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SOCIETAL ISSUES AND THEIR IMPORTANCE FOR CONTEMPORARY SCIENCE EDUCATION—A PEDAGOGICAL JUSTIFICATION AND THE STATE-OF-THE-ART IN ISRAEL, GERMANY, AND THE USA

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ABSTRACT. One common theme underlying recent reports on science education is that the content of school science and its related pedagogical approaches are not aligned with the interests and needs of both society and the majority of the students. Most students do not find their science classes interesting and motivating. These claims are especially valid regarding those students who, in the future, will probably not embark on a career in science or engineering but will need science and technology personally and functionally as literate citizens. One key problem seems to be that few science programs around the world teach how science is linked to those issues that are relevant to students' life, environment, and role as a citizen. As a result, many students are unable to participate in societal discussions about science and its related technological applications. This paper discusses the need to incorporate socioscientific ideas into the science curricula more thoroughly. This recommendation is supported by a theoretical rationale from various sources leading to a reflection about common practices in science education in three countries: Israel, Germany, and the USA. The state-of-the-art, potentials, and barriers of effective implementation are discussed.

KEY WORDS: context-based-learning, relevance, science curriculum, scientific literacy for all, socioscientific issue, teaching and learning science

An Era of Reform and the Direction to Go

In many countries, the gloomy results of the international comparative assessments, *Trends in International Mathematics and Science Study* (TIMSS; since 1995) and the *Program for International Student Assessment* (PISA; since 2000; Bybee, Fensham & Laurie, 2009; Anderson, Chui & Yore, 2010), initiated a wave of documents, all of which encompassed a call for rethinking the goals and pedagogy of science education. Both the content and pedagogy of science education are being scrutinized, and new standards have been initiated intended to shape effective science education. The innovative work *Science for All Americans* (Rutherford & Ahlgren, 1991) and subsequent publications by the Project 2061, e.g., *Benchmarks for Science Literacy* (AAAS, 1993) and the *National Science Education Standards* (NRC, 1996) in the USA,

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directly influenced similar national standards and policies in other countries such as Germany (KMK, 2004) or Israel (Tomorrow 98, 1992). In recent years, this point of view was supported by a comprehensive set of scholarly papers urging the need to develop and implement more relevant, high-skill-oriented, and contextualized science education (Eilks, Marks & Feierabend, 2008; Gilbert, 2006; Hofstein & Kesner, 2006; Holbrook, 2005; Holbrook & Rannikmäe, 2007) but also by several national and international reports, e.g., in the USA *Before it is too late* (John Glenn's committee, 2000), or in Europe *Beyond 2000* (Millar & Osborne, 1998), or *Science Education in Europe: Critical Reflections* (Osborne & Dillon, 2008).

One common feature underlying all these reports and initiatives is that the content and pedagogy of school science are not aligned with the needs of most of the students (Jenkins, 2005; Millar, 2009; Sjöberg & Schreiner, 2006). Even in countries in which the results of TIMSS and PISA are above average, students do not find their science learning motivating or relevant (Morell & Lederman, 1998; Osborne, 2003; Osborne, Driver & Simon, 1998). These claims are especially valid regarding the majority of students who, in the future, will probably not embark on a career in science and engineering, but they will need a basic understanding of science and technology in order to function as literate citizens (Holbrook & Rannikmäe, 2007; Roth & Lee, 2004; Osborne & Dillon, 2008).

There is uniform criticism that the reason for the lack of motivation and interest in science education is that in many countries the school science program is overloaded with content and that the curricula exclusively emphasize the foundational content of the science disciplines (Gräber, 2002; Gilbert, 2006; Holbrook, 1998; Millar & Osborne, 1998). This emphasis often results in science curricula characterized by isolated facts detached from their scientific origins (De Vos, Bulte & Pilot, 2002) and with little orientation toward relevant applications to students' life and the society (Holbrook, 2005). As a result, students do not make connections between the learned facts and concepts needed for their application and thus fail to develop recognition of its relevance. The learned facts become *inert knowledge* only connected to the context of being part of 'school science'. The learned science does not become *applicable knowledge*, and in the end, students are unable to participate in discussions about science and technology-based societal issues (Gilbert, 2006; OECD, 2006; Osborne & Collins, 2001). Thus, learning of science (especially chemistry and physics) is perceived by students as lacking personal relevance. This lack of perceived relevance leads to both low levels of motivation and a generally diminished interest in chemistry or physics as a discipline (Morell & Lederman, 1998; Osborne, 2003, 2007; Osborne et al., 1998) and might be one of the reasons for the decline in enrollment in science courses in upper secondary and higher education (Gilbert, 2006).

Although the idea of linking the learning of science to societal issues is not new (e.g. Solomon & Aikenhead, 1994), we will revisit this question from different perspectives and through experiences from various countries, by addressing three questions:

- What is today the pedagogical and philosophical justification for using societal issues in contemporary science education?
- What kind of societal contexts has potential to help students to become well-informed and critical citizens via science education?
- What is the actual state-of-the-art regarding implementation of socioscientific issues-based science education, what are its potentials, and what are barriers for effective implementation?

Incorporating Societal Issues into Science Teaching: a Continuing Issue in the Past 25 Years Revisited and Justified from Various Theoretical Perspectives

Science for All

In the 1980s, Hofstein & Yager (1982) and Fensham (1988) claimed that the science curricula of the 1960s and 1970s emphasized mainly preparation of a limited number of students who had enrolled in science courses to prepare themselves for future careers in science and technology. But since the early 1980s, new goals and standards for the science curriculum have been described toward adopting the idea of attaining scientific literacy *for all* students. This idea became guiding policy in the USA by the *National Science Education Standards* (NRC, 1996) promoting scientific literacy for all under explicit inclusion of standards concerning *science in social and personal perspectives*. A similar source of justification is the term *for all* in the concept of *Scientific and Technological Literacy for All*, which became a guiding policy for the UNESCO *Project 2000+* in the 1990s (Holbrook, 1998). Also the *Project 2000+* emphasized the societal dimension of science education, suggesting that it has the potential to enhance the interest of students and that subsequently it will motivate them for science learning as well as to participate in societal debates dealing with scientifically oriented issues.

A Contemporary Meaning of Scientific Literacy

As it was reflected for the *Project 2000+* (Holbrook, 1998), for a long time, debates have taken place regarding the conceptual meaning of 'Scientific Literacy' (Gräber & Bolte, 1997; Bybee, 1997; De Boer, 2000; Millar, 2009; Norris & Phillips, 2003; Roberts, 2007). Nevertheless, nearly all concepts explicitly emphasized the societal dimension as being an essential part of developed scientific literacy up to a political level. For example, based on Bybee (1997), the OECD (2006) defined scientific literacy as the basis for PISA (Bybee et al., 2009) as the understanding and skills that empower individuals to make personal decisions and appropriately participate in the formulation of public policies that impact their lives.

In all these publications, the question of making appropriate decisions about scientific and technological issues beyond individual actions by means of responsible citizenship is pronounced (Holbrook & Rannikmäe, 2007; Marks & Eilks, 2009; Zeidler, Sadler, Simmons & Howes, 2005). It is suggested that scientific literacy encompasses the learner's ability to communicate within and about science according to the original meaning of literacy (Norris & Phillips, 2003), and it also involves having an adequate understanding of the interaction of science and technology with our everyday life and the society in which we operate (Marks & Eilks, 2009).

Also, a recent definition of chemistry literacy included explicitly a societal component as a necessary dimension (Shwartz, Ben-Zvi & Hofstein, 2005, 2006). In Israel, this definition initiated the introduction of science instruction using societal relevant issues related to chemistry such as nutrition, industry, and environment. It was suggested that science programs should incorporate teaching/learning materials that assist the teacher in making science teaching more relevant by integration of socioscientific issues, to support the development of cognitive and meta-cognitive strategies as well as emotional and motivational dispositions in an interesting environment.

Regarding the issue of learning about the role of science in society, McCann-Sherman (1999) claimed that one of the ways is by studying community issues that evoke diverse viewpoints, as well as to present competing interpretations of data and to offer choices among possible actions. This is in alignment with Marks & Eilks (2009) or Sadler (2004), who advocated the idea of a stronger inclusion of authentic and controversial debates from within society into science teaching that “encourage personal connections between students and the issues discussed, explicitly address the value of justifying claims and expose the importance of attending to contradictory opinions” (Sadler, 2004, p. 523).

Following Roberts (1988, 2007), science teaching should move from what he called *Vision I*, in which knowledge and concepts should be learned and only later be applied generally in various situations, toward *Vision II*, where learning science should be situated in authentic contexts. He suggested that the objectives of secondary school science include (1) to promote an understanding of the role of science in the development of societies, (2) to promote awareness of humanistic implications of science, (3) to develop a critical understanding of those current social problems that have a significant scientific component in terms of their cause and/or their solution (e.g. air pollution, or improper use of chemicals), and (4) to promote understanding and development of skills in the methods often used by scientists. Thus, Roberts clearly suggested a more thorough orientation of science on societal issues, as Kempa (1983) did in his outline of six interrelated dimensions of teaching and learning chemistry, which explicitly include personal, cultural, and societal dimensions, and as Yager & Lutz (1995) and Hofstein & Kempa (1985) did in their suggestion that content areas related to personal, cultural, and societal dimensions have high potential to provide rich pedagogical experiences for science education.

Conceptualizing ‘Allgemeinbildung’ to Science Education

Another theoretical foundation for more societal orientation of science education is found in the central European tradition of *Bildung* in its contemporary interpretation as *Allgemeinbildung* (e.g. Elmose & Roth, 2005; Westbury, Hopmann & Riquarts, 2000). *Allgemeinbildung* describes a 200-year-old unique central European tradition of defining the aim of education. Within this concept, part of the word *Allgemein* (which can be translated as ‘general’) has two dimensions. The first dimension means to achieve *Bildung* for all persons. The second dimension aims at *Bildung* in all human capacities (e.g. Klafki, 2000). The more difficult term to explain is the idea of *Bildung*, which has a tradition dating back to works of von Humboldt (1793/2000) in the late eighteenth century. Since then, various scholars have tried to clarify the concepts *Bildung* and *Allgemeinbildung*. Our contemporary understanding stems from the 1950s to the 1970s where *Allgemeinbildung* was described as the ability to recognize and follow one’s own interests in society and to behave within society as responsible citizens, i.e., to develop the capacity for self-determination, participation, and solidarity within society (Klafki, 2000). From the idea of *Allgemeinbildung*, Klafki and others developed the tool of *Didactical Analysis* to reflect on whether a topic or issue is relevant enough to be taught in compulsory formal education (Klafki, 1958/2000b). *Didactical Analysis* consists of a set of questions. According to Klafki, the most important questions reflect whether a topic or issue has relevance or personal meaning for the learner at present or in the future as having potential to raise their capacity for self-determination, participation in society, and solidarity with others.

Based on this theoretical framework, a stronger inclusion of societal issues in contemporary science education can also be justified. Dealing with issues that are socially relevant and which are actually discussed is relevant to the lives of students in present society. Skills developed along these lines will be important for students' participation in societal debates concerning the development of their future as scientifically literate citizens.

Activity Theory and Science Education

In recent years, Van Aalsvoort (2004a, 2004b), Roth &Lee (2004), and Holbrook & Rannikmäe (2007) referred to *Activity Theory* regarding its importance for science education. *Activity Theory* deals with the important connection between scientific knowledge and social practice, which is the "interlinking of knowledge and social practice through establishing a need (relevant in the eyes of students), identifying the motives (wanting to solve scientific problems and make socio-scientific decisions) leading to activity constituted by actions (learning in school towards becoming a scientifically literate, responsible citizen)" (Holbrook & Rannikmäe, 2007, p. 1353). Thus, *Activity Theory* deals with reflecting the content and pedagogy to fulfill the students' interests and needs. Including the common goal to educate responsible citizens, Holbrook and Rannikmäe suggest that "science education should be regarded as 'education through science', rather than 'science through education'" and that "the over-riding target for science teaching in school, as an aspect of relevant education, is seen in responsible citizenry, based on enhancing scientific and technological literacy" (p. 1347).

In more details, Holbrook & Rannikmäe (2007) combine critical factors in the argument for increased emphasis on societal issues in contemporary science education—nature of science, skill development, positive attitudes, decision making, and responsible citizenship. But all of this is seen as being potentially promoted by using socioscientific contexts within science education.

STS, SATIS, STL, SSI, etc.

The literature includes a large variety of related approaches for science education, based on societal contexts. The approaches are described under names as Science-Technology-Society (STS; e.g. Solomon & Aikenhead, 1994), Science and Technology in Society (e.g. Holman, 1986), Scientific and Technological Literacy for All (e.g. Holbrook, 1998), or different approaches of socioscientific issue-based teaching (e.g. Sadler, 2004, 2008; Sadler & Zeidler, 2009) or sociocritical approaches to science teaching (e.g. Marks & Eilks, 2009). The approaches vary in their objectives and thoroughness of societal orientation. Nevertheless, they seem to have one thing in common. Their application still seems to be rare in many countries (Gräber, 2002; Pederson & Totten, 2001).

Selecting Topics and Issues for Making Science Education More Relevant; The Question of 'Good Contexts' for Science Education

What Makes a Context Good?

What characteristics of context could be termed a 'good context' for promoting *Allgemeinbildung* or scientific literacy for all students? Some authors have recommendations regarding the contextual issue (Pilot & Bulte, 2006; Gilbert, 2006; Fensham, 2009). However, Sadler (2004), Zeidler et al. (2005), and Sadler & Zeidler (2009) criticized the poor links of science teaching with society—even as is the case in some of the context-based science curricula—and suggested that teaching/learning materials should encompass a more radical socioscientific issues-based approach.

Also from the tradition of *Allgemeinbildung*, a more thorough societal orientation in selecting topics for science education was advocated. Klafki (1958, 2000) raised this plea for identifying and using society's key problems in its respective epoch as the most promising contexts for *Allgemeinbildung*. For example, one of the key problems in our epoch definitely is the debate about climate change. Climate change is recognized worldwide as one of the central problems with which all nations are faced and to which they must respond. Understanding climate change has the potential for science learning. But it also has much potential to enhance students' knowledge about an issue that is definitely relevant to and essential for their future. In addition, this topic has also the potential to learn how such an issue is handled within society, and one can introduce the interplay of science with economics, politics, as well as cultural beliefs and values (Feierabend & Eilks, 2010). On the other hand, many topics and contexts in science curricula are important for the domain from which they stem. For example, learning about specific laws regulating thermodynamics can be helpful in a later stage regarding the study of physics and/or chemistry. However, taking the viewpoint of *Allgemeinbildung*, learning science without recognizing issues like the problem of climate change might prepare the students for studying science in a later stage. But without connecting a topic like thermodynamics toward societal issues, they will have nearly no potential to help enabling students to act as responsible citizens in their society in the future.

Based on the framework of *Allgemeinbildung*, in recent years in Germany, Eilks (2000, 2002; Marks & Eilks, 2009) advocated the idea of selecting contexts for science education by applying the criterion of having authentic societal debates of a controversial character to make science teaching motivating by using its relevance. As their underlying goal for science education was described to contribute to education for responsible citizenry, they emphasized to have students learn about the actions and intentions of stakeholders, politicians, media, or advertisers who often use (very often wrongly and persuasive) science-based information in their actions and also in their decisions. Students should become informed about the use and character of information they are faced too and its intended or unintended selection to be used for specific purposes in a political debate. A key idea is that citizens, even if they are scientists, always are confronted only to 'filtered information', filtered by journalists, politicians, and pressure groups. Thus, understanding the process of 'filtering' is as important as to understand the background from science if one intends to participate in societal debate. Thus, Marks & Eilks (2009) suggested a thorough consideration of respective contexts as an initial point for science teaching representing societal debate with having varied and contradictory opinions available in everyday-life media. As revisable criteria for selecting contexts of potential in the above discussed means, Marks & Eilks (2009) suggested the following: (1) authenticity: prove whether the issue actually is present in the everyday-life media, e.g., TV, newspapers, and advertisements; (2) relevance: prove that societal decisions in the framework of the issue will have a direct impact on the students' life presently or in the near future; (3) being undetermined in a societal respect: prove that different positions are documented in the societal debate, e.g., by stakeholders, pressure groups, and politicians; (4) allows for open discussion: prove that the debate must be possible without harming any of the students by touching too deeply their ethical or religious values or their socio-economic status; and (5) deals with a question of science and technology that can be proved by analysis of the scientific background. According to Marks & Eilks (2009), if these criteria are followed, the perception of relevance will potentially grow and science teaching will attain a cognitively challenging character.

The Issue of Relevance

As in Marks & Eilks (2009), in all the debate, unanimously the question of relevance is concerned. Science education should become relevant in the eyes of the students. However, the issue of relevance is rather complicated. Teachers and curriculum developers have to be constantly aware that the issue of relevance is a subjective judgment. Issues that are relevant to curriculum developers or science teachers might be irrelevant to the learner.

Keller (1987) in his Attention, Relevance, Confidence, and Satisfaction model tried to clarify what is meant by relevance in the framework of motivation. He described strategies that promote relevance: (1) experience, (2) present worth, (3) future usefulness, (4) needs matching, (5) modeling, and (6) choice. All these strategies represent various ways to help learners understand why and what they learn is important (and relevant) to them currently and in the future. Coming from the discussion above, each of them has the potential to be interpreted in a societal dimension when learning science.

More recently, also Van Aalsvoort (2004a) discussed the question of relevance in the context of science education and formulated four subcategories: (a) personal relevance—education by making connections to pupils' lives, (b) professional relevance—education by offering pupils a picture of possible professions that they can pursue in the future, (c) social relevance—education by clarifying the purpose of science in human and social issues, and (d) personal/social relevance—education by helping pupils become responsible citizens in the future. Also this discussion not only shows the multifaceted aspect of relevance but also shows clearly the need for incorporating the societal dimension of science to come to relevant science education.

Teaching Science in Societal Contexts—The Situation in Three Different Countries

In order to illustrate the state-of-the-art and the potential of incorporating socioscientific issues in the science classroom more thoroughly, we shall discuss the situation in three different countries with different educational systems, namely Israel, Germany, and the USA.

The Israeli Perspective

Over the years, several attempts were made in Israel to incorporate socioscientific issues into the science curricula. This curricular emphasis was used, e.g., in the context of developing and implementing learning materials related to the chemical industry (Hofstein & Kesner, 2006) or within the *Science for All* program (Cohen, Ben-Zvi, Hofstein & Rahamimoff, 2004; Hofstein & Dori, 2000).

Regarding the industrial chemistry project, the educational approach was to demonstrate to the students all the variables associated with an industrial chemistry plant, e.g., technology, scientific consideration, and economy and related societal issues. The societal dimension (labor or location of the plant) is necessarily one of these components. The industrial chemistry case study approach attempts to present chemistry not only for those who prepare themselves for a career in the sciences but also for those who will participate in science-related issues as literate citizens. It was assumed that industrial chemistry has potential in educating future citizens to cope with societal and ethical issues in general and related environmental implications, in particular. In utilizing different industrial chemistry materials, as well as a wide spectrum of pedagogical interventions, it was attempted to place greater emphasis on applied chemistry; teaching takes place in an industrial socioeconomic and environmental context (Kesner, Hofstein & Ben-Zvi, 1997). As a result, a whole series of industrial case studies was developed, e.g., *Bromine and its compounds* (Hofstein & Kesner, 2006). This project was accompanied by intensive evaluation. The results clearly show that such an interdisciplinary approach involved students in learning situations (including critical and valid decision-making activities) that will eventually change their perception that chemistry not only deals with pure, theoretical aspects but that is also relevant and can be applied to one's daily life.

The *Science for all Program* focused on students in upper secondary school (10th and 11th grade, ages 15–16), who opted not to specialize in science (biology, chemistry, and/or physics). Some 20 modules were developed, e.g., 'Light and Color', 'Biotechnology, Environment and Related Issues', 'The Age of Plastic', 'The Black Gold', or 'Energy and the Human Being'. Each module emphasizes a scientific issue or topic with societal ramifications and personal implications. They are interdisciplinary in nature and present various aspects or concepts derived from different scientific domains as an integral entity. For example, the module *Brain, medicine, and drugs* (Cohen et al., 2004) integrates concepts from various scientific disciplines, technological applications, and controversial social issues. As a result, it encompasses many relevant aspects and applications that have the potential to enhance the students' interest. This topic was selected because the current tenet regarding the brain and its biological role in humans has a long history of biological concepts, scientific research methods, ethical and moral issues, as well as the need for reasoning, critical thinking, and decision making.

Both projects influenced also a more recent initiative. Societal issues became the key component (the initiator) for the European Union project *Popularity and Relevance (of) Science Education (for scientific) Literacy* (PARSEL, Holbrook, 2008). PARSEL learning materials (modules from the eight participating countries) were designed to make science teaching and learning more student-centered, more relevant, and enjoyable (popular) by relating the learning to students' everyday-life experiences (Holbrook, Rannikmäe & Kask, 2008). All together, the project consisted of about 60 different modules. In Israel, two modules were adopted: *Smile with Healthy Teeth* (developed in Greece by Tsaparlis & Papaphotis, 2002) and *Milk: Keep It Refrigerated* (developed in Estonia). Both modules deal with health and nutrition, respectively, and were taught by experienced chemistry teachers to whom the interdisciplinary approach (including the socioscientific issues) was novel. It became clear that in order to provide the teachers with valid tools that will help them implement the modules, one has to involve them in various stages of adapting to their unique school environment and to enable them to make decisions related to the content and pedagogy of the module. In order to bridge this gap, the following constraints were used as guidelines for adopting the modules (Blonder, Kipnis, Mamlok-Naaman & Hofstein, 2008): (1) from science taught for a future career in the sciences to science taught for responsible citizenship; (2) from science education emphasizing basic cognitive concepts to increased emphasis on relevance, argumentation, and collaboration, with the goal in mind of enhancing cognitive learning; (3) from a science discipline to a more interdisciplinary approach of using science content; and (4) from a teacher-centered approach to a more inquiry-type, student-centered approach.

To summarize the Israeli experience, one can claim that introducing socioscientific issues into the regular curriculum is possible. However, there are several factors that inhibit this process. The two key barriers for effective implementation of socioscientific approaches are mainly the teachers' beliefs and deficits in their respective professional development concerning pedagogical content knowledge regarding socioscientific issues-based science teaching.

The German Perspective

The roots of societal-oriented science teaching in Germany date to the 1970s. Freise and the group SOZNAT (*Naturwissenschaften sozial:* science social) tried to promote a political perspective on applying science and technology as the motive for teaching and learning science (Freise, 1994). The intention was to integrate the learning of science with the large debates of the 1970s in Germany concerning a growing ecological consciousness, or the debate about the use of nuclear technology in military and non-military applications. However, this approach was to a large extent and according to many stakeholders quite ideologically based, and therefore, it provoked a lot of resentment and animosity. Science education in this sense was perceived as promoting specific political positions. Thus, this approach was not in line with the idea of *Allgemeinbildung*, which intends to educate students to be able to develop their personal views but does not attempt to indoctrinate them with the point of view of their peers. As a result, there was a strong political movement not to politicize science education too much in general and chemistry and physics education in particular. This led to a situation whereby most of these initiatives in the 1980s and 1990s played only a minor role in chemistry and physics but with less rejection in biology. Biology education underwent a reform in which ecological and societal questions were implemented as necessary components in the curriculum, e.g., healthy nutrition, environmental protection, and family planning. Nevertheless, even in biology education, this reform did not lead to a balanced integration of socioscientific issues. In general, the teaching of biology usually focused on a traditional science background and ethical reflections and thus referred to only a part of the relevant societal dimensions.

Following the not successful results of Germany in TIMSS and PISA, a reform in its educational system began. For the first time, in 2004, Germany initiated nationwide standards for education in many subjects, among them the sciences (KMK, 2004). These standards are described in four domains: (1) scientific knowledge, (2) the generation of knowledge in science, (3) communication, and (4) evaluation. The last two domains of standards explicitly call for a stronger inclusion of socioscientific issues in the science education framework. For example, level three in the standard domain 'evaluation' refers to the ability to "weigh arguments for the evaluation of an issue from different perspectives and to reflect upon decision making processes." Together with selected standards, e.g., from the chemistry domain, i.e., B5 "The pupils discuss and evaluate societal relevant statements from different perspectives," science teaching without strongly considering a societal approach is no longer appropriate (KMK, 2004). Similar standards are also found in the biology standards but are rare in the physics standards.

Accompanying this reform, there were several initiatives and ideas with the goal in mind of promoting a stronger orientation toward teaching science by a context or socioscientific issues-based approach. One example is adopting the ideas of the Salters project from the UK (Burton, Holman, Pilling & Waddington, 1994) within the project *Chemie im Kontext* to develop a context-driven curriculum for upper secondary chemistry education (Nentwig, Parchmann, Gräsel, Ralle & Demuth, 2007) and later also was expanded to projects in biology and physics. The entire curriculum is structured using a series of contexts that are thought to be meaningful for the student rather than just supporting the conceptual approach of chemistry. Many of the units include at least some societal relevant questions, some of which even begin with a societal point of view. A similar approach was based by the German parts of the PARSEL project (e.g. Gräber & Lindner, 2008; see above within "The Israeli Perspective") which was connected to a related, industry-based approach: The project Partnership of Industry and Schools (Gräber, 2002) used partnerships involving science departments in schools with small- and medium-sized industrial enterprises and thus automatically includes the different societal dimensions every industrial enterprise has to cope with.

Also a more radical socioscientific issues-driven approach to science teaching was presented and implemented in Germany in the last 10 years, entitled "a socio-critical and problem-oriented approach to chemistry teaching" (e.g. Eilks, 2000, 2002; Marks & Eilks, 2009). This approach seeks to initiate science teaching from controversial and authentic issues from within society to promote students' skills in being able to understand, actively participate in, and reflect about societal issues regarding science-related topics (Marks & Eilks, 2009). Several modules based on this approach were developed, e.g., about low-fat and low-carb diets, about the potential risks of musk fragrances in shower gels, the problem of certain alcoholic drinks especially advertised for young people, or the use of bioethanol as a fuel (Eilks et al., 2008; Marks & Eilks, 2009). In the rare case studies where teachers implemented this approach, accompanying research clearly showed that a thorough orientation of science education along societal issues is possible and that it leads to high motivation among teachers and students and contributes to developing skills of communication and evaluation, which are necessary for developing a responsible citizenry. We suggest that one of the reasons could be by the development and implementation through action research and its potential to contribute to professional development and enhance ownership among the teachers (Marks & Eilks, 2010).

Although there have been several initiatives promoted by various scholars, which aimed at promoting a stronger orientation toward everyday-life relevant topics, technical applications, or societal issues, application of these concepts in science classrooms is still rare. The dominant practice in chemistry and physics education is still guided by a conceptual knowledge approach oriented toward the structure of the science and is organized along the inner systematics of the respective academic discipline (Fischer, Klemm, Leutner, Sumfleth, Tiemann & Wirth, 2005; Ostermeier & Prenzel, 2005).

In summary, apparently the educational system in Germany is ready for more socioscientific issues-based science teaching. The national standards allow for, if not demand, more societal-driven science education. The first textbooks, both from the *Chemie im Kontext* group and from the group working on the sociocritical and problem-oriented chemistry education, are available for upper and lower secondary chemistry education, which include respective issues, materials, and methods. Tendencies in biology and physics teaching are going in the same direction, and first materials are now available. Nevertheless, changes have not yet occurred. The main reason can be seen in the beliefs of experienced science teachers about the perceived orientation and emphasis of science teaching in schools and teachers' lack of experience with socioscientific issues in science education. However, ongoing projects, based on action research approaches or the concept of teachers' learning communities, seem to hold promise for positive change (e.g. Eilks, Parchmann, Gräsel & Ralle, 2004).

The USA Perspective

Goals for science education in the USA have long recognized personal and societal issues. Although these goals have been continually recognized, they have been subordinate with the dominate goals being scientific knowledge and scientific methods (Bybee & DeBoer, 1993). Historically, the rationale for teaching science and addressing various societal issues has been based on the fact that many, if not a majority, of contemporary societal problems have scientific and technological components underlying their origins, their solutions, or both. Although the rationale is strong, the response in curricula, instruction, assessments, etc., has been weak.

In recent years, the teaching of science in social contexts has emerged with the general aim of attaining higher levels of scientific literacy for all students and with a re-orientation about what scientific literacy in this context means. In the USA, scientific literacy has been used extensively to describe the purposes, policies, programs, and practices of science education. The realization of scientific literacy, however, does not represent the reality of science education. Evidence from curriculum materials and instructional practices suggests that somewhere between the abstract purpose and the concrete practice the science education community has failed to realize this goal.

Today, two essays stand out when discussions turn to contemporary science education and the challenges of teaching science in social contexts and attaining higher levels of scientific literacy in the USA. In "Science Education for the Twenty First Century," Jonathan Osborne (2007) makes a clear case that regardless of the use of scientific literacy as a stated aim, contemporary science education is primarily 'foundationalist' in that it emphasizes educating for future scientists versus educating future citizens. The second essay is by Roberts (2007) and identifies continuing political and intellectual tension with a long history in science education. The two politically conflicting emphases can be stated in a question: Should the curriculum emphasize science subject matter itself, or should it emphasize science in everyday-life situations in which science plays a key role? Based on the *Project 2061* (Rutherford & Ahlgren, 1991) and the *Benchmarks for Science Literacy* (AAAS, 1993) and taking into account the experiences of the STS movement in the US and Canada (Solomon & Aikenhead, 1994; Bybee, 1985), the *National Science Education Standards* (NRC, 1996, 2005) recognized the importance of helping students understand and act on various social issues. The *Standards* include 'Science in Personal and Social Perspectives' and different aspects of health at each set of grade levels (K-4, 5–8, and 9–12). There are also contexts for populations, resources, and environments at all grade levels, or included natural hazards (e.g. earthquakes, volcanoes, floods, fires, and hurricanes). Finally, they include science and technology in local, societal, and global challenges. The incorporation of 'science into personal and social perspectives' in national standards (see above) was intended as a signal that this content was considered a standard and should be included in all school science programs. It is safe to say that the intention was not realized in school programs and assessments. In reality, state standards only give marginal recognition to these standards or content that is aligned with these standards.

To sum up, introducing societal issues and fostering scientific literacy does require a different scientific perspective or emphasis on science education. In the USA, most school science programs do not emphasize scientific literacy, i.e., science presented in contexts for citizens, as a major aim of education. To clarify this issue, the term scientific literacy is constantly stated as the purpose of science education, and respective curricula and teaching materials are available (e.g. Chemistry in the Community, ACS, 1988), but those responsible for school programs interpret scientific literacy as foundationalist and primarily emphasize facts, information, and knowledge of the science disciplines and only secondarily emphasize how science applications are related to citizens' daily life situations.

Barriers for Effective Implementation of Societal Issues in the Context of Science Education and Suggested Methods to Overcome them

One of the most central factors that inhibit effective implementation of societal issues into regular science education programs is the teachers' personal beliefs. Teachers' beliefs are considered to be the most influencing factor regarding why and how they behave and act in class (Bandura, 1986). However, these beliefs are usually not developed systematically on the basis of educational evidence. The most influential factor regarding teachers' beliefs is the practice perceived by them while they were students in school (Kagan, 1992; Veal & Hill, 2004) and later in university (Geddis & Roberts, 1998), or the use of practices and experiences reported by trusted colleagues who act as a model for imitation (Appleton & Kindt, 1999). These beliefs can become barriers for effective implementation of different content, instructional techniques, and pedagogical interventions and help perpetuating traditional practices (Goodman, 1988).

A recent survey conducted in the USA (Luft, Ortegaz & Wong-Kavas, 2009) showed that a high percentage of the science teachers strongly support the importance of incorporating more real-world issues into their classroom in order to increase the relevance of science, as it was recognized by Pederson & Totten (2001) concerning societal issues. However, this does not automatically lead to a situation where the societal dimension of socioscientific issues becomes an equal partner in the teaching and learning of science because the positive view of the teachers does not receive enough support by their immediate professional community.

For most of the teachers, the socioscientific issues-based approach is unfamiliar. Although some teachers already have positive attitudes toward a stronger inclusion of societal issues into society, they often fail to implement societal issues due to the lack of support and scaffolding (Pederson & Totten, 2001). It can be assumed that, for many teachers as well as for many professional development providers, teaching science-related issues is a novel idea to which they were neither exposed in their initial training (pre-service) at the university nor in other professional development experiences. In dealing with socioscientific issues, teachers find themselves in situations in which they have to obtain and learn background materials from various sources (biology, chemistry, and physics) as well as from economy, environment, politics, ethics, health, or nutrition. This often places them in an unfamiliar situation in which they are not knowledgeable, which in return leads to a low likelihood of implementing a societal-driven approach (Pedretti, Bencze, Hewitt, Romkey & Jivraj, 2008). This situation exists in many countries since both in the pre-service as well as in-service science and science education courses provide very limited direct (or indirect) experiences through which the teacher can develop skills and knowledge needed to organize and facilitate meaningful learning experiences regarding socioscientific issues. It is suspected that without a solid background, well-developed skills, and high familiarity in using information from multiple sources, teachers will continue to be reluctant to adopt socioscientific ideas in their regular classroom programs (Pedretti et al., 2008).

Clearly, the solution should be to increase teachers' confidence regarding the implementation of societal-driven curricular approaches. Professional development providers should develop and implement more thoroughly models in which teachers will be involved in all the skills that are related to this instructional approach. One of the possible remedies to these phenomena is to make available initial training and professional development programs in which the idea of teachers' beliefs and experiences are intensively challenged. Based on our experience, running through intended teaching situations, e.g., mimicking societal debates in role playing (Marks, Bertram & Eilks, 2008), working as journalists, writing about scientific topics (Marks & Eilks, 2010), or mimicking political decision-making processes (Feierabend & Eilks, 2010), can lead to similar discussions and changes in the perception of the science education among the teachers and teacher trainees, as it does with the school students.

In addition to collecting experiences with already developed examples, the collaborative development of new examples proofed to be an effective strategy for change. In the PARSEL project, a professional development approach was applied in which teachers were highly involved in the development and adoption of the instructional strategies and learning materials (Blonder et al., 2008). It was found that the extensive involvement of teachers significantly reduced their anxiety in teaching novel scientific content and also increased their sense of ownership regarding teaching according to the new approach. Marks et al. (2008; Marks & Eilks, 2009, 2010) described similar experiences while using *Participatory Action Research* (Eilks & Ralle, 2002) to jointly develop and implement lesson plans for a socioscientific issue-driven approach. From both experiences, it is suggested that for effective implementation of socioscientific issues, teachers need to be provided with support that can be attained, for example, through continuous professional development procedures (Harrison, Hofstein, Eylon & Simon, 2008), involvement in curricular development (Hofstein, Mamlok & Carmeli, 1997), or through action research (Marks & Eilks, 2010).

Another barrier is the way students are assessed regarding their achievement and progress (Holbrook, 2005). Even when science is taught in a context with a genuine attempt to make the learning relevant, often students continue to be assessed by their teachers using traditional, concept-oriented, paper and pencil tests. Hughes (2000) wrote (based on the example of the SALTERS curriculum in the UK) that students often marginalize the socioscientific dimension of learning if the structures and language of texts and classroom practices are not aligned with a socioscientific approach. This necessarily is also aligned with the traditions and practices of external examinations systems in which the societal dimension often neglected and only the scientific topics are assessed. Unique and authentic assessment methods aligned with the goals, pedagogical approach, and content of the approach are necessary to make such an approach a success (Holbrook, 2005). This is also a question of the influence of universities and central examination boards. Both are very influential regarding how science is taught (regarding the content and the methods) and how students are assessed in the sciences (Fensham, 1993). As a result, often teachers teach mainly the pure scientific concepts by a content-structure-driven and teacher-centered approach but tend to reject or diminish a student-centered strategy for teaching the relevant societal aspect. The literature is rich in many valuable strategies for effective implementation of socioscientific issues in the science classroom (e.g. role-play, drama, business games, debates, or simulating political decision making). However, a rather gloomy picture exists regarding the development of assessment tools that are aligned with the philosophical features described here (Holbrook, 2005).

Summary and Conclusion

In this paper, we analyzed the rationale and potential role of incorporating societal issues into science education. The discussion was motivated by a critical confrontation regarding the difference between two perspectives of science teaching. The prevailing perspective is *internal* to science itself. In this perspective, educational policies, programs, or practices begin with questions such as what knowledge of science and its processes should students possess? What facts and concepts from physics, chemistry, biology, and the Earth sciences should be the basis for school science programs? In contrast, there is an *external* perspective that begins with life situations that citizens might encounter. When teachers think about educational policies, programs, and practices from this perspective, typical questions focus on: What aspects of science might be helpful for students *as future citizens*? What contexts could be the basis for introducing science and technology? The difference between these two perspectives is significant because the design of curricula, the selection of instructional strategies, and its related support for the professional education of science teachers differs, and thus subsequently, its related outcomes will also differ.

Based on several different theoretical frameworks, it was generally agreed that the inclusion of societal issues into science education should be enhanced in order to raise the potential of science education to promote scientific literacy for all students. However, it was also suggested that those societal issues that are chosen for science education should meet different criteria. Marks & Eilks (2009), based on several sets of studies, suggested a set of criteria for selecting potential socioscientific issues. The criteria should be authenticity, personal and societal relevance, openness of the societal debate, the possibility of open discussion, and the relation to science and technology. According to Marks and Eilks, if these criteria are followed, the perception of relevance will potentially grow and science teaching will attain a cognitively challenging character. However, although there are innovative projects in different countries aligned with the framework outlined in this paper, in general, a lot of those who are in the center of decision making regarding curricula and syllabuses and also most of the textbook authors in Germany, the USA, or Israel seem to hold the internalized perspective that school science programs should first and foremost emphasize the basic knowledge and processes of science and only secondarily link to social issues.

We believe that the essence of the discussion presented here suggests that if the science education community wants to foster higher levels of scientific literacy (Bybee, 1997; Shwartz et al., 2006), then it is essential to recognize the external perspective as an essential component of science education and to accept the importance of designing and developing programs and implementing teaching practices consistent with these goals. What this means, in other words, is that science teachers, science educators, and curriculum developers must more thoroughly consider societal desiderata in science education which are (a) to develop curricula and teaching materials that focus the learning about dealing with societal issues related to science and technology, (b) to develop appropriate assessments to appraise students' attainment of the objectives of these approaches, (c) to better educate teachers in a way that enable them to implement these materials and assessments effectively, and (d) to find ways of providing rewards for teachers and students who are successful in attaining the goals of socioscientific issues-based science education.

References

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

American Chemical Society (ACS) (1988). *Chemistry in the community*. Dubuque, IA: Kendall & Hunt.

Anderson, J. O., Chui, M.-H. & Yore, L. D. (2010). Special issue "First cycle on PISA (2000–2006)—international perspectives on successes and challenges: Research and policy directions". *International Journal of Science and Mathematics Education, 8*, 373–609.

Appleton, K. & Kindt, T. (1999). How do beginning elementary teachers cope with science: Development of pedagogical content knowledge in science. *Paper presented at the annual meeting of the National Association for Research in Science Teaching*. Boston, MA.

Bandura, A. (1986). *Social foundation of thought and action: A social cognitive theory*. Englewood, NJ: Prentice-Hall.

Blonder, R., Kipnis, M., Mamlok-Naaman, R. & Hofstein, A. (2008). Increasing science teachers' ownership through adaptation of the PARSEL modules: A "bottom-up" approach. *Science Education International, 19*(3), 285–301.

Burton, G., Holman, J., Pilling, G. & Waddington, D. (1994). *Salters advanced chemistry*. York, UK: Heinemann.

Bybee, R. W. (Ed.). (1985). *Science–technology–society, NSTA yearbook*. Washington, DC: National Science Teachers Association.

Bybee, R. W. (1997). Toward an understanding of scientific literacy. In W. Gräber & C. Bolte (Eds.), *Scientific literacy—an international symposium* (pp. 37–68). Kiel, Germany: IPN.

Bybee, R. W. & DeBoer, G. (1993). Goals for the science curriculum. In D. Gable (Ed.), *Handbook of research on science teaching and learning* (pp. 357–387). Washington, DC: National Science Teachers Association.

Bybee, R., Fensham, P. J. & Laurie, R. (2009). Special issue: Scientific literacy and contexts in PISA science. *Journal of Research in Science Teaching, 46*(8), 861–960.

Cohen, D., Ben-Zvi, R., Hofstein, A. & Rahamimoff, R. (2004). On brain, medicines and drugs: A model for the "Science for All" program. *The American Biology Teacher, 66*(1), 9–19.

De Boer, G. (2000). Scientific 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.

De Vos, W., Bulte, A. M. W. & Pilot, A. (2002). Chemistry curricula for general education: Analysis and elements of a design. In J. K. Gilbert, R. Justi, O. de Jong & J. Van Driel (Eds.), *Chemical education: Towards research-based practice* (pp. 101–124). Dordrecht, The Netherlands: Kluwer Academic Press.

Eilks, I. (2000). Promoting scientific and technological literacy: Teaching biodiesel. *Science Education International, 11*(1), 16–21.

Eilks, I. (2002). Teaching 'biodiesel': A sociocritical and problem-oriented approach to chemistry teaching, and students' first views on it. *Chemistry Education: Research Practice, 3*(1), 67–75.

Eilks, I., Marks, R. & Feierabend, T. (2008). Science education research to prepare future citizens—chemistry learning in a socio-critical and problem-oriented approach. In B. Ralle & I. Eilks (Eds.), *Promoting successful science learning—the worth of science education research* (pp. 75–86). Aachen, Germany: Shaker.

Eilks, I., Parchmann, I., Gräsel, C. & Ralle, B. (2004). Changing teachers' attitudes and professional skills by involving teachers into projects of curriculum innovation in Germany. In B. Ralle & I. Eilks (Eds.), *Quality in practice oriented research in science education* (pp. 29–40). Aachen, Germany: Shaker.

Eilks, I. & Ralle, B. (2002). Participatory action research in chemical education. In B. Ralle & I. Eilks (Eds.), *Research in chemical education—what does this mean?* (pp. 87–98). Aachen, Germany: Shaker.

Elmose, S. & Roth, W.-M. (2005). Allgemeinbildung: Readiness for living in a risk society. *Journal of Curriculum Studies, 37*(1), 11–34.

Feierabend, T. & Eilks, I. (2010). Raising students' perception of the relevance of science teaching and promoting communication and evaluation capabilities using authentic and controversial socio-scientific issues in the framework of climate change. *Science Education International, 21*(3), 176–196.

Fensham, P. J. (1988). Familiar but different: Some dilemmas and new direction in science education. In P. J. Fensham (Ed.), *Development and dilemmas in science education* (pp. 1–26). London: Falmer.

Fensham, P. J. (1993). Academic influence on school sciences. *Journal of Curriculum Studies, 25*(1), 53–64.

Fensham, P. J. (2009). Real world contexts in PISA science: Implications for context-based science education. *Journal of Research in Science Teaching, 46*(8), 884–896.

Fischer, H. E., Klemm, K., Leutner, D., Sumfleth, E., Tiemann, R. & Wirth, J. (2005). Framework for empirical research on science teaching and learning. *Journal of Science Teacher Education, 16*(4), 309–349.

Freise, G. (1994). *Für einen politischen Unterricht von der Natur*. Marburg, Germany: Soznat.

Geddis, A. N. & Roberts, D. A. (1998). As science students become science teachers: A perspective on learning orientation. *Journal of Science Teacher Education, 9*(4), 271–292.

Gilbert, J. K. (2006). On the nature of context in chemical *education*. *International Journal of Science. Education, 28*(9), 957–976.

Glenn, J. (2000). *Before it's too late: A report to the nation from the national commission on mathematics and science teaching for the 21st century*. Washington, DC: NCMST.

Goodman, J. (1988). Constructing a practical philosophy of teaching: A study of pre-service teachers' professional perspectives. *Teaching and Teacher Education, 4*(2), 121–137.

Gräber, W. (2002). Chemistry education's contribution to scientific literacy—an example. In B. Ralle & I. Eilks (Eds.), *Research in chemical education—what does this mean?* (pp. 119–128). Aachen, Germany: Shaker.

Gräber, W. & Bolte, C. (Eds.). (1997). *Scientific literacy—an international symposium*. Kiel, Germany: IPN.

Gräber, W. & Lindner, M. (2008). The impact of the PARSEL way to teach science in Germany on interest, scientific literacy, and German national standards. *Science Education International, 19*(4), 267–274.

Harrison, C., Hofstein, A., Eylon, B.-S. & Simon, S. (2008). Evidence-based professional development of science teachers in two countries. *International Journal of Science Education, 30*(5), 577–591.

Hofstein, A. & Dori, J. Y. (2000). The development implementation and initial research findings of 'Science and Technology for All' in Israel. *Paper presented at the international symposium on connecting communities through research in science and technology education for all: An international perspective*. New Orleans, LA: NARST.

Hofstein, A. & Kempa, R. F. (1985). Motivating aspects in science education: An attempt at an analysis. *European Journal of Science Education, 7*(3), 221–229.

Hofstein, A. & Kesner, M. (2006). Industrial chemistry and school chemistry: Making chemistry studies more relevant. *International Journal of Science Education, 28*(9), 1017–1039.

Hofstein, A., Mamlok, R. & Carmeli, M. (1997). Science teachers as curriculum developers of science for all. *Science Education International, 8*(1), 26–29.

Hofstein, A. & Yager, R. E. (1982). Social issues as organizers for science education in the 80's. *School Science and Mathematics, 82*(7), 539–547.

Holbrook, J. (1998). Operationalising scientific and technological literacy—a new approach to science teaching. *Science Education International, 9*(2), 13–18.

Holbrook, J. (2005). Making chemistry teaching relevant. *Chemical Education International*, 6 (1). Retrieved August 01, 2009, from the World Wide Web at http://old.iupac.org/publications/cei/vol6/06_Holbrook.pdf.

Holbrook, J. (2008). Introduction to the special issue of science education international devoted to PARSEL. *Science Education International, 19*(3), 257–266.

Holbrook, J. & Rannikmäe, M. (2007). The nature of science education for enhancing scientific literacy. *International Journal of Science Education, 29*(11), 1347–1362.

Holbrook, J., Rannikmäe, M. & Kask, K. (2008). Teaching the PARSEL way: Students' reactions to selected PARSEL modules. *Science Education International, 19*(3), 303–313.

Holman, J. (1986). *Science and technology in society. General guide for teachers*. Hatfield, UK: The Association for Science Education.

Hughes, G. (2000). Marginalization of socioscientific material in science–technology–society science curricula: Some implications for gender inclusivity and curriculum reform. *Journal of Research in Science Teaching, 37*, 426–440.

Humboldt, W. v. (1793/2000). Theorie der Bildung des Menschen. English translation in I. Westbury, S. Hopmann & K. Riquarts (Eds.). *Teaching as a reflective practice: The German Didaktik tradition* (pp. 57–62). Mahwah, NJ: Lawrence Erlbaum.

Jenkins, E. W. (2005). Important but not for me: Students' attitudes towards secondary school science in England. *Research in Science & Technological Education, 23*(1), 41–57.

Kagan, S. M. (1992). Professional growth among preservice and beginning teachers. *Review of Educational Research, 62*(2), 129–169.

Keller, J. M. (1987). Development and use of the ARCS model of instructional design. *Journal of Instructional Development, 10*(3), 2–10.

Kempa, R. F. (1983). Developing new perspectives in chemical education. *Proceedings of the 7th international conference in chemistry, education, and society*. Montpellier, France (pp. 34–42).

Kesner, M., Hofstein, A. & Ben-Zvi, R. (1997). Student and teacher perceptions of industrial chemistry case studies. *International Journal of Science Education, 19*(6), 725–738.

Klafki, W. (1958/2000b). Didaktik Analysis as the core for preparation of instruction. In I. Westbury, S. Hopmann & K. Riquarts (Eds.), *Teaching as a reflective practice: The German Didaktik tradition* (pp. 85–108). Mahwah, NJ: Lawrence Erlbaum.

Klafki, W. (2000). The significance of classical theories of Bildung for a contemporary concept of Allgemeinbildung. In I. Westbury, S. Hopmann & K. Riquarts (Eds.), *Teaching as a reflective practice: The German Didaktik tradition* (pp. 85–108). Mahwah, NJ: Lawrence Erlbaum.

KMK (2004). *Bildungsstandards im Fach Chemie für den Mittleren Bildungsabschluss*. München, Germany: Luchterhand.

Luft, J., Ortegaz, I. & Wong-Kavas, S. (2009). *NSTA's state of science education survey*. Washington, DC: NSTA.

Marks, R., Bertram, S. & Eilks, I. (2008). Learning chemistry and beyond with a lesson plan on potato crisps, which follows a socio-critical and problem-oriented approach to chemistry lessons—a case study. *Chemistry Education: Research and Practice, 9*(3), 267–276.

Marks, R. & Eilks, I. (2009). Promoting scientific literacy using a socio-critical and problem-oriented approach to chemistry teaching: Concept, examples, experiences. *International Journal of Science and Environmental Education, 4*(3), 231–245.

Marks, R. & Eilks, I. (2010). The development of a chemistry lesson plan on shower gels and musk fragrances following a socio-critical and problem-oriented approach—a project of participatory action research. *Chemistry Education: Research and Practice, 11*(2), 129–141.

McCann-Sherman, W. (1999). *Teaching about societal issues in science classrooms. SE 99-6*. Columbus, OH: ERIC Clearinghouse for Science, Mathematics and Environmental Education.

Millar, R. (2009). On scientific literacy and curriculum reform. *International Journal of Science and Mathematics Education, 4*(3), 201–213.

Millar, R. & Osborne, J. F. (Eds.). (1998). *Beyond 2000: Science education for the future*. London: King's College London.

Morell, P. D. & Lederman, N. G. (1998). Students' attitudes toward school and classroom science: Are they independent phenomena? *School Science and Mathematics, 98*(2), 76–83.

National Research Council (NRC) (1996). *National Science Education Standards*. Washington, DC: National Academy Press.

National Research Council (NRC) (2005). *Systems for state science assessment*. Washington, DC: National Academies Press.

Nentwig, P., Parchmann, I., Gräsel, C., Ralle, B. & Demuth, R. (2007). Chemie im Kontext—a new approach to teaching chemistry; its principles and first evaluation data. *Journal of Chemical Education, 84*(9), 1439–1444.

Norris, S. P. & Phillips, L. M. (2003). How literacy in its original sense is central to scientific literacy. *Science & Education, 87*(2), 224–240.

OECD (2006). *Assessing scientific, reading and mathematical literacy*. Paris, France: OECD.

Osborne, J. F. (2003). Attitude towards science: A review of the literature and its implications. *International Journal of Science Education, 25*(9), 1049–1079.

Osborne, J. F. (2007). Science education for the twenty first century. *Eurasia Journal of Mathematics, Science & Technology Education, 3*(3), 173–184.

Osborne, J. & Collins, J. (2001). Pupils' views of the role and value of the science curriculum: A focus-group study. *International Journal of Science Education, 23*(5), 441–467.

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

Osborne, J., Driver, R. & Simon, S. (1998). Attitudes to science: Issues and concerns. *School Science Review, 79*(288), 27–33.

Ostermeier, C. & Prenzel, M. (2005). What can we learn from different forms of evaluation? Experiences from a quality-development program in science and mathematics instruction. In J. Benett, J. Holman, R. Millar & D. Waddington (Eds.), *Evaluation as a tool for improving science education* (pp. 145–158). Münster, Germany: Waxmann.

Pederson, J. E. & Totten, S. (2001). Beliefs of science teachers towards teaching of science/technological/societal issues: Are we addressing national standards. *Bulletin of Science, Technology and Society, 21*(5), 376–393.

Pedretti, E. G., Bencze, L., Hewitt, J., Romkey, L. & Jivraj, A. (2008). Promoting issues-based STSE perspectives in science teacher education: Problems of identity and ideology. *Science & Education, 17*(8–9), 941–960.

Pilot, A. & Bulte, A. M. W. (2006). Special issue: Context based chemistry education. *International Journal of Science Education, 28*(9), 953–1112.

Roberts, D. A. (1988). What counts as science education. In P. Fensham (Ed.), *Development and dilemma in science education*. Barcecome, Lews, East Sussex, UK: Falmer Press.

Roberts, D. A. (2007). Scientific literacy/science literacy. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research in science education* (pp. 729–780). Mahwah, NJ: Lawrence Erlbaum.

Roth, W.-M. & Lee, S. (2004). Science education as/for participation in the community. *Science & Education, 88*(2), 263–291.

Rutherford, F. J. & Ahlgren, A. (1991). *Science for all Americans: The project 2061*. New York: Oxford University Press.

Sadler, T. D. (2004). Informal reasoning regarding socioscientific issues: A critical review of research. *Journal of Research Science Teaching, 41*(5), 513–536.

Sadler, T. D. (2008). Socioscientific issues in science education: Labels, reasoning, and transfer. *Cultural Studies in Science Education, 04*, 2008.

Sadler, T. D. & Zeidler, D. (2009). Scientific literacy, PISA, and socioscientific discourse: Assessment for progressive aims of science education. *Journal of Research in Science Teaching, 46*(8), 909–921.

Shwartz, Y., Ben-Zvi, R. & Hofstein, A. (2005). The importance of involving high school teachers in the process of identifying and defining the operational meaning of chemical literacy. *International Journal of Science Education., 27*(3), 323–344.

Shwartz, Y., Ben-Zvi-R & Hofstein, A. (2006). Chemical literacy: What does it mean to scientists and school teachers? *Journal of Chemical Education, 83*(10), 1557–1561.

Sjøberg, S. & Schreiner, C. (2006). How do learners in different cultures relate to science and technology? Results and perspectives from the project ROSE (the Relevance of Science Education). *APFSLT: Asia-Pacific Forum on Science Learning and Teaching*, *7*(1).

Solomon, J. & Aikenhead, G. (Eds.). (1994). *STS education: International perspectives on reform*. New York: Teachers College Press.

Tomorrow 98 (1992). *The report on reform in science education*. Jerusalem, Israel: The Ministry of Education.

Tsaparlis, G. & Papapihotis, G. (2002). Classroom activity # 47: Brushing up on chemistry. *Journal of Chemical Education, 79*, 1168A–1168B.

Van Aalsvoort, J. (2004a). Logical positivism as a tool to analyse problem of chemistry's lack of relevance in secondary school chemistry education. *International Journal of Science Education, 26*(9), 1151–1168.

Van Aalsvoort, J. (2004b). Activity theory as a tool to address the problem of chemistry's lack of relevance in secondary school chemistry education. *International Journal of Science Education, 26*(13), 1635–1651.

Veal, W. R. & Hill, C. (2004). Beliefs and knowledge in chemistry teacher development. *International Journal of Science Education, 26*(3), 329–351.

Westbury, I., Hopmann, S. & Riquarts, K. (Eds.). (2000). *Teaching as a reflective practice. The German Didaktik tradition*. London: Lawrence Erlbaum.

Yager, R. E. & Lutz, M. V. (1995). STS to enhance total curriculum. *School Science and Mathematics, 95*(1), 28–35.

Zeidler, D. L., Sadler, T. D., Simmons, M. L. & Howes, E. V. (2005). A research based framework for socio-scientific issues education. *Science & Education, 89*(3), 357–377.

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