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The Meaning of Scientific Literacy: A Model of Relevance in Science Education

Introduction

The term 'scientific literacy' has been used in the literature for more than four decades (Gallagher & Harsch, 1997), although not always with the same meaning (Bybee, 1997). It is a simple term and its major advantage is that it sums up, at the school level, the intentions of science education. The term scientific literacy avoids the use of distracting detail and, as such, convincingly portrays a complex idea which intuitively appears to be correct (Baumert, 1997). Baumert recognises that the core of the idea behind scientific literacy lies in its analogy with literacy.

Many definitions have been put forward for scientific literacy since Paul deHard Hurd used the term in 1958 (American Association for the Advancement of Science [AAAS], 1989; Bybee, 1997; Gräber et al., 2001; Holbrook & Rannikmae, 1997; Hurd, 1958; Laugksch, 2000; National Science Education Standards [NSES], 1996; Organisation for Economic Cooperation and Development [OECD], 2003; 2007). There is confusion as to its exact meaning; Norris and Philips (2003) contend that the term scientific literacy has been used to include various components from the following:

(a) Knowledge of the substantive content of science and the ability to distinguish from non-science;

(b) Understanding science and its applications;

(c) Knowledge of what counts as science;

(d) Independence in learning science;

(e) Ability to think scientifically;

(f) Ability to use scientific knowledge in problem solving;

(g) Knowledge needed for intelligent participation in science-based issues;

(h) Understanding the nature of science, including its relationship with culture;

(i) Appreciation of and comfort with science, including its wonder and curiosity;

(j) Knowledge of the risks and benefits of science; and

(k) Ability to think critically about science and to deal with scientific expertise.

They cite references to illustrate this. The confusion as to a precise meaning has led to a call to remove

such a term as a goal for school science education (Fensham, 2008). Yet the OECD sets out to determine scientific literacy for future adult life through a longitudinal international study (OECD, 2007), although this has been criticised, not least because its measures are through written tests and questionnaires, which generally show developing countries to be in poor shape to meet such a goal.

In this paper it is suggested that retaining the use of scientific literacy is still appropriate, but it is necessary to relate scientific literacy to an appreciation of the nature of science, personal learning attributes including attitudes and also to the development of social values (Holbrook & Rannikmae, 2007). For this, relevance of the learning plays a role and teaching materials, striving toward student enhancement of scientific literacy, need to consider a societal frame, introduction of conceptual science on a need to know basis, and to embrace the socioscientific situation that provides the relevance for responsible citizenship (Holbrook, 2008).

It is extremely difficult to give clarity of meaning to either the term *scientific literacy*, or *scientific and technological literacy* (a term used in recognition of the relationship between science and technology in everyday life). This is especially the case when translating the term into languages other than English. A forum on scientific and technological literacy for all (UNESCO, 1993) suggested the French term as "*la culture scientifique et techn*ologique," a translation that clearly reflects the cultural intention and points the way towards recognizing that a person who is scientifically and technologically literate is a person who can function within society as a whole, rather than simply as a scientist in the workplace.

As part of the Science-Technology-Society (STS) movement, the NSTA (1991) suggested that a scientifically and technologically literate person needs intellectual capability but that other attributes are also important. The components put forward were (subdivisions added by the authors for clarity):

Intellectual (Higher Order Thinking Skills)

1. uses concepts of science and of technology, as well as an informed reflection of ethical values, in solving everyday problems and making responsible decisions in everyday life, including work and leisure;

2. locates, collects, analyses, and evaluates sources of scientific and technological information and uses these sources in solving problems, making decisions, and taking actions;

3. distinguishes between scientific and technological evidence and personal opinion and between reliable and unreliable information;

4. offers explanations of natural phenomena testable for their validity;

5. applies skepticism, careful methods, logical reasoning, and creativity in investigating the observable universe;

6. defends decisions and actions using rational argument based on evidence;and

7. analyses interactions among science, technology and society.

Attitudinal

8. displays curiosity about the natural and human-made world;

9. values scientific research and technological problem solving;

10. remains open to new evidence and the tentativeness of scientific/technological knowledge; and

11. engages in science/technology for excitement and possible explanations.

Societal

12. recognizes that science and technology are human endeavours;

13. weighs the benefits/burdens of scientific and technological development;

14. recognizes the strengths and limitations of science and technology for advancing human welfare; and

15. engages in responsible personal and civic actions after weighing the possible consequences of alternative options.

Interdisciplinary

16. connects science and technology to other human endeavours e.g. history, mathematics, the arts, and the humanities; and

17. considers the political, economic, moral and ethical aspects of science and technology as they relate to personal and global issues.

However there are many who see scientific literacy aligned with ‘knowing science’, limited to the intellectual components expressed above, and this view is particularly prevalent on the internet. Even major projects such as Project 2061 (AAAS, 1993) try to spell out the science *content* that students should know, even though they recognise that science (and technology) are evolving at a faster and faster pace and content is prone to becoming obsolete. Millar (1997), in suggesting that civic scientific literacy – considered as the level of understanding of science and technology needed to function as a citizen – is important, puts forward data to suggest that the amount of basic school science is the strongest predictor of civic scientific literacy in adults.

Whatever the actual definition, there is, it seems, general agreement that the term ‘scientific literacy’ is used somewhat metaphorically. It thus goes beyond any notion of reading and writing, and few would claim that it refers simply to the ability to read scientific journals (Hand, 1999; Klein, 2006). The metaphorical use tends to turn scientific literacy into a slogan, meaning all things to all people, but it does serve to indicate the intentions of science education. As such, the goal of science education can be expressed as scientific, or scientific and technological, literacy (ICASE, 2003; Norris & Philips, 2003).

Scientific Literacy – Two Views

While agreement on the meaning of scientific literacy, beyond the metaphorical use, is much less universal, there seems to be two major camps, or points of view:

a) those that advocate a central role for the knowledge of science; and

b) those who see scientific literacy referring to a society usefulness.

The first camp seems to be very prevalent among science teachers today. It builds on the notion that there are ‘fundamental ideas’ in science that are essential and that there is content of science which is a crucial component of scientific literacy. It has been described as a short term view (Maienschein, 1998) of knowing science and even labelled as “science literacy” to distinguish it from a longer term view of “scientific literacy”. The term science literacy, however, is not common, and for the most part it seems to be a play on words.

The second camp encompasses the longer term view and sees scientific literacy as a requirement to be able to adapt to the challenges of a rapidly changing world. This focus sees scientific literacy align with the development of life skills (Rychen & Salganik, 2003). It recognizes the need for reasoning skills in a social context, and above all, this view recognizes that scientific literacy is for all, having little to do with science teaching solely focusing on a career in science, or providing only an academic science background for specialisation in science. In fact, it is contended that the second view refutes the need for two types of school science courses – one for general education and another for specialists – and recognises that a specialist course is simply an extension of the former with an increase of “time on task” – that is, more science lessons, which will give time for more in-depth investigation.

Between these two camps, Gräber et al. (2001) see a continuum of views that stretch between the two extremes of subject competence and meta-competence. Whereas Bybee (1997) proposed a comprehensive hierarchical model still very much driven by the discipline of science, a more central position can be taken in which subject competence is important, but is propagated by general competences within education, and this is strongly supported by Project 2061 (AAAS, 1993).

Figure 1: The Graber model for scientific literary

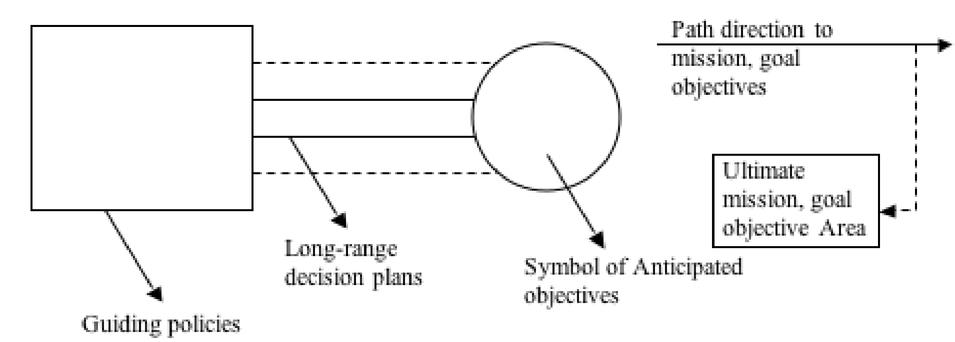


Fig. 1: Strategy as a vehicle (**Source:** Adeleke A., Ogundele O.J.K. & Oyenuga, O.O. (2003) *Business Policy and Strategy*. Lagos: Concept Publications).

A further intermediary view for scientific literacy sees the general aim as being oriented towards societal requirements, to learn how to deal with social issues and to make rationally founded decisions. Shamos (1995), however, doubts whether any definition of scientific literacy, which includes both wide and deep content knowledge and process competence, is possible. He sees scientific literacy far more in terms of promoting competent consumers of science with the ability to gain knowledge from experts as and when appropriate.

The Gräber model for scientific literacy (2001), illustrated in Figure 1, is put forward as competency-

based. The model reconsiders the balance between the various competencies and reflects on the specific contribution science education can make to the education of adults. This view upholds the need for scientific literacy to be far more than knowledge and integrates the component of values education as an essential component of science education (and although only an ethical component is mentioned, it can be seen to interrelate with human rights, tolerance, education for peace, gender equity, and the place of indigenous technologies). But it contrasts, perhaps, with ideas that point to a need for education, and especially science education, to play a strong role in the development of responsible citizens. In this area, scientific literacy would need to encompass socioscientific decision making skills (Holbrook, 1998; Holbrook & Rannikmae, 2007; UNESCO, 2003) as an area above and beyond scientific problem solving.

The Trend Towards Interpreting the Meaning of Scientific Literacy

The trend in defining scientific literacy is suggested as away from the short term product approach, in which the facts and skills are paramount, towards the inclusion of issue-based teaching, the need to go beyond scientific problem solving to encompass socioscientific decision making, and the recognition that scientific literacy relates to enabling citizens to effectively participate in the real world. The trend indicates a movement that gives less attention to scientific literacy being viewed as the possession of conceptual understanding of pure science abstract ideas and emphasises more the ability to make decisions related to the technological applications of scientific ideas or socioscientific issues facing society, these being recognized as crucial learning components. Shamos (1995) prefers the use of science awareness, rather than scientific literacy in this context. In this frame, biological literacy, chemical literacy or physical literacy are seen as non-existing entities and only the encompassing term, scientific literacy, is seen as meaningful.

The shift toward the long term view of scientific literacy does not mean that it is a single entity. At the school level, Bybee (1997) has suggested scientific literacy can be considered at four functional levels:

- nominal (can recognise scientific terms, but does not have a clear understanding of the meaning);

- functional (can use scientific and technological vocabulary, but usually this is only out of context as is the case for example in a school test of examination);

- conceptual and procedural (demonstrates understanding and a relationship between concepts and can use processes with meaning); and

- multidimensional (not only has understanding, but has developed perspectives of science and technology that include the nature of science, the role of science and technology in personal life and society).

It is clear that only the multidimensional level is the goal for the long term view of scientific literacy, and this is recognised by Bybee. While this breakdown of scientific literacy is perhaps meaningful for school purposes, it may be less applicable to adult life. Here Shamos (1995) suggests scientific literacy can be sub-divided as cultural, functional and true, where the three 3 levels are seen as increasing in sophistication.

a) Cultural literacy refers to the factual information needed to read newspapers or magazines and involves rote recall rather than an understanding of scientific terms. It has the unfortunate connotation that adults operating at this level often assume they are literate in science;

b) Functional literacy relates to some understanding of science ideas and adults at this level can engage in meaningful conversation about scientific issues, although the discussion tends to largely draw on recall with some understanding; and

c) True science literacy involves knowing about the theories of science. At this level, adults are aware of some major conceptual schemes that form the foundation of science, the role of experimentation in science, elements of investigation and the logical thought processes, plus the importance of a reliance on objective evidence.

Possible Definitions of Scientific Literacy

It should thus be clear that a single, simple definition of scientific literacy is extremely problematic. The OECD (1998) PISA study sees scientific literacy 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.

This was later modified and PISA moved to determining scientific literacy in three dimensions (OECD, 2007).

- First, *scientific concepts*, which are needed to understand certain phenomena of the natural world and the changes made to it through human activity…… The main content of the assessment is selected from within three broad areas of application: science in life and health; science of the earth and the environment and science in technology.

- Second, *scientific processes*, which are centred on the ability to acquire, interpret and act upon evidence. Five such processes that are present in OECD/PISA relate to:

o the recognition of scientific questions

o the identification of evidence

o the drawing of conclusions

o the communication of these conclusions

o the demonstration of understanding of scientific concepts.

All but the last of these do not require a pre-set body of science knowledge. Yet since no scientific process can be 'content-free', the PISA science questions will always require understanding of key scientific concepts.

- Third, *scientific situations*, selected mainly from people's everyday lives rather than from the practice of science in a school classroom or laboratory, or the work of professional scientists. As

with mathematics, science figures in people's lives in contexts ranging from personal or private situations to wider public, sometimes global issues.

An issue here is the meaning of 'key concepts' related to the second part. By introducing such a term, this more description picture contrasts with the definition put forward in the ICASE-UNESCO forum on scientific and technological literacy for all (UNESCO, 1993, p.15)

The capability to function with understanding and confidence, and at appropriate levels, in ways that bring about empowerment in the made world and in the world of scientific and technological ideas.

And both differ from a definition covering scientific and technological literacy, put forward as (Holbrook and Rannikmae, 1997, p 15):

Developing the ability to creatively utilise sound science knowledge in everyday life or in a career, to solve problems, make decisions and hence improve the quality of life."

All, however, see the need for scientific literacy to relate to an ability of functionality as a citizen within society (at home, at work, in the community), not purely at a knowledge level, but in making decisions and acting as a responsible person. Only the last, however, may be suggested as emphasising socio-scientific decision making, where it is not the changes to the natural world alone that are the focus, but also the way of thinking.

Nature of Science (NOS)

An understanding of the Nature of Science plays an important role in the development of scientific literacy. The difficulty here is that there is no specific description for appreciation the exact nature of science. It seems that the Nature of Science does not have one clear interpretation. As all philosophical concepts/terms, its context is not a continuum and hence its meaning is floating/changing accordingly to the subject-object relationship (teacher to student; scientist (1) to teacher, scientist (2) to teacher, etc.). However, there is a certain agreement as to what science is – even if different groups argue and emphasize different aspects of the nature of science (Bell & Lederman, 2003) – and it is not surprising, therefore, NOS within science education schools can be considered from different perspectives:

(a) it can relate to the development of 'big ideas' in science in a conceptual sense, especially considering these with regard to higher order (Zoller, 2001) or with regard to theories promoted by scientists.

Definitions that do not recognise the meaning of 'big ideas', or suggest that such a concept does not exist, obviously reject this interpretation of the nature of science.

(b) it can be an examination of the ways in which scientists work and a consideration of the variety of scientific methods related to process skills. Among these are inquiry learning, the investigatory approach, the development of problem solving skills, or simply through experimentation in which students follow written instructions (Tytler, Duggan & Gott, 2001).

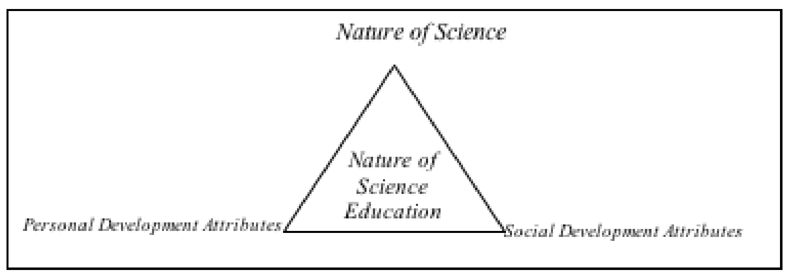
Few definitions would omit this interpretation entirely, although the alignment with scientists' science is in contrast to an interpretation of science education which rejects a scientist's logic and stresses the need that science is for all and aligned with functionality in society. In this view, content is acquired on a

need-to-know basis, and emphasis is on the skills to know how to extract and handle information when needed. It is here that a familiarity with language, or communication tools in general, can play a role.

(c) a third direction relates to the nature of science in a social setting and encompasses socio-scientific decision making. Here the nature of science is to interact with other areas such as economics, environmental, social, politics and certain moral and ethical aspects. The decision-making process sees the nature of science as one of interacting with all these areas leading to a decision in which the reasoning can be related to arguments on the importance of the science and the other aspects at the time the decision is being made. This puts forward an image of science as tentative, not able to provide a definite answer, but bringing to bear reasoned argumentation on the science theories and methods related to the issue.

This alignment is very much related to definitions of scientific literacy which recognise the need for decision making within a societal frame as important components of scientific literacy. While views on the nature of science has been researched among scientists (Schwartz & Ledermann, 2008), teachers and students (El-Khalick & Lederman, 2000; Zeidler, Walker, Ackett & Simmons, 2002; Bell and Lederman, 2003; Sadler, Chambers & Zeidler, 2004), only a few studies so far draw attention to this area of research among science educators and students outside the USA and Europe (Rannikmae, Rannikmae & Holbrook, 2006). Nevertheless, if it is appropriate to suggest that knowledge is not fundamental to the idea of scientific literacy, then the basis of scientific literacy can be considered, in general, as the nature of science, personal attributes and social development (Holbrook & Rannikmae, 2007, Figure 1).

Figure 2. The three domains which comprise the Nature of Science Education



This is proposed as a major change of focus for classroom implementation and also for the assessment of student achievements in the discipline of science education. It suggests the teaching of science subjects is through this educational structure, not simply through science content. Furthermore, such a structure forms the focus for the enhancement of scientific literacy through formal schooling. As such science content, as a specific identity rather than giving meaning to the context, has little direct relationship with scientific literacy. The teaching thrust for this form of scientific literacy has been described as education through science and contrasted with science through education (Holbrook & Rannikmae, 2007). This is illustrated in Table 1 below.

TABLE 1. A comparison of similarities and differences in emphases between ‘Science through Education’ and the alternative ‘Education through Science’ (taken from Holbrook & Rannik-mae, 2007, Table 2).

Science through Education	**Education through Science**
Learn fundamental science knowledge,	Learn the science knowledge and

concepts, theories and laws	concepts important for understanding and handling socio-scientific issues within society.
Undertake the processes of science through inquiry learning as part of the development of learning to be a scientist	Undertake investigatory scientific problem solving to better understand the science background related to socio-scientific issues within society
Gain an appreciation of the nature of science from a scientist's point of view	Gain an appreciation of the nature of science from a societal point of view
Undertake practical work and appreciate the work of scientists	Develop personal skills, related to creativity, initiative, safe working etc.
Develop positive attitudes towards science and scientists.	Develop positive attitudes towards science as a major factor in the development of society and scientific endeavours
Acquire communicative skills related to oral, written and symbolic/tabular/graphical formats as part of systematic science learning	Acquire communicative skills related to oral, written and symbolic/tabular/graphical formats to better express scientific ideas in a social context.
	Undertake socio-scientific decision making related to issues arising from the society.
Apply the uses of science to society and appreciate ethical issues faced by scientists	Develop social values related to becoming a responsible citizen and undertaking science=related careers.

Relevance

This article recognises that the relevance of school science is also important for the enhancement of scientific literacy. Relevance has been interpreted as importance, usefulness or meaningfulness to the needs of the students (Levitt, 2001). A more personal interpretation of relevance put forward by Keller (1983) defines relevance as a student perception of whether the content or instruction satisfied his/her personal needs, personal goals, and career goals. These visions suggest that relevance influences motivation and in particular intrinsic motivation.

Furthermore a number of science educational literature studies have also equated relevance with students' interest (Matthews, 2004; Ramsden, 1998). Relevance is seen as the key to raising student interests by making it more useful in the eyes of students (Za'rour, 2001).

The relevance of science education in the eyes of students is multidimensional and depends on several components (Teppo & Rannikmae, 2008). Van Aalsvoort (2004), in reviewing the literature, concludes that there are four aspects of relevance related to the study of science in school:

1. personal relevance Science lessons needs to be relevance from

a student's perspective

2 professional relevance Science lessons need to give insights into

possible professions

3 social relevance Provide insights into the role of science in

human and social issues

4. personal/social Science lessons need to help students

develop into responsible citizens

From a teaching perspective, however, these components of relevance can be divided into two major areas. From one perspective, relevance can be associated with the initial impact of the learning on the students, that is, trying to justify the answer the question 'why study this?' (personal relevance). In this way relevance is a perception by the student. It is a perception of sefulness, meaningfulness, being helpful, needfulness, and importance of the area of learning. And it is a perception before the learning starts to take place. It is thus viewed very much from the perspective of whether the learning will meet the need perceived by the student. This perceived need may have been previously initiated in a number of ways, for example, aspects in the media, debates taking place in the society, relationship with employment, both at present and in the future. This perspective suggests relevance cannot avoid 'interest' (individual interest and situational interest – Krapp, 2002) and leads towards emphasising the relevance in an appropriate, and an appropriately addressed, topic for teaching.

But it is noteworthy that relevance can also be used within the learning to show that the learning has relevance to the student i.e. relevance of the learning or if you wish, in answer to the questions 'why learn these science components?'. This relevance is triggered by the teaching (towards creating a professional, social or personal need by the student) and as such is satisfying a need, rather than being perceived as having the potential to satisfy the need.

Both are presumed to relate to 'motivation to learn' (Keller, 1983). But the first means that the initial impression or perception is important. If this does not conjure up an indication that it can meet the need, the motivation to learn is likely to be strongly affected. The emotional response is likely to be 'why am I studying this?' Thus here relevance precedes motivation and becomes a trigger to motivate the student. This relevance might be called the *relevance of the topic* presented to the student for study.

To gain a relevant initial impression, the title of the section of learning and the 'situation' that introduces this (setting the scene) become very important. These form the impression. If the title has unfamiliar, scientific terms with no obvious link to the student's prior experiences, why should this be perceived as

relevant? And if the introductory situation is abstract, or related to another culture, why should this be perceived as having meaning for the world of the student? The title and ‘situation’ thus need to relate to familiar terminology (everyday language) and to the life experiences of the student.

The second meaning of relevance leads to satisfying a need. It is sufficiently motivationally promoted that the student participates in the learning and, if other factors promoting motivation also function well, the student wants to, and does, learn. Here motivation drives relevance by the science teaching satisfying student learning needs. Such relevance may be dependent on the classroom situation, the comprehensibility of the science and how the learning might help with a career or further studies. This relevance might be called the *relevance of the projected subject matter*.

Towards a Model of Relevance in Science Education

When these two components of relevance are applied to the student (i.e., relevance in the eyes of the student from an initial encounter and also in the progression of the teaching towards satisfying needs at a professional, personal and social level), then relevance is a measure of appropriateness for the student as perceived by the student.

If R = relevance, then a model of total relevance for the student ($R_{s,t}$) is taken to be a function of $R_{s,x}$, $R_{s,y}$, $R_{s,z}$, $R_{s.t.,c}$ and $R_{s.t,p}$

where $R_{s,\ x}$ = students perception of the relevance of the initial introduction for self;

$R_{s,\ y}$ = relevance of the subject to the student as a component of motivation;

$R_{s,\ z}$ = satisfaction and performance (assessment) by self from the learning;

$R_{s,t,c}$ = students perception of curriculum perception/implementation by the teacher plus assessment demands; and

$R_{s,\ t\ ,p}$ = students satisfaction with teacher perception (ability) to meet student needs and motivate.

Whereas $R_{s,\ x}$ comes for the initial teaching set up (the ‘scenario’ for a lesson or series of lessons) and is thus geared to relevance of the topic, $R_{s,\ y}$, $R_{s,\ z}$ play a role later in ‘sustaining’ relevance in the teaching and are thus components of relevance of the teaching of the subject matter. Also, both $R_{s,\ t,\ c}$ and $R_{s,\ t,\ p}$ are seen to play a role in the relevance of the teaching and are thus extrinsic motivational components that drive relevance.

$R_{s,x}$ is seen as having the potential to be the most crucial aspect of relevance for the student and can play a strong motivational role (relevance driving intrinsic motivation). When $R_{s,x}$ is seen as high by the student, then learning is more likely to take place ($R_{s,\ t} \sim R_{s,\ x}$). In addition, popularity and liking (interest, enjoyable) are more likely when $R_{s,\ x}$ is high.

Irrelevance for the student, however, is not solely dependent on $R_{s,\ x}$. This component can be absent

($R_{s,\ x}$ = 0), while for example $R_{s,\ t,\ c}$ can be very dominant. Irrelevance is given by $R_{s,\ t}$ = 0, where relevance of the initial topic and the subject teaching approach are absent in the eyes of the student.

In the absence of examination pressure, $R_{s,x}$ can be the most important motivator of students. This suggests intrinsic motivation is dependent on this aspect of relevance and hence a key component in the drive to enhance scientific literacy. Unfortunately international studies have shown that topic and subject relevance of much of current science education is suspect (Sjoberg, 2002), because it seems that students do not find the knowledge taught to be useful in their future and everyday life (Holbrook, 1998; Osborne & Collins, 2001).

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