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A Reflection on Distorted Views of Science and Technology in Science Textbooks as Obstacles to the Improvement of Students' Scientific Literacy

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Scientific literacy has been increasingly considered a major goal of science education. While textbooks remain the most widespread tools for pursuing this goal within classrooms, they have been slow to adapt to the most recent epistemological paradigms, often still conveying distorted views of science and technology. Accordingly, we present herein a theoretical framework specifically intended to highlight the potential of textbooks to promote students' scientific literacy. It is additionally argued that, often, the misconceptions conveyed by textbooks represent obstacles to the acquisition of a fair image of science and, therefore, to the acquisition of scientific literacy. Finally, a textbook analysis is suggested.

Key Words: scientific literacy, knowing about science, science, inquiry, technology, society, environment, textbooks, conceptions

Introduction

Science and technology interfere constantly, and in tight coexistence, with our daily lives. In spite of that, the complex arguments raised in the course of scientific and technological controversies are often not well understood (Miller & Pardo, 2000; Organisation for Economic Co-operation and Development [OECD], 2007). Although the media increasingly make scientific information available to the public (Brossard & Shanahan, 2006; Lewenstein, 2001), this information seems to be unintelligible to the vast majority of consumers. Therefore, the challenge in the classroom is to provide individuals with the background required to understand the news. Koelshe (1965) already highlighted the pressing need to improve peoples' scientific background. Nevertheless, scientific-technological issues, frequently involve complex interactions between several social entities. Their analysis, understanding and judgement must rely on more than the underlying scientific knowledge (Reis, 2008). Citizens should be aware of what triggered certain research, how knowledge was achieved, what this achievement represents and how it may positively or negatively affect individuals, society and the environment.

Science educators in particular have the double task of conveying, to all students, the scientific background required for conscious citizenship, while preparing students intending to pursue scientific careers. In consequence, Osborne and Dillon (2008) pointed out the importance of 'scientific literacy' (SL) in science education, irrespective of the students' professional future. Hereby, the actual meaning of the term "SL" needs discussion, especially which content should be conveyed, how students are helped to become scientifically literate citizens, whether current learning materials in particular science

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textbooks are adequate means to that end and, finally, how deficiencies in textbooks are to be surveyed. Therefore, the objectives of our study are the following:

- (i) To reflect about the concept of SL, which is seen as a pre-condition to identify the range of general requirements a citizen should comply with in order to reach scientific literacy. In our view, science textbooks need to foster the development of SL. These ideas exceed the level of factual knowledge (knowledge of science), which is quite rigidly determined by syllabi, and therefore less dependent on textbook authors' options or epistemological orientations. Consequently, our focus was set on the fields known as Nature of Science (NoS), Nature of Scientific Inquiry (NoSI) and Science-Technology-Society-Environment (STSE), to which guidelines allow wider elbowroom.
- (ii) To highlight the potential of textbooks to promote the understanding of science and technology and their interplay with society and the environment.
- (iii) To discuss how distorted views of science and technology (misconceptions), consciously or unconsciously conveyed by textbooks, may constitute obstacles to that understanding.
- Last but not least (iv) to highlight how detecting those distorted views in textbooks can help to determine the extent to which a textbook may contribute to SL.

Science Curricula: Problems and Challenges

A major concern, for instance, expressed by Osborne and Dillon (2008) is that progressively fewer young people seem to be interested in scientific and technical subjects. Research has shown that even bright and creative science students, discouraged by a boring and irrelevant curriculum, drop out of science (Aikenhead, 2002). On the other hand, to students who are pursuing neither scientific nor technical careers, the conventional school curriculum has little relevance to their future lives (Aikenhead, 1980; Layton, Jenkins, Macgill, & Davey, 1993; Millar & Osborne, 1998).

Although several voices (Rocard 2007; Osborne & Dillon, 2008) claim the importance of developing efforts to re-imagine science education in order to fit the modern world and meet the needs of all students. These authors argued that, during the last two decades, little attention has been given to its nature and structure, and curricula mainly focus on factual knowledge. Fensham (2002), for instance, claimed an urgent need to recruit new “drivers” to form a counterweight to those who are steering the curriculum process. Contesting the value of the preponderance of factual knowledge in curricula, he argued that, in conflicting decisions, individuals values are more important determinants of trust in the scientific information than factual knowledge of science. Moreover, he criticized attempts to enrich this curriculum with NoS or STS material, because it is simply been added to an already excessive body of scientific content. Considering the traditional techno-scientific approaches, some authors argue that they have failed in the classroom because they have not been prepared explicitly to embrace ethical considerations as a preliminary to any discussion of civic SL (Zeidler, Sadler, Simmons, & Howes, 2005; Sadler & Zeidler, 2004; Bell & Lederman, 2003).

This problem is intimately connected with that of representations of science and technology being placed in curricula which, according to Rudolph (2003), are shaped by scientists’ activities and the social and political context in which they are developed. Quessada and Clemént (2007) favoured the didactic transposition of scientific ideas as resulting from the interaction between knowledge, values and social practices and pointed to a delay associated with the transfer of scientific ideas from curricula to textbooks. It is legitimate to assume that not only is factual knowledge affected by these constraints, but also by the ideas having emerged from the epistemological debate surrounding the image of science and how it should be conveyed to students.

Scientific Literacy: State of the Art

The term “SL” became a recognized educational term connected with the contemporary educational goal of “science for all” (UNESCO, 1983), and nowadays it represents the main goal of science education (DeBoer, 2000; Hodson, 1998). However, a consensual definition has not yet been reached (Shamos 1995). Together with the concern for public engagement in science and technology that emerged in the 1980s, the movement for Public Understanding of Science (PUoS) arose to instil confidence in and support the scientific enterprise. Another movement, “science for all”, envisaged a shift of the curricular science education towards the needs of the majority of students, those not pursuing scientific or technological careers. It thrived under the catchy American slogan “SL” (Turner, 2008). Several definitions of SL have been proposed since then, varying according to their historical and political contexts (Turner, 2008), and based on interest groups (Laugksch, 2000) or on economical, utilitarian, cultural, democratic, or even moral arguments (Millar, 2002; Osborne, 2000; Thomas and Durant, 1987). Among them, two major labels prevail: “nature of science” (NoS) and “science, technology, and society” (STS) which, together, converge to the concept of “civic SL” (Turner, 2008). From that perspective, these two domains comprise the knowledge that citizens should be aware of as requirements for understanding and judging scientific and technological advancements. However, note that STS and civic SL are not just two labels for the same concept.

Consonant with the Nature-of-Science movement (NoS), for Durant (1993, p. 129) SL stands for “what the general public ought to *know about science*”. Jenkins (1994) extends this concept by arguing that SL requires “an appreciation of the nature, aims, and general limitations of science” (p. 5345), which can also be summarized as *knowing about science*. However, in his view this knowledge must be coupled with some understanding of the conceptual knowledge achieved by the scientific enterprise. Schwartz and Lederman (2008) also linked these two domains, although emphasizing each of them differently. According to them, scientifically literate individuals should possess not only a conceptual knowledge of science, but also epistemological views of science that are consistent with the currently acceptable ones. For these authors, epistemological views of science involve two separate yet overlapping concepts: one’s view of scientific knowledge as a way of explaining the nature of science (NoS); and one’s view of the processes through which that knowledge is acquired, constructed and justified - nature of scientific inquiry (NoSI).

Some authors defend that students’ understanding of the scientific enterprise (involving both the NoS and the NoSI) is increased by allowing them to engage in authentic science (Gaskell, 1992; Turner & Sullenger, 1999; Scharfenberg & Bogner, 2010). The "authentic science movement" entered into powerful symbiosis with the constructivist learning theory, as it expected students to extract an individual meaning from the results they obtained, both through analysis of obtained data and through classroom discussion and negotiation (Turner, 2008).

Along these lines, the so-called Rocard report (Rocard et al., 2007), while calling for an urgent reform of science education, recommended inquiry-based methods for raising students’ interest in science and for developing certain intellectual skills. It is, however, relevant to determine to what extent inquiry-based teaching contributes to the students' SL. According to NSES (NRC, 1996) and *Benchmarks for Science Literacy* (AAAS, 1993), it is the *understanding* of NoSI, rather than the *skills* of inquiry, that contribute to scientific literacy.

For different reasons, the arguments above support the thesis that understanding the nature of scientific enterprise from the internal perspective and its methods contributes to SL. Nevertheless, recent studies point out that students’ attitudes towards socio-scientific issues are determined more by ethical assumptions than their understanding of the “methods of inquiry” or by the “nature of science” (Turner 2008). Halfway between these two positions the referenced Rocard report, despite emphasizing inquiry-based methods, highlights the understanding of the interactions between science, technology and society as a pre-requisite for acquiring “science literacy”. Major multinational studies are currently being carried out to support the requirements above formulated (*e. g*. EU-projects such as PATHWAY, ESTEM, FIBONNACI, *etc*.).

A shift in science education appears to be occurring as goals are being set beyond the internal perspective of science, crossing the boundaries of the subject-focused scientific community. The relationship between science and technology, as well as their positive and negative repercussions in society and the environment, has been gaining increased prominence. Over the past three decades a movement called "Science-Technology-Society" (STS) (Turner, 2008) challenged the *status quo* of science education and asked for a redefinition of SL. Accordingly, the STS slogan changed during the last five decades due to growing concerns about environmental degradation, assuming the designation of STSE ("E" for environment) movement (Aikenhead, 2002).

These evolutions exceeded the debate among scholars and penetrated the general school syllabi. The STS curricula were intended to promote SL in citizens, trigger the interest of students in science and technology, foster an interest in the complex interactions between science, technology and society, and to develop students' critical and logical reasoning skills in order to promote abilities in creative problem resolution and conscious decision making (Aikenhead, 1994; Bybee, 1985; Solomon, 1993). This movement drifted, therefore, away from the investigatory activity that generated knowledge. It focused instead on the impact of technology, in consonance with the more recently emergent concept: civic SL (Turner, 2008).

Despite the different roots and different learning visions of STSE and NoS, some STS defenders (Ratcliffe, 2001; Solomon & Aikenhead, 1994; Ziman, 1994) believe that the impact of science on society and the environment, together with the Nature of Science in the broad sense, must be approached inseparably, as co-operators in a common final product. Indeed, the understanding of the means through which scientific knowledge is achieved, both from the conceptual and the methodological perspectives, seems to be a prerequisite for citizens to understand the real meaning of "scientific evidence" or scientific "truths" required to follow techno-scientific issues. The perception that scientific knowledge is merely tentative, despite the fact that it is the best we have (McComas and Olson, 1998), disassembles the naive views of science either to a super confidence in science and technology or an extreme scepticism. It is only with awareness of their benefits and negative implications in all these domains that it is possible to critically analyse a certain controversial issue and to judge more objectively the connected economic interests, and corresponding political decisions.

The above referenced concept of civic SL was proposed by Miller (1998) as a three-dimensional construct: (1) a *vocabulary of basic scientific knowledge* sufficient to read competing views in a newspaper or magazine, (2) an *understanding of the process or nature of scientific inquiry*, and (3) some level of *understanding of the impact of science and technology on individuals and on society*. In more recent cross-national studies of civic SL, the author observed that the dimension (3) is supposed to vary substantially in content among different countries according to their corresponding socio-cultural contexts. This suggests that the expected optimal level of SL in a certain community should consider its historical pathway and its background in science and technology (McComas, Clough and Almazroa, 2000).

Nevertheless, despite the acceptable variability, a definition of the concept and the clarification of its requirements remains a matter of great importance. The domain of *knowledge* prevails in the definitions of SL and the majority restrict themselves to it. This position in the range of definitions is shared by other authors (Lee, 1997; National Science Teachers Association [NSTA], 1971; Shamos, 1995); Scottish Consultative Council on the Curriculum [SCCC], 1996); Hodson, 1998; NSTA, 1971; OECD, 2007; SCCC, 1996; Shamos, 1995); Aikenhead, 2002; Miller, 1998; NSTA, 1971).

Nevertheless, other dimensions embracing more than knowledge are included by several authors in the definition of the concept, such as scientific *skills* (OECD, 2007), *attitudes* towards the role of science in society (Hodson, 1992; Mathews, 1998; OECD, 2007; SCCC, 1996; Turner, 2008) and the *ability* to take a stand (Hodson, 1998; NSTA, 1971).

This synthesis illustrates the broadness of the term "SL", encompassing many historically significant educational themes that have shifted over time (DeBoer, 2000), as well as "the wide spectrum of opinions that exists today among educators" (Turner 2008, p. 56).

Boundaries of Our Present Study

It is not our purpose to discuss the essence of the concept of SL. Nevertheless, we also attempt to position ourselves in this spectrum of opinions according to the following: In our perspective, a scientifically literate citizen should be capable of, at least, a superficial understanding of the "happenings" in all scientific and technological domains. Even people who pursue a career in science or technology cannot follow the primary literature for all scientific disciplines (Bauer, 1994). Therefore, a scientist with expertise in a certain field is no more skilled than any other citizen when exposed to a completely different field of knowledge. Accordingly, we don't consider scientific skills to be essential to the understanding of science and technology. While these may influence positively the understanding of science, they should only be required to reach another level of SL: the researcher's SL.

Our conception of SL does not comprise the *attitudes* towards science and technology nor the *ability* to take a stand. Indeed, a good level of SL may have influence these areas, but they also depend on other factors, such as values, personal experiences, individual interests and personality, among others. Therefore, we place our conception of SL in the domain of knowledge, particularly in knowledge of science and technology, for the following reasons:

Firstly, we recognize the possession of scientific knowledge as the cornerstone for comprehending science and technology. Knowing the lexicon of a certain scientific or technologic domain, and being aware of the concepts underlying a particular issue, are prerequisites for understanding evidence provided by science and for following scientific and technological developments.

Secondly, we also consider the awareness of how relative scientific "truths" really are to be an indispensable requirement of SL. To reach this level of critical thinking citizens should, whether by engaging in real science or by analysing the work of others, be acquainted with the way scientific evidence is generated (NoSI). Unless they are able to understand the different processes that contributed to the reported results as well as the researchers' reasoning, common citizens feel lost when equally qualified researchers assume different positions (Bauer, 1994).

Furthermore, citizens must gain awareness of a more embracing concept of science, far beyond its methods of inquiry: scientific knowledge must be seen for what it is, a social construct (McComas and Olson, 1998; Osborne *et al.*, 2003). Scientists, rather than working in isolation, establish vertical relationships with their predecessors and horizontal relationships with their peers and with other disciplines. Therefore, the understanding of the ways in which knowledge evolves within the scientific community (NoS) may also contribute to a more realistic image of science.

Finally, in our view, understanding science nowadays requires knowledge of: (1) the social factors which have triggered, slowed down, or even impeded a particular scientific research; (2) the way scientific and technological progress influences society and the environment, and of its ethical implications (STSE issues).

In summary, there is a coincidence between the conception of SL that binds the present reflection and that of Miller. It can be defined as the knowledge of, and about, science and technology, that together with personal experiences and cultural values contributes to the development of attitudes and behaviours required for a participative citizenship, as represented in Figure 1.

In view of the reasons laid down above, the scope of this article is the discussion of the potential and the fragilities of science textbooks to convey knowledge about science and technology, with the focus placed on the domains of NoS, NoSI and STSE.

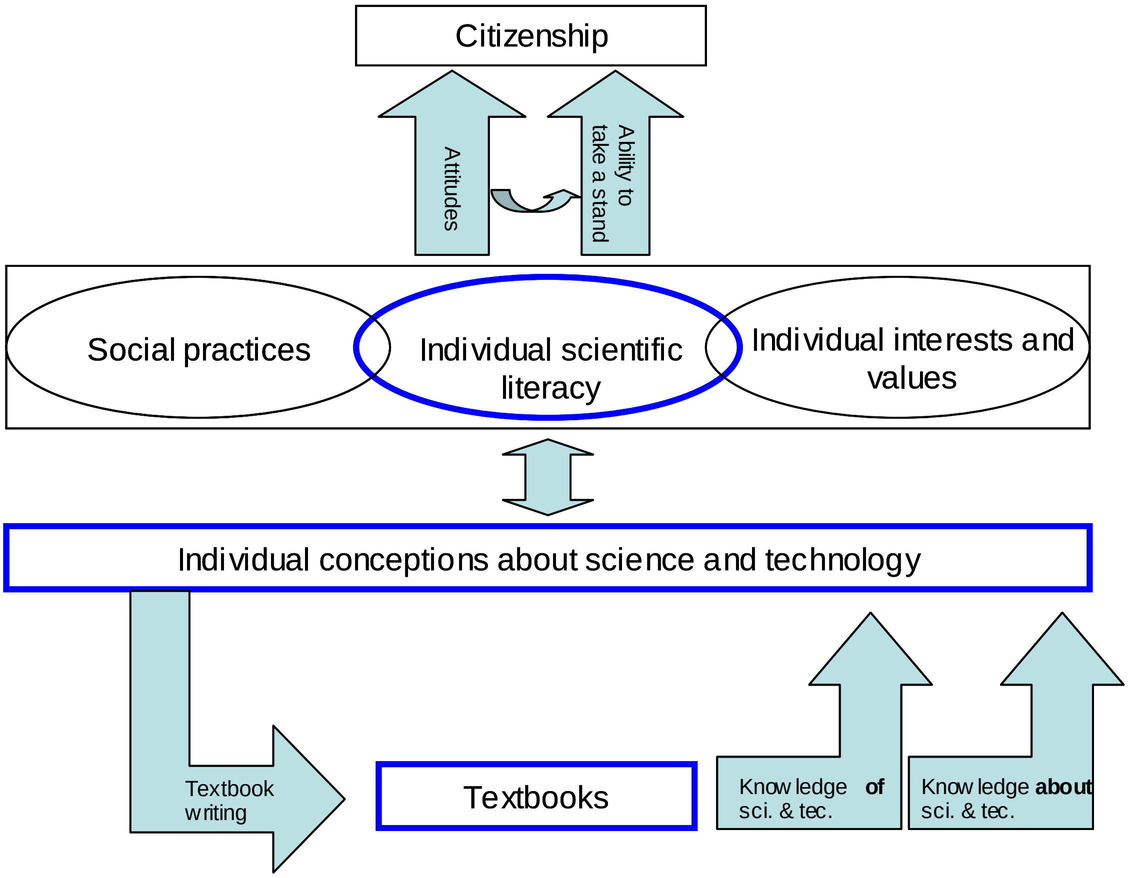

Figure 1 - Schematic representation of the concepts involved in the present work

Sources of Scientific Knowledge about Science and Technology

Having placed the conception of SL in the domain of knowledge, a reflection on the sources of the knowledge essential to becoming a scientifically literate citizen is required. Millar and Osborne (1998) pointed out that the main purpose of the teaching of science is to prepare students for a critical interpretation of the news conveyed by the media, and to promote the construction of personal opinions about daily socio-scientific questions. The authors suggest that the media are the prevailing sources of new information about scientific research for the common citizen. Nevertheless, despite its potential importance to SL, Zimmerman, Bisanz, Bisanz, Klein and Klein (2001) state that little is known by common citizens about the content of media reports. Is science education therefore failing to achieve its main objective?

There is a time lag between the advancements disclosed by scientific and academic journals and their announcement in the general media. Furthermore, news is shaped by journalists' interpretation of scientific reports, without describing the processes behind the achievements (Wellington, 1991). An equivalent delay (Quessada and Clemént, 2007) and erosion occurs between the descriptions of research disclosed by the original sources of scientific knowledge and their appearance in textbooks, as conventional and well established science contents Zimmerman, Bisanz, Bisanz, Klein and Klein, 2001. Bauer (1992) calls particular attention to the difference between *frontier science*, the one that is reported by the media, and *science textbooks*, that is filtered and modified. Traditional science portrayal is, therefore, frequently only a selective representation of the scientific practices (Rudolph, 2003).

Despite this limitation, learning materials represent privileged opportunities not only to present the established fundamental knowledge in science, but also to expose those aspects of science and technology that are not discussed in the media. Are textbooks fulfilling their task? To what extent do science textbooks present material that may contribute to the students' understanding of science and technology?

The potential of textbooks as vehicles of SL

Textbooks, in general, are relevant as learning materials, but they also seem to dictate the curriculum for many teachers (Osborne, Duschl and Fairbrother 2003). Textbooks provide them with guidance and support, also promoting the participation of parents (Bartholomew, Osborne, and Ratcliffe, 2004) and enable students to learn independently (Aufdermauer & Hesse, 2006). Science textbooks are referred to by several authors (Chiappetta, Fillman & Sethna, 1991; Hodson, 1996; Leite, 2002) as powerful resources for teachers and students alike. As discussed above, in parallel with the mere presentation of achievements of science and technology, science textbooks also offer teachers and students the opportunity to work out the way in which they have been achieved. That can be accomplished by contextualizing events (Leach, Millar, Ryder and Séré, 2000; Rudolph, 2003) externally and internally to the scientific community by describing processes and demonstrating the repercussions of scientific and technological events in society and in the environment. This can be done through brief references to events emphasizing their meaningful aspects, or by exploring historical reports of representative events (Hodson 1996), generally referenced as case studies. The latter may include stories and anecdotes about scientists which illustrate scientific and technological progress (Leite, 2002).

Despite the unquestionably informative and motivational potential of case studies, some considerations about their inclusion in textbooks are required: primarily, teachers must be aware of the principal shortcomings of case studies. Secondly, even though every single case, as reported by historical documents, does illustrate particular aspects of science and technology, any individual case should not be expected to contain all the relevant aspects of science. For instance, while some case studies evoke the social factors that triggered particular research, others display how knowledge was acquired, while still others are more appropriate for explaining how scientific ideas succeed each other or what their repercussions are in society or in the environment. Additionally, ideas about science and technology can also be conveyed to students if the use of simple references to historical or contemporary scientific and technological achievements are accompanied by meaningful details. Therefore, through a balanced combination of extensive reports and brief references to illustrative events, textbooks can help students realize how scientific knowledge was generated, evolved and established itself. Actually, studies undertaken with undergraduate students provided evidence that the use of hermeneutical circle strategies, besides enhancing students' understanding of textbook content, also operate changes in students' views of science (Kalman, 2011).

Despite the above, it is important to note that analysing reports of others' experiments or following suggestions or instructions for experimental activities, is not the same as performing science. Nevertheless, awareness of the nature of scientific inquiry (NoSI) may also be achieved, not only as learning science *by* inquiry, *i. e.*, by engaging in real science, but also learning science *as* inquiry (Tamir 1985). Learning science *as* inquiry includes learning about the way in which the scientific endeavour progresses by analysing the inquiry process performed by others, either using historical perspectives (Bybee, 2000), or discussing contemporary research.

Historical events of science have been largely recommended and used as a means of understanding the contemporary social issues of science (Shortland and Warwick, 1989). However, the history of science is still being written and in our view goes far beyond the classical case studies. It also embraces contemporary "cases", which illustrate new challenges to science and technology and their desirable, undesirable and even controversial repercussions in the present world. Science textbooks should, therefore, comprise detailed reports of relatively recent events, thus providing students with the opportunity to perceive what remains constant in scientific activity and what has changed over time.

The description of contemporary case studies is most clearly advantageous in content such as genetics, gene technology or nuclear energy. Addressing socio-scientific issues in this context may confront teachers and students with questions that frequently have moral and ethical implications. This confrontation has been considered by several authors (Hamm, 1991; Gaskell, 1992; Vaz e Valente, 1995; Kolsto, 2001; Aikenhead 2002; Reis, 2008) as a valuable strategy for preparing citizens to face problems that could be perceived and judged from different perspectives, frequently involving values.

Consequently, textbooks should provide adequate and reliable material supportive of discussions of both classical and contemporary socio-scientific issues in the classroom. This material should facilitate the conveyance of correct ideas about science and technology, thus representing a step towards lessons promoting SL.

What Knowledge or Ideas about Science and Technology Should Be Taught?

It is quite consensual that the domains: NoS, NoSI and STSE need specific consideration when accessing SL. Nevertheless, it still remains questionable which ideas about science, scientists' work, and the interactions between science, technology, society and the environment students should be made aware of. While some authors, such as Stanley and Brickhouse (2001); Hipkins, Barker and Bolstad (2005), express concern about the negligible consensus amongst philosophers, historians of science, scientists, and science educators about which ideas about science (IAS) should be placed on curricula, others (Smith, Lederman, Bell, McComas, & Clough, 1997; Smith & Scharmann, 1999) point out the existing consensus on fundamental IAS that are relevant and accessible to school science education. Osborne, Duschl and Fairbrother (2003) challenged the latter statement by arguing that the studies based on curriculum documents, such as Benchmarks for SL (AAAS, 1993) and others from New Zealand, Canada, the United Kingdom and Australia (McComas & Olson, 1998), rather than displaying a consensus, represent a necessary compromise for the drafting of reports by the committees. According to these authors, those studies simply fail to represent the lowest common denominator around which it would be possible to reach agreement, thus also failing to represent a coherent account of the NoS. As a counterproposal, those authors have conducted a *Delphy* study to empirically determine the extent of any consensus among scientists, science teachers, philosophers, sociologists of science and science educators on IAS that should be included in the school science curricula. In their article a parallelism between the consensual ideas and those identified by Mc Comas and Olson (1998) was described and was concluded that a considerable agreement between both sets does exist. Meaning, despite the use of differing methods in different studies, many of the ideas referred to are also consensual among scholars.

However, despite the considerable correspondence between most agreed and consensual ideas, some of them reveal divergent epistemological orientations. The observed divergence may be a reflex of differing underlying conceptions of science, from both conceptual and methodological perspectives of individual scholars. This is the case in, for example, the ideas expressed by the statements "science is tentative" (McComas & Olson, 1998) and "science and certainty" (Osborne *et al.*, 2003). Regarding such divergences, these two sets, though containing relevant nuclear ideas, would hardly provide adequate guidelines for writing or analysing science textbooks. Moreover, as described below, abundant bibliography points out other ideas about science and technology which, though not consensual, seem to be indispensable for many science education researchers in constructing a correct image of these interconnected entities.

With respect to the specific domain of NoSI, recent studies built upon international science education standard documents and the existing literature in science education, and undertaken by Schwartz and Lederman (2008), produced an instrument suitable for surveying the scientists' views of scientific inquiry (VoSI). The indicators used in this study could therefore provide an appropriate basis for defining detailed and precise criteria for checking the presence or absence of relevant ideas about scientific practice in textbooks.

The Knowledge about Science in Science Textbooks

The content included in science textbooks for illustrating the context and processes through which scientific knowledge and technological advancements were achieved, should be wisely selected in order to display an epistemologically established image of both, and of their interaction with other spheres. “The kind of historical material used and the way it is used is what determines the image given to students (even if an incorrect one) of science, scientists and scientific practice” (Leite, 1986, p. 334). The same considerations apply to the contemporary events, in particular to socio-scientific issues, which should consider their controversial nature as well as their ethical, moral and religious implications.

Several studies already exist that focus on the *knowledge about science* in textbooks. For instance, Orpwood (1984) analysed biology textbooks from the perspective of STSE and the image of science conveyed by textbooks (he has gone beyond that, also focusing on the domains stated intentions and scientific skills). Two of Orpwood's themes, namely scientific skills and the image of science, were also used by Tamir (1985) while analysing how biology textbooks approach the scientific inquiry.

Chiappetta, Fillman and Sethna (1991) selected four aspects or themes of SL which had been pointed out by the NSTA (1982) as components of SL: science as a body of knowledge; science as a way of investigating; science as a way of thinking; and the interaction between science, technology and society. This method has also been followed by Wilkinson (1999) while analysing Physics textbooks from the same perspective.

Chiang-Soong and Yager (1993) analysed the pure space devoted to STS issues in textbooks and concluded that they receive poor coverage, worsening with increasing grade levels. Rosenthal (1984) analysed social and controversial issues in textbooks and concluded that attention to social issues decreased between 1963 and 1983. Leite (2002) focused on the quality of the approach to history of science in physics textbooks, while Abd-El-Khalick, Waters, Le (2008) analysed the representations of NoS in high-school chemistry textbooks. Teachers’ views, and therefore very likely textbook writers’ views (since they are predominantly teachers) of the NoS are not consistent with currently accepted definitions (Lederman, 1992; Leach, Millar, Ryder and Séré, 2000; Lederman, Wade, and Bell, 1998; Gil-Pérez et al., 2005). Rosenthal (1984) analysed the treatment of social issues in biology textbooks and found that attention to social issues decreased between 1963 and 1983. Nevertheless, Chiappetta, Fillman and Sethna (1991) argue that if one were to analyse some of the more recent textbooks, a higher proportion of their content would probably be devoted to STS since this theme has been attracting progressively more attention in science education.

If there is a gap between ideas emerging from the scientific and the educational communities and curricula, then an equally meaningful gap exists between each official curriculum and the content conveyed to students. This discrepancy depends upon several elements of the “hidden curriculum” (Cachapuz, Praia, Jorge, 2004; Pingel, 1999), such as the decisions of publishers conditioned by market dynamics, the conceptions of textbook authors, and the interpretations of teachers which are influenced by their own conceptions about science.

Textbooks usually present science as a body of knowledge acquired in a linear way (Finley, 1994), avoiding or neglecting movements back and forth (Leite, 2002) that characterize the dynamics of scientific research and, therefore, the evolution of scientific ideas. Chiappetta, Fillman and Sethna (1991) state that the empiricist vision of science displayed by students and teachers is due to the fact that textbooks, explicitly or implicitly, place an emphasis on facts, while processes are omitted.

Distorted Views of Science in Science Textbooks

Having defined the domains of knowledge as essential components of SL (chapter 3), it is imperative to collect from the epistemological and science education debates the ideas about science and technology that can contribute to a formal science education oriented to SL. Based on these ideas, criteria should be specified according to which both science lessons and textbook content may be evaluated and compared. As explained in the previous chapter, studies in this domain were undertaken by several researchers but, in our opinion, a method capable of providing a holistic overview of the same reality is still absent.

Along with concerns for the promotion of scientific understanding in the broad sense, many scholars draw attention to both the lack of information about science and technology placed in textbooks, and the incorrect ideas displayed by them. Incorrect ideas can represent filters or even barriers to the achievement of SL in students. They can induce and cement distorted views that interfere in the construction of a fair image of science as a body of knowledge, as well as in the comprehension of scientists' work and of the role of science and technology in our lives.

At first glance, compliance with the requirements of SL can be surveyed by looking for absent or incorrect ideas about science and technology. However, in our opinion this method misses an important point: there is evidence that incorrect ideas and the absence of correct ones, do not appear in isolation or at random. Instead, their occurrence is interconnected with other ideas, according to certain patterns revealing distorted views of science and technology. For example, by nourishing the idea that all scientists are exceptional people, one is hardly able to recognize that science has a collaborative character. Instead, one is drawn to the idea that scientists work in isolation in their ivory towers. These two incorrect ideas occur very likely together as components of a distorted view of the scientific enterprise.

Fernández, Gil, Carrascoa, Cachapuz and Praia, (2003) identified seven distortions of the image of science mostly referred to in the literature. These views coincided with those found by Fernández (2000) in his analysis of current science teaching practice by means of, among other procedures, analysis of textbooks, laboratory guides and assessment exercises, and by direct observation of classroom activities, as well as questionnaires and interviews. Given continuity to that work, Gil-Pérez *et al.* (2005) argued that the simplistic conception of the relationship between science and technology, according to which technology is seen as a mere product of science or as applied science, and the role of technology in the construction of scientific knowledge is underestimated or even disregarded. That misunderstanding appears to underlie the distorted views of science and technology, often considered as one of the main obstacles to renovation in science education.

According to Fernández, Gil, Carrascosa, Cachapuz and Praia, (2003) and Gil-Pérez, Gil-Pérez et al. (2005), the seven most commonly identified distorted views are the following:

1. Empiric-intuitivist and non-theoretical conception of science

This is considered as the most referred to conception in the literature. It emphasizes the role of "neutral" observation and experimentation as if the knowledge had been achieved by chance, without "contamination" by previous ideas. The hypothesis as the focus of investigation, as well as the role of theories as a coherent body of knowledge that guides the whole process and upon which the design of new research relies, are both disregarded.

2. Rigid conception of scientific activity

A conception that conveys a rigid (algorithmic, rigorous, fail-safe) image of scientific work. The figure of “scientific method” is often explicitly referred to or implicitly presented as a set of rigid steps to be mechanically followed. Quantitative processing and rigorous control of experiments are emphasized, while “invention”, “creativity” and “doubt“ are disregarded.

On the other hand, the rejection of this rigid and dogmatic view of science can conversely lead to an extreme relativism. This view qualifies both the methods used in science (Feyerabend, 1975), and the concepts of science, thus denying any certainty in science. This follows the principle that the “only basis for scientific knowledge is the consensus of the research community”, and thereby neglects the value of empirical evidence.

3. A non-problematic and non-historic conception of science

This conception is quite commonly referenced and is denounced by the presentation of already elaborated knowledge and a disregard for the process of its gradual construction. There is a misrepresentation of the underlying problems that motivated progress, the limitations of current scientific knowledge, how ideas evolved and which difficulties confronted scientists, or the potential of science for giving yet unknown answers. In other words, the rationality of the scientific process as an answer to a question is omitted.

4. An exclusively analytic conception of science

This conception was rarely considered by *research*, but was identified by these authors in over 80% of teachers and textbooks. It is characterized by a disregard for the complexity of problems and therefore, for the multidisciplinary character of the scientific construction.

5. Merely cumulative conception of scientific development

This is the second less referenced conception in the literature. It is characterized by a disregard for crises and revolutions as stimuli to scientific development, as well as mere references to events, therefore suggesting a linear cumulative growth of scientific knowledge.

Leite (2000) points out that textbooks frequently present tables summarizing the chronological sequence of science and technology events, mainly at the end of chapters, misrepresenting the real evolution of achievements.

6. An individualist and elitist conception of science

This is one of the most commonly occurring conceptions in the literature, according to which scientific knowledge is formed out of isolated genii completely neglecting collective work and cooperation between teams as a pre-requisite to progress. Contrary to this conception, another distorted view has been noticed, according to which scientific activity is seen as something very simple and close to common sense.

7. A decontextualized and socially neutral conception of scientific activity

The connections between science, technology and society are approached superficially. It is a conception of positivist root, very much cantered on the products of science, which are represented as an absolute factor of progress, while technology is considered as a mere application of scientific knowledge, its role in the construction of scientific knowledge being neglected. Contrasting with this naive view, there is also a tendency to attribute to science and technology the responsibility for environmental degradation.

The seven distorted views presented above represent common occurrence patterns of incorrect ideas about science. Stemming from this evidence, and in order to extract higher meaning from the compliance of textbooks with correct ideas about science and technology in the three mentioned domains of knowledge, a new task arose: the identification of the distorted ideas about science that have been transferred into individual textbooks. This task may offer the advantages of providing an overview of the textbook profile and of determining how close the textbook comes to fulfilling its potential contribution to students' SL.

8. Identifying distorted images of science in science textbooks

As argued above, certain ideas about science propounded by teachers, textbook writers, or inherited through patented pictures stored in databanks and placed in textbooks, represent indicators of conceptions that according to the current epistemological paradigm are considered *misconceptions about science and technology* or *distorted views of science and technology*.

Based on the descriptions presented by Gil-Pérez et al. (2005), a correspondence can be observed between the seven distorted views of science and technology and the three domains that together represent the knowledge about science to be acquired by citizens, namely, NoS, NoSI and STSE issues, as presented in Table I. This correspondence suggests that each of the described distorted views is rooted in a misunderstanding of one or more of the three domains of knowledge. More importantly, it is also to be expected that the inclusion of these distorted views in teaching practice and textbooks, conveys misunderstandings to students in the same domains.

Table I – Correspondence between the seven distorted views of science and technology considered in the present article, and the domains of knowledge affected by them

	Domains of knowledge about science		
Distorted views of science and technology	NoS	NoSI	STSE
1. Empiric-intuitivist and non-theoretical conception of science	X	X	
2. Rigid conception of scientific activity		X	
3. A non-problematic and non-historic conception of science	X		X
4. An exclusively analytic conception of science	X	X	
5. Merely cumulative conception of scientific development	X		
6. An individualist and elitist conception of science	X		
7. A decontextualized and socially neutral conception of scientific activity			X

Final Considerations

It is herein assumed that the contribution of textbooks to SL is directly proportional to the concordance of the conveyed ideas with the ideas about science and technology that, together, form a realistic image of the scientific and technological enterprises. Conversely, textbooks displaying distorted images or misconceptions are assumed to steer away from the goals of SL.

For these reasons, we draw attention to the importance of carrying out textbook analysis in order to raise consciousness of the fact that naive and distorted ideas about science and technology are still conveyed by textbooks. According to our expectations, such analysis would render multi-faceted results, with samples exhibiting highly acceptable ideas coexisting and contrasting with very (according to the current epistemological paradigm) outdated ones.

In view of the considerations above, we believe that seven groups of criteria for textbook analysis should be defined from the lens of the seven distorted views proposed by Gil-Pérez et al. (2005) in order to detect:

i) the absence of key ideas about science and technology, which, *per se*, represent indicators of a certain misconception of science;
ii) the presence of wrong ideas about science and technology that reinforce the presence of this misconception;
iii) and similarly, but from a more positive perspective, to detect indicators that contribute to dismounting / refuting the presence of a certain misconception.

Results should also be analysed by verifying the compliance of textbooks with groups of criteria that point out if, and to what extent, distorted images of science and technology are displayed by the analysed textbooks. This procedure has the advantage of not only showing the position of textbooks relatively to SL according to the three domains, NoS, NoSI and STSE issues, but also of emphasizing aspects that require improvement.

It should be stated that is not our purpose to focus on the surveillance of authors' conceptions, but rather on the conceptions that are conveyed by textbooks. Notwithstanding the above, we believe that it may be useful for the production of future textbooks to emphasize two aspects: (i) The intentional selection of contents (case studies or statements about briefly referenced events) should be carried out according to their potential to illustrate the real evolution of scientific knowledge and technological development. Moreover, the most effective way of presenting them should also be chosen. (ii) Finally, in interplay with the deliberate selection of contents, a "hidden curriculum" resulting from the authors' conceptions also influences the final product.

In view of the above, an analysis of textbooks restricted to the subject of Genetics and focussing on the domains of NoS, NoSI and STSE is currently being carried out. The criteria applied therein result from the combination of the consensus around the concept of SL with the seven predominantly referred misconceptions about science and technology.

References

AAAS, American Association for the Advancement of Science (1989). Science for all Americans: Project 2061. Washington.

AAAS, American Association for the Advancement of Science (1993). Benchmarks for science literacy. New York: Oxford University Press.

Abd-El-Khalick, F. Waters, M. Le, A. (2008). Representations of Nature of Science in High School Chemistry Textbooks over the Past Four Decades. Journal of Research in Science Teaching, 45(7), 835-855.

Aikenhead, G.S. (1980). Science in social issues: Implications for teaching. Science Council of Canada. Ottawa.

Aikenhead, G. (1994).What is STS science teaching? In J. Solomon and G. Aikenhead (Eds.), STS education: International perspectives on reform, pp. 47-59. New York: Teachers College Press.

Aikenhead, G. (2000). Renegotiating the culture of school science. In Millar, R., Leach, J., and Osborne, J. (eds) Improving Science Education: The Contribution of Research, pp. 245-264. Buckingham and Philadelphia: Open University Press.

Aufdermauer, A. & Hesse, M. (2006). Eine Analyse von Biologie-Schulbüchern – unter besonderer Berücksichtigung des Experimentierens mit Pflanzen. IBD Münster: Bericht des Institutes für Didaktik der Biologie, 15, 1-32.

Bartholomew, H., Osborne, J., & Ratcliffe, M. (2004). Teaching students' "ideas-about-science": Five dimensions of effective practice. Science Education, 88, 655-682.

Bates, B. (2005). Public culture and public understanding of genetics: a focus group study. Public Understanding of Science, 14(1), 47-65.

Bell, R.L. & Lederman, N.G. (2003). "Understanding of the NOS and Decision Making on Science and Technology-Based Issues". Science Education, 87(3), 352–77.

Brossard, D., Shanahan, J. (2006). Do they know what they read? Science Communication, 28(1), 47-63.

Bybee, R. (1985). The Sysyphean question in science education: What should the scientifically and technologically literate person know, value and do – as a citizen? In R.W. Bybee (Ed.), Science-technology-society. 1985 NSTA Yearbook, pp. 79-93. Washington: National Science Teachers Association.

Bybee, R. (2000). Achieving technological literacy: A national imperative. The Technology Teacher, 60, 23-28.

Cachapuz, A., Praia, J., Jorge, M. (2004). From Science Education to Science Teaching: an epsitemological rethinking. Ciência & Educação, 10(3), 363-381.

Chiappetta, E., Fillman & Sethna, G. (1991). A method to quantify major themes of scientific literacy in science textbooks. Journal of Research in Science Teaching, 28, 713-725.

Chiang-Soong, B., & Yager, R.E. (1993). The inclusion of STS material in the most frequently used secondary science textbooks in the U.S. Journal of Research in Science Teaching, 30(4), 339-349.

DeBoer, G. (2000). Scientifc Literacy: Another Look at Its Historical and Contemporary Meanings and Its Relationship to Science Education Reform. Journal of Research in Science Teaching, 37(6), 582-601.

Dimopoulos, K. & Kouladis V. (2003). Science and Technology Education for Citizenship: The Potential Role of the Press. Science Education, 87(2), 241-256.

Donnelly, J. (2005). Reforming Science in the School Curriculum: A Critical Analysis. Oxford Review of Education, 31(2), 293–309.

Durant, J. R. (1993). What is scientific literacy? In J. R. Durant & J. Gregory (Eds.), Science and culture in Europe, pp. 129–137. Science Museum. London.

Fensham, P. (1988). Development and Dilemmas in Science Education. Bristol: Taylor & Francis.

Fensham, P.J. (2002). "Time to Change Drivers for Scientific Literacy," Canadian Journal of Science, Mathematics and Technology Education, 2(1), 9–24.

Fernández, I. (2000). Análisis de las concepciones docentes sobre la actividad científica: una propuesta de transformación. PHd tesis. Departamento de Didáctica de las Ciencias Experimentales y Sociales. València: Universitat de València.

Fernández, I., Gil, D., Carrascosa, J., Cachapuz, A. & Praia, J. (2003). "Visiones Deformadas de la Ciencia Transmitidas por la Enseñanza". Enseñanza de las Ciencias, 20(3), 477–488.

Feyerabend, P. (1975). Against Method: Outline of an Anarchistic Theory of knowledge. London: NLB.

Finley, F. (1994). Por qué los estudiantes tienen dificultades para aprender de los textos de ciencias. In C. Santa & D. Alvermann. (comp.). Una Didáctica de las Ciencias. Argentina: AIQUE Didáctica.

Gaskell, P.J. (1992). Authentic Science and School Science. International Journal of Science Education, 14, 265–72.

Gil-Pérez, D., Vilches, A., Fernández, I., Cachapuz, A., Praia, J., Valdéz, P. & Salinas, J. (2005). Technology as "Applied Science": A Serious Misconception that Reinforces Distorted and Impoverished Views of Science. Science & Education, 14, 309-320.

Hodson, D. (1992). "Redefining and Reorienting Practical Work in School Science". School Science Review, 73(264), 65-78.

Hodson, D. (1996). 'New Thinking on the Role of Practical Work in Science Teaching'. In D. Stow & G. McCall (Eds), Geoscience Education and Training in schoolsand Universities, for Industry and Public Awareness, pp. 215–232. AGID, A. A. Balkema.

Jenkins, E. W. (1994). Scientific literacy. In T. Husen & T. N. Postlethwaite (Eds.), The international encyclopaedia of education, 9(2) 5345–5350. Oxford: Pergamon Press.

Kalman, C. (2011). Enhancing Students' Conceptual Understanding by Engaging Science Text with Reflective Writing as a Hermeneutical Circle. Science & Education. 20(2), 59-172.

Knain, E. (2001). Ideologies in School Science textbooks. International Journal of Science Education, 23(2), 319-329.

Koelsche, C. L. (1965). Scientific literacy as related to the media of mass communication. School Science and Mathematics, 65(8), 719-725.

Laugksch, R. C. (2000). Scientific Literacy: A Conceptual Overview. Science Education, 84(1), 71–94.

Layton, D., Jenkins, E., Macgill, S. & Davey, A. (1993). Inarticulate science? Perspectives on the public understanding of science and some implications for science education. Driffield: Studies in Education.

Leach, J., Millar, R., Ryder, J. & Séré, M-G. (2000) Epistemological understanding in science learning: the consistency of representations across contexts. Learning and Instruction, 10(6), 497-527.

Lederman, N. G., Wade, P. D., & Bell, R. L. (1998). Assessing understanding of the nature of science: Ahistorical perspective. In W. McComas (Ed.), The nature of science and science education: Rationales and strategies, pp. 331–350. Dordrecht: Kluwer Academic.

Lederman, N. G. (1992). Students' and teachers' conceptions of the nature of science: A review of the research. Journal of Research in Science Teaching, 29, 331-359.

Lederman, N. G., & Lederman, J. S. (2005). The nature of science and scientific inquiry. In G.Venville & V. Dawson (Eds.), The Art of Teaching Science, pp. 2-17. Crows Nest: Allen & Unwin.

Lee, O. (1997). Scientific Literacy for All: What Is It, and How Can We Achieve It? Journal of Research in Science Teaching, 34(3), 219-222.

Leite, L. (2002). History of Science in Science Education: Development and Validation of a Checklist for Analysing the Historical Content of Science textbooks. Science Education, 11, 333-359.

Lewenstein, B. V. (2001). Who produces science information for the public? In J. H. Falk (Ed.), Free-choice science education: How we learn science outside of school, pp. 21-43. New York: Teachers College Press.

Mathews, M. (1998). "The Nature of Science and Science Teaching", in B. Fraser & K. Tobin (Eds), International Handbok of Science Education, pp. 981-999. Dordrecht: Kluver Academic Publishers.

McComas, W., Clough, P. & Almazroa, H. (2000). The role and character of the nature of science in science education. In McComas W. (2002) The nature of science in science education: Rationales and strategies (pp. 3-39). Dordrecht: Kluwer Academic Publishers.

McComas, W. & Olson, J. (1998). The nature of science in international science education standards documents. In W. F. McComas (Ed.) The Nature of Science in Science Education: Rationales and Strategies, pp. 41-52. The Netherlands: Kluwer Academic Publishers.

Millar, R. & Osborne, J. (1998). Beyond 2000: Science Education for the Future. The Report of a Seminar Series Funded by the Nuffield Foundation. London: King's College London, School of Education.

Millar, R. (2002). Towards a science curriculum for public understanding. In S. Amos & R. Boohan (Eds.). Teaching science in secondary schools, pp. 113-128. London: Routlege/Falmer and The Open University.

Miller, J. (1998). The measurement of civic scientific literacy. Public Understanding of Science, 7, 203.

Miller, J. & Pardo, R. (2000). Civic scientific literacy and attitude to science and technology: A comparative analysis of the European Union; THE United States and Canada. In Dierkes, M. & Grote, C. (Eds.), Between understanding and trust: The public, science and technology. Oxon: Routledge.

National Research Council (1996). National Science Education Standards. Washington: National Academic Press.

National Research Council (2000). Inquiry and the National Science Education Standards. Washington: National Academic Press.

National Science Teachers Association (1971). NSTA position statement on school science education for the 70's. The Science Teacher, 38, 46 - 51.

OECD (2007). PISA 2006. Science competencies for tomorrow's world – analysis. Retrieved from http://www.oecd.org/dataoecd/30/17/39703267.pdf

Orpwood, G. W. (1984). Science education in Canadian Schools, 1. Quebec: Canadian Government Publishing Centre.

Osborne, J. (2000). Science for citizenship. In M. Monk & J. Osborne (Eds.), Good practice in science teaching, pp. 225-240). Buckingham: Open University Press.

Osborne, J., Collins, S., Ratcliffe, M., Millar, R. & Duschl, R. (2003). What "ideas-about-science" Should Be Taught in School Science? A Delphi Study of the Expert Community. Journal of research in science teaching, 40(7) 692-720.

Osborne, J. & Dillon, J. (2008). Science Education in Europe: Critical reflections. London: The Nuffield Foundation.

Osborne, J., Duschl, R., Fairbrother, R. (2002). Breaking the mould: Teaching science for public understanding. London: The Nuffield Foundation.

Pingel, F. (1999). UNESCO guidebook on textbook research and textbook revision. Hannover: Verlag Hahnsche Buchhandlung.

Quessada, M. & Clément P. (2007). An Epistemological Approach to French Syllabi on Human Origins during the 19th and 20th Centuries. Science and Education, 16, 991-1006.

Ratcliffe, M. (2001). "Science, Technology and Society in School Science Education". School Science Review, 82, 83–92.
Reis, P. R. (2008). A Escola e as Controvérsias sociocientíficas: Perspectivas de Alunos e Professores. Lisboa: Escolar Editora.
Rocard, M., Csermely, P., Jorde, D., Dieter Lenzen, Walberg-Henriksson, H. and Hemmo V. (2007). Science Education Now: A Renewed Pedagogy for the Future of Europe. Brussels: Directorate General for Research, Science, Economy and Society.
Rosenthal, D. B. (1984). Social issues in high school biology textbooks. Journal of Research in Science Teaching, 21(8), 819–831.
Rudolph, J. L. (2003). Portraying Epistemology: School Science in Historical Context. Science Education, 87, 64-79.
Ryan, A. & Aikenhead, G. (1992). Students' preconceptions about the epistemology of science. Sience Education, 76(6), 559-580.
Sadler, T. D. & Zeidler, D.L. (2004) "The Morality of Socioscientific Issues: Construal and Resolution of Genetic Engineering Dilemmas". Science Education, 88(1), 4–27.
Scharfenberg, F-J & Bogner, FX (2010). Instructional efficiency of changing cognitive load in an out-of-school laboratory. International Journal of Science Education, 32(6), 829-844.
Schwartz, R. S. & Lederman, N. G. (2008). What Scientists Say: Scientists' views of nature of science and relation to science context. International Journal of Science Education, 30(6), 727-771.
SCCC, Scottish Consultative Council on the Curriculum (1996). Science education in Scottish schools: Looking to the future. Broughty Ferry.
Shamos, M. H. (1995). The myth of scientific literacy. New Brunswick: Rutgers University Press.
Smith, M. U., Lederman, N. G., Bell, R. L., McComas, W. F. & Clough, M. P. (1997). How Great is the Disagreement about the Nature of Science: A Response to Alters. Journal of Research in Science Teaching, 34(10), 1101-1103.
Smith, M. U., & Scharmann, L. C. (1999). Defining versus describing the nature of science: A pragmatic analysis for classroom teachers and science educators. Science Education, 83, 493-509.
Solbes, J. & Vilches, A. (1997). 'STS Interactions and the Teaching of Physics and Chemistry. Science Education, 81(4), 377–386.
Solomon, J. (1993). Teaching science, technology and society. Buckingham: Open University Press.
Solomon, J. & Aikenhead, G. (1994) STS Education: International Perspectives on Reform. New York: Teachers College Press.
Stanley. W. B. & Brickhouse, N. W. (2001). Teaching sciences: The multicultural question revised. Science Education, 85, 35-49.
Stocklmayer, S. & Treagust, D. (1994). A Historical Analysis of Electric Currents in Textbooks: A Century of Influence on Physics Education. Science and Education, 3, 131-154.
Thomas, G. & Durant, J. (1987). Why should we promote the public understanding of science? Scientific Literacy Papers, 1, 1-14.
Tamir, P. (1985). Content analysis focusing on inquiry. Journal of Curriculum Studies, 17 (1), 87-94.
Turner, S. (2008). School Science and its controversies; or, whatever happened to scientific literacy? Public Understanding of Science, 17, 55-72.
UNESCO (1983). Bangkok: Science for all.
UNESCO (2005). Paris: Unesco science report.
Wellington, J. (1991). Newspaper science, school science: friends or enemies?. International Journal of Science Education, 13, 363-372.
Wilkinson, J. (1999). A Quantitative Analysis of Physics Textbooks for Scientific Literacy Themes. Research in Science Education, 29(3), 385-399.

Zeidler, D.L., Sadler, T.D., Simmons, M.L. & Howes, E.V. (2005). Beyond STS: A Research-Based Framework for Socioscientific Issues Education. Science Education, 89(3), 357–77.

Ziman, J. (1994) The Rationale of STS Education is in the Approach. In J. Solomon & G. Aikenhead (Eds) STS Education: International Perspectives on Reform, 21-31. New York: Teachers College Press.

Zimmerman, C., Bisanz, G. L., Bisanz, J., Klein, J. S. & Klein, P. (2001). Science at the supermarket: A comparison of what appears in the popular press, experts' advice to readers, and what students want to know. Public Understanding of Science, 10(1), 37-58.