This paper establishes a clear definition of science communication by defining the contemporary meaning of related terms—wherever possible using accepted definitions from the literature—and identifying where science communication fits. The proposed definition is particularly applicable to science outreach and provides a conceptually simple basis for evaluating the effectiveness of science communication.

2. Defining related terms

To understand science communication, agreement needs to be reached about the meaning of some foundational terms.

(Key words are in italics, and words in bold summarize core definitions.)

 [0963-6625(200304)12:2;183–202;034658]

The public

The simplest and most useful definition of **the public is every person in society.** It is acknowledged that "the public" is a very heterogeneous group; it is as multifaceted and unpredictable as the individuals that compose it. In fact at least six overlapping groups within society (sometimes known as "publics"), each with its own "needs, interests, attitudes and levels of knowledge" have been identified for the purposes of science communication activities and/or research.[2] These are:

- "Scientists: in industry, the academic community and government.
- Mediators: communicators (including science communicators, journalists and other members of the media), educators, and opinion-makers.
- Decision-makers: policy makers in government, and scientific and learned institutions.
- General public: the three groups above, plus other sectors and interest groups. For example, school children and charity workers.
- Attentive public: the part of the general community already interested in (and reasonably well-informed about) science and scientific activities."[3]
- Interested public: is composed of people who are interested in but not necessarily well informed about science and technology.[4]

Two other terms are also commonly used:

- The "lay public" identifies people, including other scientists, who are non-expert in a particular field.[5]
- The "science community" or "science practitioners" are people who are directly involved in some aspect of the practice of science.

Together these groups form "the public," and the public together with its customs, norms, and social interactions constitute a society.

Participants

Participants are not the same as stakeholders (people with a vested interest in a particular outcome) or clients (persons paying for a service), although they may also be these. In the context of this paper, **participants are members of the public who are directly or indirectly involved in science communication.**

Examples of *direct* involvement include visiting a science center, attending science theatre, or writing a letter to the editor of a newspaper on a science-related matter. The venue, sponsor, and promoter of a science communication event may be classified as *indirect* participants (but may still have a large impact on the success, or otherwise, of the actual event).

Participants are individuals who belong to the general public and may therefore specifically include scientists, science communicators, businesses and members of the media.

Outcomes and responses

Outcomes may be defined as the result of some action, and there is always at least one result of every reaction. **Response has been defined as "action, feeling, movement, change etc., elicited by stimulus or influence."**[6] While the meaning of the words response and outcome both equate to consequence, responses are more personal and immediate, and therefore more dynamic.

Science communication outcomes and responses may not be easy to study scientifically; they inevitably occur in the "real world" rather than the controlled conditions of a research laboratory and usually require skills from the social rather than the physical sciences. In practice, outcomes that are useful for evaluation or research are usually limited to measurable, fairly short-term and, in some way, quantifiable results. Deeper understanding of science communication may be revealed using qualitative methods. It is also important to recognize that significant long-term consequences of science communication may occur as participants contemplate their existing knowledge, encounter other new experiences, and reorganize their thinking.[7]

Science

Defining science is notoriously difficult. The Panel on Public Affairs of the American Physical Society, for example, proposed a definition that some describe as pure science:

> "Science is the systematic enterprise of gathering knowledge about the world and organizing and condensing that knowledge into testable laws and theories." They went on to explain that ". . . the success and credibility of science is anchored in the willingness of scientists to expose their ideas and results to independent testing and replication by other scientists . . . (and) abandon or modify accepted conclusions when confronted with more complete or reliable experimental evidence."[8] Many dictionaries (e.g., *New Shorter Oxford English Dictionary*, 1993) amplify this definition by highlighting the use of the scientific method as the way of identifying any activity as part of science. The report "Science for all Americans" identifies the fact that science is carried out in, and consequently influenced by, its social context.[9]

Many other terms are often grouped together under the banner of science. For example, mathematics may be viewed as the language of science. Technology and medicine are frequently considered as applications of pure science, and engineering is often regarded as the link between pure science and technology.[10] In recognition of this problem, acronyms such as S&T (Science and Technology), SME (Science, Mathematics, and Engineering), S&E (Science and Engineering), and SET (Science, Engineering, and Technology) are used to describe more accurately or to group together science-related endeavors.

There has been much discussion in the literature about the exact definition of science; in most instances the word "science" has, either explicitly or implicitly, taken on a much broader contemporary meaning than just "pure science."[11] Most of the arguments in support of scientific literacy and most of the assessments of its level include aspects of at least medicine and technology.[12] **In the context of science communication, science is deemed to include "pure science"** (as defined above), **mathematics, statistics, engineering, technology, medicine, and related fields.**

Awareness

The simple dictionary definition of **awareness as being "conscious, not ignorant" of . . . something** is sufficient for the moment.[13] It is only when the word "awareness" is used to describe people's relationship to science that it develops much broader connotations.

Understanding

Defining the concept of understanding is not as straightforward as it would at first appear.[14] Specifically, the meaning of the word "understanding" cannot be equated to the simple dictionary definition of acceptance or consent.

Although there is little disagreement that understanding, in itself, is a good thing, there is evidence to suggest that under some social conditions people will deliberately choose ignorance.[15] For example, Gregory and Miller report the case where nuclear workers would rather trust their colleagues to provide a safe work environment than attempt to understand the health risks of alpha, beta and gamma radiation themselves.[16]

Understanding is not a binary condition, something that you either have or you don't have,[17] but rather **a developing comprehension of both the meaning and implications of some knowledge, action or process based on appropriate commonly accepted principles**. For scientific understanding, the appropriate commonly accepted principles would be science's theories, laws, and processes identified in the science section together with some appreciation of their ramifications.

Communication

A large portion of this paper could be devoted to discussing and defining the single word "communication." Numerous communication models have been proposed over the years, but each of these models was based on slightly different assumptions about, or definitions of, communication.[18] A subset of these has been applied, with mixed results, to the communication of science.[19] What is clear is that any communication that involves the general public is complex and highly contextual. Simple linear models (transfer of information from sender to receiver via a medium) and diffusion models (disperse the information widely and let it soak in) do not adequately represent the science communication process. More recent models recognize the importance of context and social negotiation of meaning, and have been more successful in explaining the complexities of communication.[20]

Schirato and Yell (1997) propose a definition based on this point of view. They simply define **communication as ". . . the practice of producing and negotiating meanings, a practice which always takes place under specific social, cultural and political conditions."**[21] The following terms are actually labels for established fields. As such, their meaning is defined, not so much by the definition of their component words, but by the aims of the field that they represent.

Public Awareness of Science (PAS)

Learning about science can occur in either formal or informal settings.[22] Science education at primary, secondary, and tertiary institutions is the usual formal setting, while informal settings are commonly grouped under the label of either "public awareness of science" or "public understanding of science."

Gilbert, Stocklmayer, and Garnett (1999) defined the **public awareness of science (PAS) as a set of positive attitudes toward science (and technology) that are evidenced by a series of skills and behavioral intentions**. But PAS does not stop there:

> The skills of accessing scientific and technological knowledge and a sense of ownership of that knowledge will impart a confidence to explore its ramifications. This will lead, at some time, to an understanding of key ideas/products and how they came about, to an

> evaluation of the status of scientific and technological knowledge and its significance for personal, social and economic life.[23]

On occasions, the term "public awareness of science" has been used as a synonym for "public understanding of science." Their aims are similar and their boundaries do overlap, but PAS is predominantly about *attitudes* toward science. PAS may be regarded as a prerequisite—in fact, a fundamental component—of PUS and scientific literacy.

Public Understanding of Science (PUS)

A clear definition of public understanding of science is useful because, as Wynne remarked, "public understanding of science (PUS) is a wide and ill-defined area involving several different disciplinary perspectives."[24]

The House of Lords' "Science and Society" report defined the public understanding of science in general terms as the:

> . . . understanding of scientific matters by non-experts. This cannot of course mean a comprehensive knowledge of all branches of science. It may however include understanding of the nature of scientific methods . . . awareness of current scientific advances and their implications. Public understanding of science has become a shorthand term for all forms of outreach (in the UK) by the scientific community, or by others on their behalf (e.g., science writers, museums, event organisers), to the public at large, aimed at improving that understanding.[25]

In the context of science education, Millar proposed three aspects of an understanding of science that may be generalized to concisely define **the public understanding of science as:**[26]

1. "Understanding of science *content*, or substantive scientific knowledge (known as *content*).[27]
2. Understanding of the *methods of enquiry* (so-called *process*).[28]
3. **Understanding of *science as a social enterprise***." (Awareness of the impact of science on individuals and society; an extensive dimension summarized by the label of *social factors*).[29]

Jenkins uses the terms *conceptual*, *procedural*, and *affective* to describe comparable aspects, while Paisley identifies a similar list of prerequisites for scientific literacy.[30]

Scientific Literacy (SL)

> The interpretation of scientific literacy has changed somewhat over the years, moving from the ability to read and comprehend science-related articles to its present emphasis on understanding and applying scientific principles to everyday life. Although the meaning of the term scientific literacy is sometimes not clear, this condition is due to its complex and dynamic nature rather than to a lack of definition.[31]

Early definitions of scientific literacy tended to prescribe extensive lists of skills or attitudes. In 1975, Shen proposed three broad categories.[32]

1. *Practical scientific literacy,* is scientific knowledge that can be applied to help solve practical problems. (Maienschein et al. called this *science literacy.*)[33]
2. *Civic scientific literacy* enables a citizen ". . . to become more aware of science and science-related issues so that he and his representatives would not shy away from

bringing their common sense to bear upon such issues and thus participate more fully in the democratic processes of an increasingly technological society."[34]

3. *Cultural scientific literacy,* is an appreciation of science as a major human achievement, ". . . arguably the greatest achievement of our culture."[35]

Miller built on this thesis and developed his earlier research to propose that *civic* scientific literacy (category 2 above) ". . . should be conceptualized as involving three related dimensions:

(a) a vocabulary of basic scientific constructs sufficient to read competing news stories in a newspaper or magazine (*content*)
(b) an understanding of the process or nature of scientific inquiry (*process*)
(c) some level of understanding of the impact of science and technology on individuals and on society." (*social factors*)[36]

Miller, Durant and others have used an assessment of content and process dimensions to estimate the extent of public scientific literacy in many countries around the world.[37] These ideas developed into contemporary holistic definitions of scientific literacy such as Hacking, Goodrum, and Rennie's (below), which more broadly describe scientific literacy in terms of interrelated contexts, skills, and "ways of thinking" and acting.

> **Fundamental to the ideal picture is the belief that developing scientific literacy should be the focus of science education in the compulsory years of schooling. Scientific literacy is a high priority for all citizens, helping them to be interested in and understand the world around them, to engage in the discourses of and about science, to be skeptical and questioning of claims made by others about scientific matters, to be able to identify questions, investigate and draw evidence-based conclusions, and to make informed decisions about the environment and their own health and well-being.**[38]

This definition was selected because it highlights that, while universal high levels of scientific literacy are not currently achievable in practice (it is an "ideal"), it is nevertheless a valid and critically important *goal* for modern society.

There are many other definitions of scientific literacy in the literature. Maienschein et al. critically reviewed definitions from the American Association for the Advancement of Science (AAAS), the National Academy of Sciences (NAS) and the National Science Foundation (NSF), and Popli compared the AAAS definition to others from Iran and India.[39] They found that the definitions shared very similar basic ideals but, due to differences in national interests and cultures, had slightly different contextual emphases. (See also Laughsch for a more detailed overview of scientific literacy.)[40]

Scientific Culture (SC)

The term "scientific culture" has been used in many different ways. For example:

1. Scientific culture may be considered as the set of ". . . values, and ethos, practices, methods and attitudes based on universalism, logical reasoning, organized scepticism and tentativeness of empirical results" that exist *within the scientific/academic community*.[41]
2. Researchers Godin and Gingras proposed that ". . . scientific and technological culture is the expression of all modes through which individuals and society appropriate science and technology."[42] The preceding definition of scientific culture as a value system

belonging exclusively to scientists and academics (sub-groups within society), is a striking contrast to this denotation that depicts scientific culture as the means by which *any member of society* may access science and technology.

3. Most European nations use the words "scientific culture" (culture scientifique) to describe a field known in the UK as "public understanding of science" and USA as "scientific literacy."[43] There is, however, an important additional emphasis on the cultural environment in which science and the society interact. **Scientific culture is an integrated societal value system that appreciates and promotes science, *per se*, and widespread scientific literacy, as important pursuits.**

Although the first two versions are helpful in exploring the breadth of the topic, it is proposed that the third definition of scientific culture represents the most generally accepted and useful interpretation of the term. Australia's chief scientist, Dr. Robin Batterham, described scientific culture in Australia as needing to be ". . . a transparent framework of public support within which (science and innovation) can flourish. Public awareness and involvement in SET are important."[44]

3. Science and society: where does science communication fit in?

Around the world there is a growing recognition that the relationship between science and the public is at a critical phase.[45] During the next few years the choices made, either deliberately or by inaction, will deeply affect the future both of science and society:

> On one hand, there has never been a time when the issues involving science were more exciting, the public more interested, or the opportunities more apparent. On the other hand, public confidence in scientific advice to the (UK) government has been rocked by a series of events . . . and many people are deeply uneasy about the huge opportunities presented by areas of science . . . which seem to be advancing far ahead of their awareness and assent.[46]

In addition, surveys suggest that the public does not know much about science, and it appears that scientists don't know much about the public.[47] Recent surveys indicate continued high levels of interest *in* science but continuing low levels of assessable understanding *of* science.[48] This is in spite of extensive government-supported science promotion and education programs, especially in the USA and UK.

Together, the name "public understanding of science," and the interpretation of early surveys of scientific literacy resulted in the so-called *deficit model* of public understanding of science.[49] This model characterized the public as having inadequate knowledge, and science as having all the required knowledge. Critics have pointed out that surveys, which identify the public as being deficient in scientific knowledge, may not adequately address the true complexity of the issue.[50]

For example, do the polls indicate widespread scientific illiteracy or do they really just capture the public's ambivalence to science (or at least to the aspects of science that were assessed)? Is it realistic to test the public's knowledge of scientific facts?[51] If so, which ones? How able are survey questions, particularly multiple choice questions, to capture the public's true knowledge of and attitudes toward science? Why should the public be expected to be more literate in scientific matters than others; for example politics, art, music or literature?[52] And how do social and cultural factors influence the results?[53]

About a decade ago studies by Wynne, Irwin, Latour, Collins, and Pinch, Jenkins, Layton, Yearley, McGill, and Davey promoted a new model that became known as the *contextual approach*:[54]

> The deficit model is asymmetrical: it depicts communication as a one-way flow from science to its publics . . . (whereas) The contextual model explores the ramifications of its very different root metaphor; the interaction between science and its publics. In consequence, the contextual model is symmetrical: It depicts communication as a two-way flow between science and its publics. The contextual model implies an active public: it requires a rhetoric of reconstruction in which public understanding is the joint creation of scientific and local knowledge . . . In this model, communication is not solely cognitive; ethical and political concerns are always relevant.[55]

In the UK, the title of the House of Lords report, “Science and Society”, is being promoted to replace the PUS label and identify that nation’s commitment to the contextual approach.[56] The aim is for science and society to start working together in ways that are positive, inclusive, and productive. Science communication is a vital part of that process.

4. Science communication: a contemporary definition

It is apparent that, while the terms public awareness of science, public understanding of science, scientific literacy, and scientific culture should not be used interchangeably, considerable commonality does exist between them. They have broadly compatible aims but different philosophies, approaches and emphases. In essence:

- Public awareness of science aims to stimulate *awareness* of, and positive attitudes (or *opinions*) towards science.
- Public understanding of science, as the name suggests, focuses on *understanding* science: its content, processes, and social factors.
- Scientific literacy is the ideal situation where people are *aware* of, *interested* and *involved* in, form *opinions* about, and seek to *understand* science.
- Scientific culture is a society-wide environment that appreciates and supports science and scientific literacy. It has important *social* and *aesthetic* (affective) aspects.

The aims of scientific awareness, understanding, literacy, and culture may be distilled into five broad *personal* responses to science. If sufficient people exhibit these responses, then they may be considered as applying to *the public*. These personal responses may be grouped under the label AEIOU (the vowel analogy): **A**wareness of science; **E**njoyment or other affective responses to science; **I**nterest in science; the forming, reforming or confirming of science-related **O**pinions (or attitudes); and **U**nderstanding of science. **The vowel analogy—AEIOU—is a concise label that personalizes the impersonal aims of scientific awareness, understanding, literacy and culture, and thereby defines the purpose of science communication.**

To date, science communication has not been clearly defined. “Science communication is typically thought of as the activities of professional communicators (journalists, public information officers, scientists themselves)” or simply as “. . . the promotion of the public understanding of science . . .”[57]

The 2000 report “Science and the public: A review of science communication and public attitudes to science in Britain” defines science communication as a term that “encompasses communication between:

- groups within the scientific community, including those in academia and industry
- the scientific community and the media
- the scientific community and the public

- the scientific community and government, or others in positions of power and/or authority
- the scientific community and government, or others who influence policy
- industry and the public
- the media (including museums and science centres) and the public
- the government and the public."[58]

This definition is useful in that it identifies the important participants in science communication, however it is lacking in that it is descriptive only. It does not address the how or why of science communication. It is deficient in the same way as, for example, the hypothetical person who defines teaching as "what teachers do." The definitions aren't wrong; they just don't extend understanding.

Bryant elegantly defined science communication as ". . . the processes by which the culture and knowledge of science are absorbed into the culture of the wider community."[59] The strength of this denotation is that it identifies the intangible cultural aspects of science communication. It also identifies science communication as a continual process, rather than a one-off, linear activity.

Some care is required though. Undoubtedly science communication is a process; however it is not *just* a process. It should never be done for its own sake, in an ad hoc or inappropriate manner. For science communication to be effective—*in fact, to allow any valid assessment of its effectiveness*—it must always have predetermined and appropriate aims.

Figure 1 provides a definition of science communication that builds on the preceding discussion and related definitions.

As an area of study, science communication has a short history. Although its boundaries within the general field of scientific literacy and with other disciplines are often quite indistinct, it is nevertheless an identifiable and vitally important area of practice and research.

SCIENCE COMMUNICATION (SciCom) may be defined as the use of appropriate skills, media, activities, and dialogue to produce one or more of the following personal responses to science (the vowel analogy)

Awareness, including familiarity with new aspects of science

Enjoyment or other affective responses, e.g. appreciating science as entertainment or art

Interest, as evidenced by voluntary involvement with science or its communication

Opinions, the forming, reforming, or confirming of science-related attitudes

Understanding of science, its content, processes, and social factors

Science communication may involve science practitioners, mediators, and other members of the general public, either peer-to-peer or between groups.

Figure 1. The AEIOU definition of science communication. This definition clarifies the purpose and characteristics of science communication and provides a basis for evaluating its effectiveness

5. Focusing on science communication

The following sections illustrate and examine the proposed definition in greater detail.

Modelling science communication: a mountain-climbing analogy

"... an analogue to 'You are what you eat,' is 'You know what you display.'"[60]

How then can science communication be modeled, or displayed?

The "two stage" representation or the classical "canonical account" are currently the most widely accepted pictorial representations of science communication.[61] These models have two circles: one representing scientists and the other the public. (The canonical account has a third circle labeled "media.") The arrow connecting the scientists to the public (via media) represents science communication and is carried out by specialists known as mediators, science communicators, or the media.

These models appear simple and robust, however they are unsuitable because they are based on outdated linear communication models. Science communication is implicitly defined as a transfer process from scientist to public (via media). This is a significant impediment to effective science communication within the contextual model of science and society.

In the context of formal science education, Koballa, Kemp, and Evans proposed a model of an individual's scientific literacy that could be visualized as a landscape of mountain-like peaks and valley-like troughs on a three-dimensional x-y-z axis. The position of the peak along the y horizontal axis indicated the *domain* or area of literacy, for example knowledge about the physical sciences, earth sciences, or the history of science. The height of the peak in the vertical, z direction represents the *level* of personal achievement within that domain, the higher the peak the greater the literacy in that particular domain. The depth of the peak (ie the x dimension in the x-y horizontal plane) reflected the *value* that the person associated with the domain; a very broad base would indicate that a particular domain was very important to a certain individual.[62]

A simple holistic model that identifies the essential characteristics of science communication is proposed. It shares some of the Koballa et al., "3-dimensional landscape of scientific literacy," however the analogy presented here depicts a much wider field, which includes informal learning contexts. There are significant differences between the two analogies. Figure 2 attempts to visualise the 'big picture' of science and society.

Without being overly simplistic or trying to wring too much from the mountain-climbing analogy, the following points should be considered.

Developing literacy in one particular area of science may be likened to climbing a mountain. It is dynamic, participatory, and it inevitably changes the participant's view of the world. This climbing process is facilitated by science communication. Appropriate skills, media, activities, and dialogue are used to improve *individuals'* awareness, enjoyment, interest, opinions, or understanding (AEIOU) of science. When viewed at the *public* level, this is equivalent to moving upward through the continuum of public awareness of science, public understanding of science, and scientific literacy shown in figure 2.

It is necessary to address the following common misconceptions:

1. Science communication will not always cause an immediate increase in scientific literacy. Many participants will experience an increased interest in, or a change of attitude toward, science that may at some later time lead to enhanced scientific literacy.[64]
2. It is often incorrectly assumed that science communication is *solely* for the benefit of

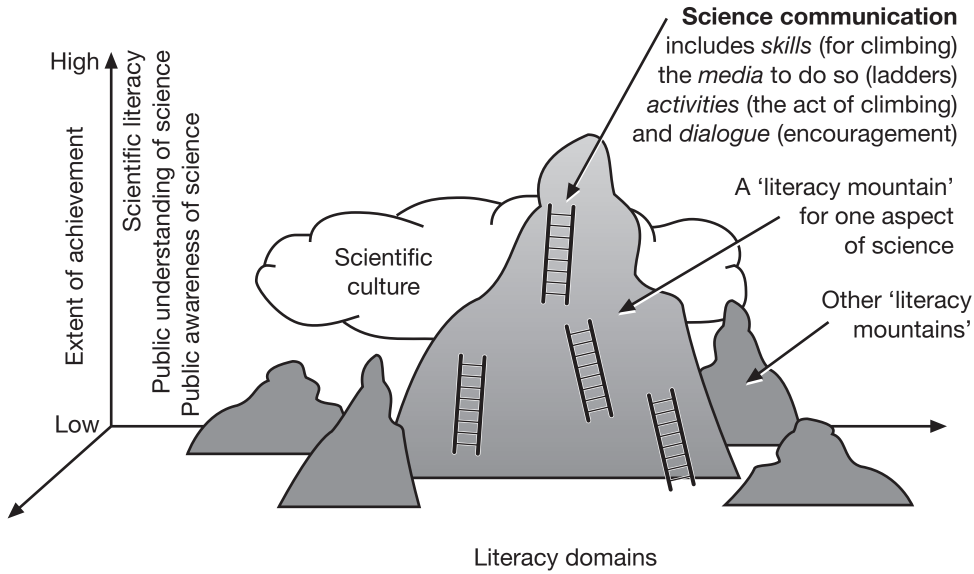

Figure 2. A mountain-climbing analogy. A unifying structure that fits public awareness of science, public understanding of science, scientific culture, scientific literacy and science communication together into one big picture of science and society[63]

the lay-public, but this is not the case. Science practitioners and mediators, as well as other science-related groups including scientific businesses, politicians, decision-makers, and members of the media, may benefit from using the tools of science communication to share scientific messages. Furthermore, the need to explain complex issues in lay terms can lead to new perspectives on a topic and a deeper understanding of the field by the professional.

3. Science is actually an expansive mountain range (i.e., multiple literacy's), not a single peak. There are many different areas of S&T as well as other cultural literacy's scattered across the horizontal plane of domains, and each one could be considered a mountain in its own right. For example Paisley identified at least 44 major topical literacy's in US journals and popular media covering such areas as business, computers, health, information, media, politics, religion and technology.[65]
4. A person's mountain range profile (the extent of literacy, in a variety of domains) is unique but will change over time as the individual ". . . learns, or forgets science skills and knowledge, or comes to value different areas in new ways."[66]
5. Scientists are not at the top of the mountain and the lay public at the bottom. While some scientists may be at the top of one or two mountains, they will be at the foot of many more. "Indeed, given the current state of scientific specialization, ignorance about a particular domain of science is almost as great among scientists working in another domain as it is among lay people."[67] All people are somewhere between a plain and a peak.

Public awareness of science begins the scientific literacy ascent. The awareness that a mountain (a scientific domain) exists may lead to the subsequent adoption of the skills and methods required to ascend it.[68] Public understanding of science is the consequence of individuals (and therefore the society of which the individuals comprise), building on their awareness of science to achieve higher levels of comprehension and application of scientific matters.

The summit of *scientific literacy* is a very high objective. The proposition that relatively few people will achieve it in practice, has been the source of criticism of scientific literacy.[69] In society (i.e., outside the specific context of formal education), scientific literacy may be considered as people's mean altitude—the extent to which they have achieved literacy—within the science mountain range. By this measure, some level of scientific literacy is achievable for all people.

Scientific culture (depicted by the cloud) is the all-encompassing atmosphere that motivates and sustains climbers, like Koballa's third dimension of "values."[70] Without this vital atmosphere of scientific culture, people would find it socially, politically, or personally unacceptable to begin to climb. Even if they did commence an ascent, without the support of scientific culture, their journey would be stalled in the same way that smoke or pollution in the air may halt a real climber. Scientific culture makes climbing (increased involvement in science) valuable and worthy of the required effort.

Science communicators (mediators) may be thought of as the mountain guides. They teach people how to climb (skills), provide ladders (media), assist with the actual climbing event (activities), and keep climbers informed about progress, possible dangers, and other issues related to the climb (dialogue).

Ladders and science communication work in two ways, for ascent and descent. This is not to suggest that science communication can be used to reduce a person's scientific literacy, rather it allows access between people at different levels. Scientists, mediators and other groups with higher levels of scientific literacy are able to learn something from groups at lower levels of scientific literacy. Many scientists, including such famous identities as Einstein and Feynman, have acknowledged the benefits *to scientists* of communicating their work with the public. This sharing of knowledge may develop the scientists' communication skills, clarify their understanding, and provide useful feedback and a fresh perspective on various issues. There are, of course, similar benefits to science practitioners when they use science communication with their peers.

Once one mountain has been tackled, even if the summit was not reached (i.e., there was an increase in scientific awareness, in some aspect of science), the prospect of climbing the next peak is not as difficult; the climber may even find the experience enjoyable.

The science communication tool kit

The proposed definition identifies skills, media, activities, and dialogue as enabling the processes of science communication. They may be thought of as the tools of science communication.

Skills. Various personal skills are the intangible basis of science communication. The skills may directly relate to communicating science at an interpersonal or public level, or more indirectly applied to designing, organizing or facilitating science activities.

An increasing number of science communication courses are being offered at various centers around the world.[71] While many of these courses focus on science journalism, others teach a broader range of skills that enable science workers to communicate more effectively with each other and with the general public. For example, Australia's most well known qualification in science communication, the Graduate Diploma in Scientific Communication from the Australian National University (ANU), selects science graduates and provides them with training and experience in theoretical and practical aspects of science communication.

The program provides extensive opportunities to develop and refine science communication skills. Practical work includes presenting science shows and interactive displays across Australia with the Shell-Questacon Science Circus; working with the public in media and museum situations; and developing organizational, teamwork, administrative, financial, design, and construction skills.

Media and activities. A wide variety of media and activities are necessary to cater for the large range of personalities, learning styles, social and educational backgrounds that people bring to their experience with science. Although the following list is far from comprehensive, it gives a broad overview of some common approaches. Examples of formal science communication which, like formal learning, "... typically are well structured, compulsory, assessed, planned, and solitary" include:[72]

- Science education at schools, colleges, and universities that may include lectures, tutorials, workshops, laboratory sessions and other learning activities
- Accredited courses and training programs
- Academic and professional conferences, presentations, and seminars
- Production of science textbooks and distance education materials

Examples of informal science communication which "... are more often voluntary, non-assessed, accidental, and social" include:[73]

- Science centers and museums
- Media programs or coverage on film, television, radio, or in print
- Community or Internet forums on scientific topics
- Science groups, clubs and societies
- Computer-based activities on CD-ROM, DVD, or WWW
- Science shows and theatre
- Open days at universities and research organizations
- Popular science books and magazines
- Community or school-based involvement in collecting research data
- Science competitions, events and festivals

Dialogue. In spite of the prevailing bias toward presenting science *to* the public, science communication as defined here cannot be considered as a one-way dissemination of information to the lay public. Modern science communication is part of the contextual approach that "... sees the generation of new public knowledge about science much more (as) a dialogue in which, while scientists may have the scientific facts at their disposal, the members of the public concerned have local knowledge of, and interest in, the problems to be solved."[74]

All science practitioners are challenged to be science communicators and to enter into dialogue with their peers, with the public, and with mediators. However, in doing so, it is important to realize:

- There is a critical need for feedback in any effective communication. Even television and radio, that have been modeled as simple linear communication processes, are affected by feedback in the form of audience ratings.[75]
- There is a possible change of meaning with a change of context.
- Clear, consistent, appropriate and interactive dialogue is required. The use of jargon and other exclusive practices must be avoided.

- Effective science communication may provide one or more of the AEIOU responses for each of the participants including students, members of the public, industry, business or government *but also* the science practitioners and mediators.

The proposed definition of communication stressed the importance of “meaning making” (or “negotiating meaning”). This does not indicate that the facts of science are somehow made less certain. What is indicated is that the personal significance of these facts is influenced by the social, cultural and political conditions in which they were produced and promoted. Science facts, without social significance are essentially meaningless and useless to society. It is therefore critical to actively involve all participants in science communication and to frame their interactions in a meaningful context.

Science communication’s AEIOU participant responses

The AEIOU responses (the vowel analogy) of science communication that are discussed briefly in the following sections are not hierarchical prerequisites for scientific literacy but rather a continuum of desirable personal reactions to science communication.

A is for awareness. In his “Chance for Change” discussion paper, Batterham pointed out that”:

> Awareness and demonstration of relevance are responsibilities of all in the SET base. It is only through constructive and continuous communication between science and the community that these positive attitudes can be maintained.[76]

The significance of awareness should never be underestimated. By definition, awareness is the lack of ignorance, and enlightenment in almost any field is generally accepted as a good thing. For science, it provides the foundations of knowledge, broadens the mind and opens up personal and public opportunities that did not previously exist.

In the context of science museums, Jesse Shore wisely designs interactive exhibits to cater for three types of awareness:

> When selecting and structuring exhibit content I consider what will attract and involve visitors who are *uninformed* or disinterested in the overall subject (the lay public). At the same time I seek ways to maintain interest of those who are *informed* (interested public) or even *specialists* (attentive public) in the material.
>
> I view uninformed people as those *who don’t know what they don’t know* about a given subject. The challenge is to make them aware that a subject exists and has an effect on their lives and that they can choose to learn more about it.
>
> The informed are those *who know what they don’t know* and actively make choices about when to expand their level of knowledge on the subject.
>
> The specialists *know*. They are likely to have greater familiarity and detailed knowledge of the subject then the exhibition developer.
>
> The goal is to identify and communicate the fundamentals of the subject which are relevant to the *uninformed*, have enough variety to intrigue the *informed* and reinterpret the content with freshness and humor to surprise and entertain the *specialists*. (original emphasis)[77]

The level of awareness ranges from simply exposing participants to some new aspect of science, to inspiring them to attain higher levels of scientific literacy or engaging in further science communication events.

E is for enjoyment. Enjoying science? Is this, in itself, a worthwhile result for science communication?

Yes!

Enjoyment and other affective responses may evoke positive feelings and attitudes that may lead to subsequent, deeper encounters with science. "The idea that an experience is 'just fun,' which is so often denigrated by those in the PUS domain can, in fact, have powerful (learning) consequences if followed by further positive experiences."[78] Thus, enjoyment is a highly desirable component of all science communication. It also contributes to a healthy scientific culture within society.

Enjoyment of science may occur at two broad levels:

1. At a superficial—but nevertheless important—level, enjoyment may be described as a pleasurable experience with science as a form of entertainment or art. This may occur at science shows (live science demonstrations or theatre) and during brief visits to science centers and museums.
2. A deeper level of personal involvement and satisfaction is usually derived from discovering, exploring, presenting or resolving science-related matters. Examples include reading a popular science book, participating in school or community-based scientific contests and events, and protracted or repeat visits to science centers and museums.

Understanding rarely, if ever, occurs without motivation to learn, and enjoyment (an affective response) and interest (a cognitive response) are very powerful motivators. "The importance of the cognitive and affective is widely recognized in informal learning circles. Positive experiences, enjoyment and interest are recognized as valid learning outcomes of, for example, a museum visit."[79]

I is for interest. The definition of science communication proposed in this paper does not directly specify education as one of its outcomes. Instead, it suggests that science communication may be effective if it inspires as does reading a great book, entertains as listening to a fine piece of music, or involves and enthuses like a favorite sport. Whereas SL, PUS, and to a lesser extent PAS are more focused on informational or educational outcomes, science communication uses various approaches to produce a diverse range of participant responses. One of the most important is interest.

Jenkins proposed interest as a possible fourth dimension of public understanding of science.[80] In 1995, the editor of *Nature* suggested that ". . . the experience of the last decade has shown that the practical purpose of public understanding is to give young people an enthusiasm for science."[81] These references reflect the general agreement that interest in science is an altogether reasonable result of science communication. Innovative and appropriate science communication activities may tap participants' personal interest or spark situational interest that may, in turn, enhance their recall and understanding of the event.[82] Even if this does not occur, a positive increase in interest in science will contribute to an improved scientific culture.

National and international surveys indicate a strong public interest in science, technology and particularly medical science.[83] The challenge for science communication is to develop and channel new or pre-existing interest in science into practical outcomes that are useful for individuals and society.

A person's voluntary involvement or re-involvement with science is a strong indicator of his or her interest. (In fact, the importance of volunteers and interested supporters, in any endeavor, should never be underestimated.)

A university colleague who frequently organizes public science communication events summarized this argument nicely: “The fact that some of today’s audience may not have learned anything from our presentation doesn’t worry me in the slightest. If we’ve done a professional job and interested them enough to enroll at university, then we have three years to teach them science!”[84]

O is for opinion. A person’s attitude or opinion is very complex, personal, and multifaceted. Opinions are strongly linked with, and influenced by, knowledge, beliefs, and emotional reactions and consequently may be quite difficult to study.[85] Evans and Durrant (1995) suggested that “interest in science may well be a stronger predictor of attitudes than is scientific understanding.”[86]

The method by which personal opinions develop and evolve can be likened to Steve Alsop’s Informal Conceptual Change Model (ICCM) for learning. Alsop proposed that “. . . conceptual change depends on the learners’ current conceptions . . . as well as their cognitive, affective, and conative, epistemological commitments.”[87] In a similar manner, the mechanism by which people alter their opinions may be influenced by their personal beliefs and understanding of the issue in question. They will modify their opinions—move from some initial to revised position—only if motivated to do so by the need to change.

The need to revise one’s opinion could occur:

- If the person’s understanding (cf. ICCM cognition dimension) is challenged. Alsop suggests that in the ICC model this may occur if the person becomes dissatisfied with his or her existing knowledge and it is intelligible, plausible and fruitful to change to the alternative.
- Similarly, a change of opinion may occur if there are relevant, outstanding or appealing challenges to the person’s beliefs (cf. ICCM affective dimension).
- There may be reasons to revise the opinion itself (cf. ICCM conative dimension) if the alternative view is useful, trustworthy or enhances the individual’s influence or control of the situation.[88]

Science communication is most powerful when it causes participants to reflect on, and form, reform or affirm their attitudes to science and society.

U is for understanding. Much has already been said about understanding. To recapitulate briefly, understanding of science includes comprehension of science content, processes, and social factors. It is a prerequisite for higher levels of scientific literacy and, particularly within the context of science communication, emphasizes applications and implications of science.

6. Conclusion

Science communication has a vital part to play in modern society. It is not just about producing attractive science events. Many science communication outcomes are long-term or of a personal nature, and are therefore difficult to recognize and assess. The proposed definition identifies AEIOU (Awareness, Enjoyment, Interest, Opinion-forming, and Understanding of science) as important personal responses to science communication.

Science communication aims to enhance public scientific awareness, understanding, literacy, and culture by building AEIOU responses in its participants. It empowers the public to attain “. . . an interest in science, a confidence to talk about it, and a willingness to engage with science wherever and whenever it crosses their paths."[89] Science communication also provides skills, media, activities, and dialogue to enable the general public, mediators, and science practitioners to interact with each other more effectively.

Science communication is a significant field of enterprise worthy of ongoing practice and research.

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