Promoting Scientific Literacy: Science Education Research in Transaction

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PREFACE

This proceedings volume is a documentation of a symposium that was part of the Linnaeus Tercentenary 2007 Celebrations held at Uppsala University. Gaalen Erickson and Douglas Roberts received Honorary Doctorates in the area of Science Education and to celebrate this, a special symposium entitled *Promoting Scientific Literacy: Science Education Research in Transaction* was held. A large group of invited speakers presented a diversity of perspectives as they explored a future vision for science education research and practice by articulating a more expansive notion of scientific literacy than has previously been the case. These explorations involved discussions of both theoretical and practical issues in relation to questions regarding the teaching and learning of this 'revised' notion of scientific literacy at both the individual and the societal levels.

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STATEMENT OF CONCERN

We, the members of the 2007 Linné Scientific Literacy Symposium, wish to express our concern about the current state of science education in many countries on the following grounds.

Attitudinal data from many sources indicate that it is common for many school students to find little of interest in their studies of science and to quite often express an active dislike of it. In comparison with a number of other subjects, too many students experience science education as an experience dominated by the transmission of facts, as involving content of little relevance, and as more difficult than other school subjects. This experience leads to disinterest in science and technology as personal career possibilities, and only a mildly positive sense of their social importance.

Science education has often overemphasized the learning of a store of established scientific knowledge at the expense of giving students confidence in, or knowledge of, the scientific procedures whereby scientific knowledge is obtained. Science education researchers have thus given increased attention to how various aspects of the Nature of Science can be taught, but school science curricula remain too loaded with content knowledge for these aspects to be sufficiently well-emphasised by teachers.

In the last decade there have been widespread moves across many countries to increase the formal assessment of learning in science. These efforts have typically given more value to the students' retention of bits of scientific knowledge than to their abilities with the procedures of science and the application of scientific knowledge to novel real world situations involving science and technology.

Science education, perhaps because of the sheer depth and volume of the knowledge base of modern science, has isolated that knowledge from its historical origins and hence students are not made aware of the dynamic and evolving character of scientific knowledge, or of science's current frontiers. There is little flavour in school science of the importance that creativity, ingenuity, intuition or persistence have played in the scientific enterprise. Nor is there any real sense of any meaningful exploration of issues that relate ethical and personal accountability to modern scientific activity. Indeed, the existence of human enterprise that makes science possible is almost ignored in science education. Curricula and assessment need to support teachers' being able to share the excitement of the human dramas that lie behind the topics in school science with their students.

Recent policy statements about the changing nature of our Work and the Knowledge Society have challenged education systems to give priority to the development in students of competencies that focus on generic skills. In doing so they undermine the importance of those other competencies that are intimately dependent on content knowledge such as those that are associated with subjects such as science.

Citizens' lives are increasingly influenced by science and technology at both the personal and societal levels. Yet the manner and nature of these influences are still

largely unaddressed in school science. Few students complete a schooling in science that has addressed the many ways their lives are now influenced by science and technology. Such influences are deeply human in nature and include the production of the food we eat, its distribution, and its nutritional quality, our uses of transportation, how we communicate, the conditions and tools of our work environments, our health and how illness is treated, and the quality of our air and water.

Science education is not contributing as it could to understanding and addressing such global issues as *Feeding the World's Population, Ensuring Adequate Supplies of Water, Climate Change,* and *Eradication of Disease* in which we all have a responsibility to play a role. Students are not made aware of how the solution of any of these will require applications of science and technology, along with appropriate and committed social, economic and political action. As long as their school science is not equipping them to be scientifically literate citizens about these issues and the role that science and technology must play, there is little hope that these great issues will be given the political priority and the public support or rejection that they may need.

Reforms of science education that continue to frame scientific literacy in terms of a narrow homogeneous body of knowledge, skills and dispositions, fail to acknowledge the different ethnic and cultural backgrounds of students. Such science education stands in strong contrast to the popular media. It omits a discussion of the reciprocal interactions between science and world views and between values and science, that the media regularly recognises as important to the public interest. Furthermore, it fails to contribute to a fundamental task of schooling, namely, redressing societal inequalities that arise from differences such as race, sex and social status. Instead of equipping students to participate thoughtfully with fellow citizens building a democratic, open and just society, school science will be a key factor in the reproduction of an unequal and unjust society.

In the papers that follow, these concerns are directly addressed and a number of new directions for school science that have strong research support will be presented.

LINNÉ SCIENTIFIC LITERACY SYMPOSIUM
Opening Remarks by Douglas A. Roberts
University of Calgary, Canada

Introduction

The issues that frame our symposium are very broad and quite diverse. We are discussing one of the most prominent terms in recent science education professional literature. *Scientific literacy* and several closely related terms, including *science literacy*, *public understanding of science*, and *la culture scientifique*, are very much a part of the landscape of science education writing and research of the past half century. Indeed, such writing and research continues to amass at a steady, if not accelerating, rate.

Part of the background reading for the symposium is a chapter I prepared on the history and current status of the concept of scientific literacy, for a newly released handbook of research on science education (Roberts, 2007). The phrase refers to a broad umbrella goal for orienting science curriculum and teaching. Since its debut in the science education literature some fifty years ago, this concept has been given so many definitions that it now refers, at least potentially, to every conceivable objective of school science education and even out-of-school, or informal, science education provided by zoos, museums, science centres, and the like.

In my chapter I proposed that there appear to be two schools of thought that characterize all of this definitional activity, based on two 'visions' of the appropriate basis for generating conceptions of scientific literacy appropriate for school science. They are called, simply, *Vision I* and *Vision II*. On one hand, Vision I looks inward at science itself – its products such as laws and theories, and its processes such as hypothesizing and experimenting. According to this vision, goals for school science should be based on the knowledge and skill sets that enable students to approach and think about situations as a professional scientist would. Vision II, on the other hand, looks outward at situations in which science has a role, such as decision-making about socio-scientific issues. In Vision II thinking, goals for school science should be based on the knowledge and skill sets that enable students to approach and think about situations as a citizen well informed *about* science would.

Generating goal statements for school science from these two different points of view is nothing new. Neither is it new to cast them as 'inward' and 'outward' looking as I have done. I was influenced long ago by David Layton's (1972) characterization of the 1950s/1960s science curriculum reforms in England and the United States, as emphasizing an understanding of science "in its internal disciplinary aspects" to the neglect of science "in its external relations, of the nature of the science-society interface" (p. 12). What is new, however, is having the same phrase (scientific literacy) refer to both. How did this state of affairs come about?

An Emerging Educational Slogan

Scientific literacy is primarily a concept about curriculum goals. It suggests in very broad terms the overall character of what school science should be all about, what it should emphasize about science. Like many concepts about educational goals, this one started out as a slogan, when it first began to appear in the professional science education literature of the 1950s. In 1956, even before Sputnik generated considerable

turmoil about science education in the United States, a group of science education professionals formed the *Science Manpower Project* at Columbia University. A sizable number of American businesses and foundations (three dozen, in fact) funded this project, and people from universities and school systems across the country were involved. In their monograph containing policy recommendations for the nation (Fitzpatrick, 1960), the authors specified two concerns about science education in universities and schools: (1) the "inadequate" national output of new scientists, technologists, technicians, and science teachers, and (2) a widespread "species of scientific illiteracy" among many public officials "who were being called upon to resolve problems involving a number of scientific factors" but who have "little real familiarity with science" (p. vii). The latter group is singled out again in a cautionary note later in the report. Despite the importance of promoting and developing scientific manpower (sic), the authors asserted, it would be very important to promote and develop *scientific literacy* in the general public. That is, the citizenry needs to understand the way science works, how it is important in comprehending events of daily life, and similar aspects of knowing *about* science.

At about the same time, some prominent science educators in the United States (e.g., Hurd [1958], Johnson [1962]) were calling attention in the professional literature to the significance of scientific literacy for the task of rebuilding the school science curriculum. From the beginning of its appearance in United States policy and professional literature, scientific literacy has existed as a curriculum goal concept alongside the more familiar orientation of school science, namely the early pre-professional training of scientific 'manpower'. Klopfer (1969) even went so far as to suggest that alongside the "potential scientist stream" a separate "scientific literacy stream" be established, perhaps in separate high schools, for the "90% of students" who are not "potential scientists." A variation on this arrangement, in a less drastic form than separate schools, is currently being implemented and researched in England, in the program known as *21st Century Science*.

My focus on attention to scientific literacy in the United States in that particular time period is not intended to suggest that such considerations were not a part of educational thinking elsewhere in the world. It is simply to acknowledge that the literature on school science education in the United States contains a visible public record of professional discourse about scientific literacy stretching back to the late 1950s..

I would be remiss if I did not mention, at this point, the extraordinary life and work of the man in whose honour we are celebrating a 300th birthday in this city and throughout Sweden. Carolus Linnaeus, or Carl von Linné (as he took his name when made a Knight of the Realm in Sweden), was a most remarkable scientist, pharmacologist, physician, and teacher. There is no school child anywhere science is taught who has not heard of, and learned how to use, the Linnean classification system for plants and animals. But Linné also classified minerals in the soil, because he was interested especially in their role in the nourishment of different kinds of plants. Whenever you hear the opening strategic question in the game of Twenty Questions ('Is it animal, vegetable, or mineral?'), think of this extraordinary gentleman. There was no citizen of Sweden (and many other countries) this man did not reach out to, by collecting and sharing knowledge that linked organisms to economics, to nutrition, and to health. We might say he was the original 'Mr. Scientific Literacy' (or perhaps 'Professor Scientific Literacy,' since he held professorships in both Medicine and Pharmacy at Uppsala University). It is entirely

fitting that we are engaging in a symposium on scientific literacy in this place, at this time.

A Deluge of Definitions

So in the United States in the late 1950s and early 1960s, there was a phrase – a slogan – in the air: scientific literacy. Why all of the definitions? And how did we get to *Vision I* and *Vision II*? In educational thinking and language, a slogan is a rallying cry to pay attention to something, in this case something about the science curriculum. However, educational slogans have a slippery logic. They require that definitions flow from them, in order to be more precise about what to do, how to plan, how teaching should be conducted, and so forth. Between a slogan and its logical progeny, a definition, there is a logical act of stipulation, a choice about what the slogan means. It's sort of like Humpty Dumpty said to Alice, in Lewis Carroll's *Through the Looking Glass*: "When I use a word, it means just what I choose it to mean – neither more nor less."

A lot of definitional activity about scientific literacy ensued in the science education literature of the United States throughout the 1960s. Some researchers tried to consolidate all of that into a consensus. Milton Pella, at the University of Wisconsin Center for the Study of Scientific Literacy, was one of the most prominent. There is one common feature in all of this defining, as well as the attention paid at about this time in England to the concept of *public understanding of science*. Everyone agrees that students can't become scientifically literate without knowing some science, and everyone agrees that the concept needs to include some other types of understanding *about* science. The differences in definition have to do with just what, how much, for whom, and in what sort of conceptual balance.

We can get a quick glimpse of this unusual feature of moving from slogan to definition in education if we shift for a moment to the way slogans are used in advertising. I'll use a couple of examples from advertising in the post-war period in the United States that impressed me as a teenager. One is an ad from the duPont Corporation that said "Better Things for Better Living through Chemistry!" Nobody takes the trouble to parse a slogan of that sort to see what it really means. We don't usually do that with advertising slogans, because we don't need to. How about "There's a FORD in Your Future!" – vintage about 1946. Does that mean the Ford Motor Company is going to see to it that everyone's future includes owning a new Ford, even if the company has to give the cars away? Of course not, and we can catch the drift without needing a definition. However, suppose educational policy discourse promised a student "Better Living through Scientific Literacy!" or "There's Scientific Literacy in Your Future!" The nature of our enterprise is such that we could not escape the imperative to come through with a definition. And so it was with the slogan scientific literacy. The practical work of science education demands that we define such a term.

As I suggested earlier, the current status of the concept of scientific literacy can best be grasped if we cut through the many details about definitions and concentrate on two 'visions.' On one hand is the Vision II concept suggested by Fitzpatrick's original use of the slogan: a citizen's understanding of the enterprise of science and how it permeates human affairs other than – but also including – scientific investigation itself. On the other hand, Vision I concentrates on having students understand human affairs as a scientist would.

There is nothing new about this kind of tension in the teaching of school subjects. There has always been a tension between setting curriculum policy and objectives based on the image of an educated and accomplished professional in the area (say, a professional musician, or a professional athlete) and setting objectives based more on the image of an educated, non-specialist citizen (music appreciation, physical education for a healthy lifestyle). Nevertheless, this tension in the case of scientific literacy forms a general backdrop for our Symposium. While it is not my intention to comment on each of the papers, nor is it my role to do so in these Opening Remarks, in the next section I shall refer to some papers that contain observations related to state-of-the-art appraisals of the situation worldwide in school science education at this time.

Have We Entered a New Epoch in Science Education History?

The papers by Jonathan Osborne and Svein Sjøberg both characterize the current situation in science education in terms of a disconnect between what science classrooms are generally offering, on one hand, and students' science-related preoccupations and interests, on the other. Although this may be nothing 'really' new in science education history, the particular features of this disconnect strike me as a signal that a different kind of challenge for science educators is now afoot. Indeed, Peter Fensham says as much in his paper, suggesting that what has been happening in recent years has posed the necessity that science education be re-conceptualized once more.

Earlier, Fensham (1992) identified science education reforms as being marked by identifiable time periods at which notably different types of science education activity were going on. For example, he singled out "The 1950s/60s" as a time period of substantial change in the United States and England especially. The subsequent time period, during which activity was occurring with a broader scope both geographically and conceptually, he called "The 1980s and Beyond." Graham Orpwood also refers to these time periods and suggests they are differentiated by "paradigm shifts" and "revolutions," in the sense that Thomas Kuhn used those concepts to describe certain aspects of scientific research. Peter is referring primarily to the different foci and goals of curriculum development reforms. Graham is referring primarily to different paradigms guiding assessment and how those relate to goals, research, and conceptualization within the field. Both authors suggest that something significant was happening in the late 1990s. In his paper for our Symposium, Peter suggests that a new conceptualization of school science education is upon us. Graham cautions that the techniques and methodologies for assessment are lagging behind re-conceptualization of the field, which will threaten the viability of the new conceptualization. Both are correct, in my view.

I want to propose an encompassing term that captures at one go the sense of a time period, the significant events occurring in curriculum development in school science, and the features of the research and thinking paradigms that characterize activities of the research community. That term is *epoch,* selected for the following reasons.

One of the persistent complexities of our field, as a research endeavour, it that the events we study are always influenced by changing socio-political and demographic factors, factors that are an important part of using the term 'epoch' in historical accounts. Let us reflect for a moment on how different those factors were in

the 1950s/60s and the 1980s/Beyond – say, until the early 1990s. I agree with Peter that, starting at some point in the late 1990s, school science education entered a new epoch. Some of the indicators are external demands on our field: the increasing pace of globalization, a more intense focus on accountability, the rise of international testing programs to new prominence, the drive to increase the participation of females in science, and I would even toss in the signing of the Kyoto Protocol as a medallion of many nations' concerns about climate change. Among the internal developments within school science education were some major policy revision documents for science education such as *Beyond 2000* in England and the *National Science Education Standards* in the United States. Scientific literacy is prominent in both of these. Indeed, McEneaney (2003) asserts that scientific literacy (however defined) now enjoys a "worldwide cachet."

I suggest, therefore, that the papers prepared for our Symposium reflect, and illustrate, the onset of a new epoch in the history of school science education. This epoch is now, and will continue to be, marked by the contrast – indeed, the competition – between Vision I and II of scientific literacy. That contrast is marked already, in some features of the previous two epochs, as discussed below.

How Did We Get Here?

The epoch of the 1950s/60s was characterized by curriculum development projects with an intense focus on Vision I. All of the prestigious, high profile science courses developed for schools under auspices of the National Science Foundation in the United States and the Nuffield Foundation in England were focussed on two curriculum emphases (Roberts, 1982a, 1988), namely *Structure of Science* and *Scientific Skill Development*. Both are the inward looking manifestations of Vision I. Then, in the epoch of the 1980s and Beyond, Vision II began to make its presence felt significantly in the STS movement and other broader concerns about science education such as the relationships between science and technology, science and the environment, and science and health. There was more attention to curriculum emphases such as *Everyday Coping* and *Science, Technology, and Decisions.* With the benefit of hindsight, we can look back and sketch out a couple of trends that bear directly on our Symposium and on the features of this new epoch.

First, Vision II was more noticeable in the 1980s, to be sure. However, Vision I resurfaced in 1985 with the beginning of AAAS Project 2061, and continues to flourish. The project's *Benchmarks for Science Literacy* (published in 1993) and *Atlas of Science Literacy* (Volume 1 was published in 2001, Volume 2 "completing the maps" just this year) have now captured the imagination and commitment of the science curriculum development apparatus of many states in the United States. The expression *science literacy* in the Project 2061 materials is used consistently and deliberately instead of the more widespread expression *scientific literacy*, as the latter was used historically and still is in use in other countries. The distinction is a conspicuous marker for Vision I. It also stands in noticeable contrast to the use of *scientific literacy* as a backbone concept in the U.S. *National Science Education Standards*.

Second, the past 15 years or so have been marked by explosive development of research into various aspects of Vision II – the great variety of so-called companion meanings that accompany scientific meaning during science teaching and learning (Roberts and Östman, 1998). Science education research literature has changed

dramatically in this time period. New and different questions are being asked, and the papers prepared for this Symposium are good examples of this re-conceptualization of the field. Some of the questions being raised are perennial ones, but others reflect changing circumstances under which science education professionals have to work. Those changing circumstances in turn reflect the changing socio-political and demographic factors at work in this new epoch. It is to be expected that research will change under such circumstances.

I find it helpful to think about changes in research at these times of epochal change in terms of the distinction Joseph Schwab made some 40 years ago between "stable enquiry" and "fluid enquiry" (his terms, his spelling). This follows directly on Graham Orpwood's argument, because the distinction is much like Kuhn's distinction between normal science and revolutionary science, respectively. It is revolutionary science, in Kuhn's thinking, that is triggered by "paradigm shifts." My contention is that in recent years the field of science education research has gradually found serious inadequacies in the stable enquiry associated mainly with Vision I, and has entered the onset of a period of fluid enquiry. Schwab (1962, p. 14) characterizes the function of stable enquiry in the sciences as follows: "to accumulate what a doctrinal education teaches us to conceive as the whole of scientific knowledge. If the current principles of physiology [for example] are organ and function, the stable researcher in physiology is concerned with discovering the function of this organ, then that one, than another." Thus, if science education research writ large is generally preoccupied with Vision I stable enquiry, typical research questions have to do with how well students learn this bit of subject matter, then that one, then another; how well they master this process, then that one, then another; what misconceptions they hold in this domain, then that one, then another; their grasp of this aspect of scientific inquiry, then that one, then another. This is not for a moment to lessen the importance of the fruits of investigative labour in these areas. But this kind of research has increasingly shown itself to be unsatisfying to researchers who ask Vision II questions and practitioners who have Vision II concerns about their classrooms and curriculum committees.

Schwab characterized fluid enquiry in the sciences as a natural occurrence in the development of disciplines as they mature. Stable enquiry requires that knowledge building in a discipline adheres to, and accepts, the legitimacy of certain guiding principles of enquiry. But those principles can become exhausted. To persevere for a moment with the structure-function example cited earlier, Schwab's instances are as follows: "In physiology, for example, an organ is found which appears to have different functions under different circumstances." In physics, "particles are discovered whose behaviour has no stable connection with their charge and mass" (p. 16). "Fluid enquiry then proceeds to the invention of new conceptions and tests of them for adequacy and feasibility. Its immediate goal is not added knowledge of the subject matter, per se, but development of new principles which will redefine that subject matter and guide a new course of effective, stable enquiries" (p. 17).

In later work about the field of curriculum studies, first published in 1969, Schwab (1978) used these two aspects of knowledge building to make the case that theory alone is inadequate as a basis for conceptualizing curriculum research and curriculum making. In so doing he pointed to a number of symptoms that suggest theorizing in curriculum studies had reached a "crisis of principle" related to the field's reliance on principles of enquiry that were, essentially, exhausted. Symptoms include these, for example: all of the significant questions about the existing

principles have been answered, or else there are conflicting results in the literature that cannot be resolved. There is contentious debate in the literature, and a "flight" from the discipline itself to the sidelines, in critiques and meta-theories – some of which have the potential to re-conceptualize the field. Thus, he concluded, continued reliance on theory *alone* would not address the "moribund" state of the field, because theory has to be mediated with choices and actions about what should be done in practical settings.

To put that another way, say in science education, studies of effective ways to teach X, of the misconceptions students have to overcome to understand X, of the Piagetian stage of development most suitable for learning X – all of these are based on the assumption that X is what should be taught. Schwab's point is that continuing to imitate science-like theory as a basis for understanding curriculum is not a profitable way for the discipline to go, and the crises of principle are the signifiers that the discipline is sort of spinning its wheels. The same applies to the sub-disciplines, such as science education (see Roberts & Russell, 1975).

Crises of principle in a discipline can be methodological, as well. Science education research experienced a collective methodological crisis of principle that reached its peak in the early 1980s. In general, the science-like controlled experiment was at that time the 'gold standard' – the first among equals in a cluster of acceptable quantitative research methodologies. This was true for the acceptance of doctoral theses in most universities, for publication in refereed journals, and for placement on the program of research conferences. It was a hallmark of the education of new science education researchers as well, of course. Yet, unquestioned reliance on that methodological principle of enquiry left many important questions unanswered – questions that corroded the relevance of our discipline's knowledge building. We were collectively unable to develop understanding of some fairly significant challenges faced by practitioners. Many practitioners and researchers alike 'knew,' or at least suspected, that a lot was going on in school science classrooms other than the learning of science concepts and processes. Investigating the *qualities* of student experience required new and different qualitative methodologies. Yet, even the most careful and rigorous qualitative research methodology was dismissed as either story telling or else merely reporting the researcher's opinions. To be fair to those who were trying to protect the gold standard, there was a need for justification of qualitative research on a conceptual basis (Roberts, 1982b). The restrictions that existed on publication of qualitative research in that earlier epoch are almost unimaginable now.

Concluding Comments

I want to close with a few very general comments about the breadth, depth, and significance of the collection of papers prepared for our Symposium. The papers exemplify the best aspects of the new epoch in school science education, in my view. There are three notable features on which I will comment.

First, the papers explore a variety of aspects of Vision II. One recurring theme is relevance for students, which is a key factor that distinguishes Vision II from Vision I. Another is the relationship between school science and students' identity formation vis-à-vis science-related matters. Yet another is the exploratory development of new courses and new approaches to teaching in a manner that privileges Vision II.

Second, new research methodologies continue to gain acceptance in our research community and are well represented in this Symposium. The sea change that made qualitative studies a more or less acceptable research methodology happened during the onset of the epoch Fensham called the "1980s and Beyond." That was no coincidence. Different kinds of questions require different research methodologies, and different kinds of questions follow on changes in policy and practice. In this new epoch, we see a substantial increase in attention to methodologies that are tailored to the questions being asked, rather than vice-versa. The methodologies of discourse analysis, case studies, narrative inquiry, phenomenology, phenomenography, and critical theory are examples that come to mind.

Third, there is a notable expansion of acceptable theoretical perspectives brought to bear by, and accepted by, science education researchers. Once again, this variety is well represented in our Symposium. Just reflect for a moment on the number of new theoretical perspectives you can identify in the literature of the past 15 years or so. It used to be that the favoured perspectives for acceptance by refereed journals and conference program committees were fairly limited. You were safe if you based a study on Piagetian developmental psychology, either behavioural or cognitive psychology and its link to learning theory, several variants of the characteristics of science inquiry and, latterly, constructivism in its various guises. (A colleague of mine once quipped that you were either on one of those wagons, or under it.) Gradually, but inexorably, we have seen the marked appearance of such perspectives as those associated with gender studies, situated cognition, linguistics, non-Western/non-Eurocentric thought systems, moral and aesthetic philosophy, and the sociology of science. All of these allow us to explore the multiple qualities of students' and teachers' responses to aspects of Vision II scientific literacy.

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In the Path of Linnaeus: Scientific Literacy Re-Visioned with Some Thoughts on Persistent Problems and New Directions for Science Education

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I. Introduction

As you walk around the city of Uppsala (and other parts of Sweden) you can see signs that say "Linne Was Here". These signs identify locations and contexts that represent some aspect of Linne's travels around Sweden and provide some insight into the plant nomenclature that defined so much of his work.   So you might say that Carl von Linne (or Linnaeus as he is usually called) was very successful in preparing a path for us to follow these 300 years later. I like the 'path metaphor' as it not only provides some indication of his approach to pedagogy[1], but it is also a variant of the enactivist notion of "laying down a path in walking" (Varela, 1987). This metaphor has been further developed in the field of complexity theory as it informs educational thought and practice (Breen, 2005; Davis, Sumara & Kieran, 1996).

As I've read and been exposed to the many thoughts and reflections on the life and the contributions of Linnaeus's work it is clear that he prepared a very visionary path **both** in terms of the way that he conceptualized and subsequently formalized the living world that he experienced, and in terms of the pedagogy that he used to communicate his understanding of the natural world to the public as well as his own students.   In other words he was addressing what I will refer to later as the important "What Questions" in life as well as the "How Questions".

It would seem as though he may have been one of the first university professors, at Uppsala at least, to engage his students directly with the phenomena, be it showing specimens to his students during his classroom lectures or taking them on his famous nature walks. He was clearly aware of the importance of the context of learning and also the importance of the nature of the complex relationships between living things – particularly the holistic and inter-dependent relationships between humans and nature. These are still very contemporary themes and problems in both the scientific and pedagogical literature that I will discuss later in my paper

While attending a week of events celebrating Linnaeus's 300th birthday, I was struck by comments on Linnaeus's work from individuals in two very different settings.
Both the Archbishop of Sweden, Anders Wejryd (in his opening remarks welcoming guests to the Uppsala Cathedral) and the King of Sweden (in his comments at a state banquet) issued a challenge to all as they spoke in terms of our collective responsibilities and duties to continue on with the Linnaeus mission of better understanding the complex relationships between all living objects and the environment that supports and sustains them. It seems to me that this challenge is particularly germane to science educators. While the contexts and subsequent relationships change over time, our responsibilities as educators remain similar and given the current socio-ecological-political situation that we find ourselves, these responsibilities take on the form of a 'moral imperative'. Perhaps Archbishop Wejryd

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[1] The path metaphor is reminiscent of Donald Schön's notion of a "Follow me model" (Schön, 1987) for coaching a novice practitioner into some of the complexities of a professional practice.

said it best when in commenting on Linnaeus's life and work:

> [he] searched for what could hold life together. Through natural science,
> humanities and belief he tried to do his part in clearing a road from chaos
> to cosmos, both personally and for mankind. ... [We also] must accept
> the moral responsibility for the stewardship of life".

The Archbishop's message is clear: we have a moral responsibility for the stewardship of life so that future generations will have the opportunities to continue in the never ending quest to deepen our understanding of the interdependence of the biotic and abiotic world in which we live and to sustain hope for our collective future. These are some of the challenges that we face as educators as we engage in discussions and deliberations in symposia like the Uppsala Conference on "Promoting Scientific Literacy: Science Education Research in Transaction" and in other aspects of our personal and professional lives.

One of the aims of the Uppsala Symposium focuses on analyzing the science education community's current conceptions of scientific literacy with an end in view of generating some promising new lines of science education research. While this agenda is ambitious, it represents a bold attempt to bring together a group of science education researchers with a diverse set of interests and experiences to engage in sustained dialogue regarding problems and practices in the field of science education. In this regard any written materials emanating from the symposium ought to function like a good, synthetic review article by charting the terrain and bringing into sharp relief some of the current issues and dilemmas facing the field. Furthermore we should aim to map out some strategies for addressing these issues and for developing more satisfying ways of managing the dilemmas[2] that we identify in our deliberations. The juxtaposition of a focus on scientific literacy, which I'm taking to be a placeholder for the on-going deliberations about desirable aims and a rationale for teaching science in our educational institutions, with a "transactional" view of inquiry or research (Clancey, 2004, in press) provides a very rich topography upon which our various perspectives and points of view can take shape.

I am going to draw upon two quite different resources in responding to the challenges represented by the two thematic areas identified above. The first resource is somewhat unusual in that it comes from the language education community, not from the science education literature. I wish to consider both the process and the resultant products from this group of language educators deliberating (not unlike the current symposium) to rethink existing perspectives and research practices around "literacy pedagogy" (New London Group, 1996). The issues that they were grappling with and the approaches that they adopted to address two key questions for altering traditional literacy pedagogies (what they referred to as the "what question of literacy" and the "how question of literacy pedagogy) in my view resonate very nicely with the concerns of the current symposium.

The second resource will be a review article that I wrote with Rosalind Driver close to 25 years ago where we set ourselves a rather similar set of goals of both describing the state of play in the field of student science learning and identifying some possible fruitful directions for future research (Driver & Erickson, 1983).

My primary purpose in writing this paper is not to systematically review the literature in the area of scientific literacy or on current approaches to science pedagogy – other participants at this symposium are much more immersed in these

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[2] For a more extensive discussion on the nature of dilemmas and how they must be 'managed', rather than solved, see Cuban (1992).

literatures and have written important review papers on these two broad themes. Rather, my purpose is to try and stimulate a conversation about what I perceive to be some of the important issues facing science educators writ large[3] and it will be primarily based upon my experience of teaching and researching in the fields of science education and teacher education for over thirty-five years.

In this paper, then, I will first briefly review what I take to be some of the central issues surrounding the notion of scientific literacy, drawing primarily upon two sources: first, Robert's (2007) recent, extensive review of this conception; and second, a theme issue on scientific literacy in the Canadian Journal of Science, Mathematics and Technology where Fensham (2002) wrote the lead article accompanied by a number of other science educators responding to that article. I will then lay out some of the key issues identified by the New London Group as they deliberated about adopting a much more expansive notion of literacy and developed an action plan for how their newly constructed notion of "multiliteracies" could become an integral component of a new literacy pedagogy.   Then I will examine some of the issues that we were grappling with 25 years ago regarding the research literature on student learning and determine to what extent these issues, in particular as they pertain to pedagogy, are still germane and fruitful to the science education community. I will close with some thoughts on how we might proceed to address some of the problems raised by Roberts, Fensham and others regarding the 'what questions' of scientific literacy and some of the problems of pedagogy raised by the 'how questions'.

II. The '*What Question*' of Scientific Literacy

As I indicated earlier, my aim is not to engage in yet another review of 'scientific literacy', rather I want to identify what I see to be some of the key issues surrounding the use of this term as they might pertain to past and current work on the 'how question' of pedagogy. Over the past fifty years or so since the concept was purportedly introduced to the science education community by Hurd (1958), there has been considerable debate over the various meanings entailed by the use of this term and the associated aims for teaching science (Laugksch, 2000; Fensham, 2002; Roberts, 1983, 2007; Shamos, 1995). In a much earlier analysis of this concept Roberts (1983) suggested that scientific literacy "has had so many interpretations that it now means virtually everything to do with science education" (p. 22) and that it had "come to be an umbrella concept to signify comprehensiveness in the purposes of science teaching in the schools" (p. 29). Hence he concluded at that time that the term looked more like a slogan used by scientists and science educators to elicit support for teaching science in the schools than a clearly articulated aim for teaching science in the schools.

While the use of the term has waxed and waned over the years[4], the fact remains that 'scientific literacy' still occupies a central position in the rationale and statement of aims for many contemporary curriculum reform projects (e.g. AAAS, 2001; CMEC, 1997; Millar & Osborne, 1998; OECD, 1999; Wei & Thomas, 2006). For this reason, among others, it is important to try and bring some further conceptual

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[3] I think that we need to expand our traditional definition of science educator beyond that of university-based and school-based teachers and researchers to also include those educators working in informal settings and in the media.

[4] For example, Roberts (2007) points out that the term was used sparingly in reviews of the literature in the 90's.

clarity to the term.

Roberts has undertaken just such a task in completing an extensive and thorough review of the literature on scientific literacy for a recently released Handbook on Science Education Research (Roberts, 2007). In brief, he argues that there has always been a "continuing political and intellectual tension … [between] two legitimate but potentially conflicting curriculum sources: science subject matter itself, and situations in which science can legitimately be seen to play a role in other human affairs. … At issue is the question of balance." He labels the resulting curricular activities and practices arising from these two curriculum sources as Vision I and Vision II respectively, where his notion of a 'vision' constitutes a much broader analytical category than a definition.

The issue of achieving some form of 'balance' raises a number of important if not perplexing questions. How do we go about determining this balance? Is it just another way of expressing the need to deliberate upon and establish priorities for competing goals in science education? Does the balance shift in different educational contexts and settings? These are but a few of the questions that come immediately to mind.

Peter Fensham also has a long history of scholarship associated with scientific literacy. In his article entitled "Time to change drivers for scientific literacy" (Fensham, 2002), he outlines some of the underlying forces (what he refers to "educo-political forces") and conceptual perspectives that have resulted in Vision I perspectives dominating most of the earlier and even more recent science curriculum development initiatives (with some notable exceptions). He argues that the previous and current dependence upon academic scientists and science educators as the primary drivers of articulating a view of scientific literacy (and subsequently the science curriculum) has continued to reinforce this Vision I approach. Fensham goes on to claim that if we are to develop a more socially relevant and personally satisfying science curriculum (i.e. one based on a Vision II approach) that would be suitable for teaching *science for all pupils*, not just those aiming towards post-secondary degrees in the sciences, then we need to enlist the support of "societal experts". I will not elaborate upon his argument for this claim, suffice it to say that all five of the commentators in the journal agree with his overall claim that we need to broaden the base for deliberations about what ought to be the preferred curricular content and approaches, although each had their own perspective and narratives on how this might best be accomplished.

The New London Group

The ambiguity and contested meanings around the use of the term 'literacy' has not been confined to the science education community. There have also been extensive debates as to the various meanings and associated pedagogies that have been ascribed to the traditional uses of the term in the language education community. The so called "New London Group" (hereafter referred to as NLG) consisted of a group of ten prominent language educators who initially met for a week long series of discussions to deliberate about a number of important questions related to the conception and the teaching of language 'literacy'. Their influential article entitled "A pedagogy of multiliteracies: Designing social futures" (The New London Group, 1996) which chronicles the process and products of their deliberations was a "result of a year's exhaustive discussions, yet it is by no means a finished piece". Some consideration of their outcomes seems germane to our present context for two reasons. First, they were dissatisfied with the traditional conception of literacy as it was being

operationalized in the research literature on language pedagogy. They argued that the traditional views of literacy which entailed "teaching and learning to read and write in page-bound, official, standard forms of the national language" (p. 62) were inadequate to deal with the central mission of education which is "to ensure that *all students* benefit from learning in ways that allow them to participate fully in public, community, and economic life." This stance coheres very nicely with the writings in the field of scientific literacy and the current concerns about the dominance of the Vision I perspective of scientific literacy and Fensham's (2000; 2002) writings on "science for all".

Second, they generated a number of interesting strategies for addressing two important organizing questions that they referred to as the 'What" and the 'How' of literacy pedagogy. These two questions also provide a frame for addressing the two orienting themes of this symposium – the search for further conceptual clarity around the competing notions of scientific literacy (the 'what' question) and the development of fruitful models of educational inquiry (the 'how' question).

The questions that served to animate and focus their discussions included:

- How do we best address the changing context of our culturally and linguistically diverse and increasingly globalized societies and the plurality of texts that circulate within these settings?
- How do we ensure that differences of culture, language, and gender are not barriers to educational success? And what are the implications of these differences for literacy pedagogy?

While these are difficult questions and the process of debate and deliberation around these questions and others was extensive, they opted for a parsimonious, one word, encapsulation of their discussion – "multiliteracies". This construct has subsequently been developed in much greater detail by the NLG, but more importantly it has generated a large body of research and development on literacy practices and pedagogy by many other language education researchers in the ten years since it was introduced to that community. For instance, if you type in 'multiliteracies' into Google you receive 122,000 results, not quite in the same league as 'constructivism', but nonetheless a very significant uptake of this construct in the educational community.

In their article the NLG also argued for a new form of pedagogy which would address two of their goals of "creating access to the evolving language of work, power, and community, and fostering the critical engagement necessary for them [the students] to design their social futures and achieve success through fulfilling employment" (p. 60). These two goals bear important family resemblances to the age-old discussion of general goals in science education of the preparation of future scientists and engineers (Vision I) and developing a scientifically literate citizenry (Vision II).

They framed much of their discussion around the issue of social change: "changes in our working lives, our public lives as citizens, and our private lives as members of different community lifeworlds". What do these changes then mean for literacy pedagogy? To address the 'what question' of literacy pedagogy they introduced the notion of "Design, in which we are both inheritors of patterns and conventions of meaning and at the same time active designers of meaning. And as designers of meaning, we are designers of social futures – workplace futures, public futures, and community futures". The resultant product of that analytical work was six design elements describing different aspects of in the meaning-making process with respect to literacy practices.

The next phase of their deliberations was one of translating the 'what' into a 'how' by considering a series of four pedagogical components. These components are fairly generic approaches to teaching and learning and hence are worth considering in our own deliberations regarding "science educational research in transaction". These pedagogical components are:

- Situated Practice, which draws on our experience of meaning-making in all relevant contexts;
- Overt Instruction, through which students develop an explicit metalanguage of Design;
- Critical Framing, which interprets the social context and purpose of Designs of meaning;
- Transformed Practice, in which students, as meaning-makers, become Designers of social futures (New London Group, 1996, p. 83).

It was the intent of the group to nurture and develop collaborative research relationships and programs of curriculum development to "test, exemplify, extend, and rework the ideas tentatively suggested in this article".

Insights from The New London Group

What insights, if any, can be drawn from both the process and the products of the NLG initiatives?[5] Some of the above listed components clearly cohere with some of the dominant perspectives on pedagogy in the science education community, while others could serve as heuristic agendas as they are considered in terms of their potential to generate meaning-making practices in particular educational contexts. Firstly, one might argue that a sustained and concerted effort by a group of researchers coming from a diverse set of personal and academic backgrounds can have a significant impact upon a field of inquiry providing that the group comes to some consensus on what constitutes the important problems in the field, engages in the difficult analytical work of mapping out the appropriate theoretical resources to bring to bear upon these problems, and then sets out a realistic empirical research programme. As indicated above, these tasks were not accomplished in their week-long symposium – it required a further year of sustained work to come to agreement on their preferred theoretical and research frameworks.

Secondly, our group might also look at their analysis of the concept of literacy and literacy pedagogy to see whether the science education community can draw upon some of their conceptual insights. For example, how does their notion of "multiliteracies" map onto our deliberations regarding the different types of scientific literacy? Are there multiple manifestations of scientific literacy elicited by different pedagogical contexts and purposes? Could we obtain sufficient consensus in our group on the important issues facing the science education community writ large? I think that some of these questions could at least provide some interesting 'starting points' for our own group deliberations. I will return to possible connections between

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[5] It is interesting to note that there was one earlier conference and subsequent publication that appeared to be modeled rather closely on the New London Group approach. Their editorial had the interesting title of "Message from the 'Island Group': What Is Literacy in Science Literacy?" (Hand *et. al.*, 2003*).* Even though there was one common participant in both Groups, James Gee from the University of Wisconsin, the Island Group seemed to focus on a more restricted set of structural and pedagogical issues related to "border crossings" between the language education and the science education communities and arguing that language is an integral part of science and science literacy.

the NLG analyses of literacy and potential science education research initiatives in a later section of this paper.

III. The '*How Question*' of Scientific Literacy Pedagogies

In this section I will examine some of the issues that bring the two general themes of this symposium into relationship with each other. While I acknowledge that these issues pertaining to a series of 'how questions' with respect to pedagogies represent only a small part of the much more expansive terrain of 'science education research in transaction', it seems to me that they occupy a central place both in the research literature and in the teaching practices of science educators. It is in this section that I wish to revisit some of the claims and issues that I have advanced in my previous writing – in particular a piece I co-authored with Rosalind Driver in 1983 and a more contemporary one I wrote in 2000 (Driver & Erickson, 1983; Erickson, 2000). I'm doing this because I think that, like the NLG, it is important to engage in a careful analysis of some of terms and theoretical perspectives that are informing our work (c.f. Sjøberg, 1995). In large part this was what these two earlier pieces were about. The intent in both cases was to synthesize the literature in a defined field of study for the purpose of articulating trends, gaps or discontinuities, and identifying problems that need to be addressed in future research. In the earlier article the field of study was the burgeoning literature on student conceptions research and in the latter article my objective was to identify changes in the Lakatosian-type 'research programmes' that have occurred in the science education literature on students science learning over the past 25 years. Some of the issues that we identified, even 25 years ago, are still in need of continued scrutiny and deliberation today.

A second reason for revisiting these works is that questions of pedagogy figure prominently in both of them and many of these questions are germane to our deliberations in this symposium. I think that is important for all of us to engage in some form of retrospective analysis where we examine field of inquiry over a longer period of time rather than focusing on a single study or project. In this instance, I think that such an analysis will provide us with some insight as to why Vision I has been so dominant in the science education research field. This discussion, then, is an extended elaboration of the point made by Fensham (2002) that "the explosion of research studies of students' alternative conceptions about scientific phenomena and concepts also unintentionally reinforced the traditional content of school science" (p. 13).

Theories-in-Action Article Revisited

This article (Driver & Erickson, 1983) was framed around a classic, syllogistic argument with three empirical premises, one normative premise and a conclusion. The empirical premises emanated from the existing research literature and the normative premise were at the heart of the overall claim we were making in the paper regarding the importance of attending to the pedagogical concern of how to improve student learning in educational settings. The claims embedded in these premises are still being addressed in the literature and the entire argument pattern was recently used by Taber (2006) to frame his recent review paper entitled "Beyond Constructivism: The Progressive Research Programme into Learning Science". Our argument was:
Empirical Premise One: Many students have constructed from previous physical and
    linguistic experience frameworks which can be used to interpret some of the
    natural phenomena which they study formally in school science classes.

Empirical Premise Two: These student frameworks often result in conceptual confusion as they lead to different predictions and explanations from those frameworks sanctioned by school science.

Empirical Premise Three: Well-planned instruction employing teaching strategies which take account of student frameworks will result in the development of frameworks that conform more closely to school science.

Normative Premise One: One should conduct research which will lead to a better understanding of school science by students.

Conclusion: We ought to engage in research endeavours which will uncover student frameworks, investigate the ways they interact with instructional experiences and utilize this knowledge in the development of teaching programmes.

In reviewing the literature associated with the first two empirical premises, we claimed that there existed a "proliferation of terms, techniques and supporting theoretical rationales for describing students' cognitive commitments [leading to] considerable confusion over the types of commitments which should be identified and described, a debate over appropriate data gathering and data analysis techniques and difficulties in extending or even replicating existing studies" (Driver & Erickson, 1983, p. 39). This state of affairs of a proliferation of meanings and perspectives for describing student learning I later interpreted (Erickson, 2000) as signaling a shift in research programmes in the science learning literature from a Piagetian Research Programme, which was dominant in the 60's and 70's, towards a Constructivist Research Programme.

The conclusion of our argument in the 1983 paper was that we should be undertaking the type of research that would enhance student learning of standard science concepts as found in the curricular documents and science textbooks of the day. What is worth noting here, in light of our current deliberations, is that we were exclusively addressing Vision I aims, as our research agenda was strongly influenced by our collaborative work with classroom teachers. Issues, such as those identified by the NLG, Fensham (2002), and many others, of differential access to science learning, social justice, and 'science for all' – Vision II type curricular objectives – were not part of our research agenda.

We ended our article by identifying what we considered to be five important directives for future research. They were:

1. The necessity of developing methods and research designs that will examine the extent to which students make use of their school learning in practical, everyday situations. In particular, how might we assess students' knowing-in-action?

2. The need for developing learning programs and research studies that span years as opposed to hours or days.

3. The potential danger in a proliferation of studies of student ideas or beliefs in the absence of any systematic and integrated theoretical/pedagogical framework.

4. Research programmes should be based upon a collaborative model involving researchers, teachers and students engaged in a process of restructuring their views of knowledge and of the nature of learning.

5. School science practices should provide opportunities for students to explore new phenomena and ideas, to appreciate alternative points of view, and to develop confidence in their own capabilities to act and construct knowledge of the phenomena under consideration

Some of the questions that we might consider then are: Are these ideas and directives still relevant today? What progress has the science education community made in addressing these issues? How do they compare to the NLG pedagogical components?

Relevance and Progress of Issues from 1983 Article

Acknowledging that our 'what questions' were limited in scope (even though they still dominate the practice of many science teachers at all educational levels), where did we stand on the 'how questions'? An important organizing principle for both our pedagogical and methodological stance was the crucial role played by the 'context', as we called it then. This was prior to the surge in interest in "situated cognition" (Hennessey, 1993; Brown, Collins & Duguid, 1989) and "social constructivism" (Cobb, 1994; Driver et al, 1994). Hence, we struggled at the time to find the appropriate language to describe the nature and the importance of these learning contexts. Like others (e.g. DiSessa, 1981; Strauss, 1981 & Viennot, 1979), we were convinced that much of students' "common-sense knowledge" about the physical world had already been constructed long before they encountered the formal explanations of science concepts in science classrooms, textbooks, or the media. In trying to describe the nature and process of students' active engagement with physical phenomena we referred obliquely to this type of learning as "kinesthetic knowing" or "knowledge in the muscles". But when we presented these terms to our colleagues in conference presentations or seminars they seemed puzzled.

We ended up calling our perspective on this aspect of children's knowledge construction as a type of "phenomenological position" where we argued that students often displayed a type of awareness and understanding that resembled Polanyi's (1967) "tacit knowing", and this understanding was primarily elicited in situations where the students had direct access to physical phenomena. We thought that this phenomenological, contextualist perspective on student understanding was so central to our perspective that it was the primary phrase in our title – "Theories in Action". Our intuitions about the importance of this type of "knowing-in-action", as Schön (1983, 1987) came to call it, continues to be a source of considerable inquiry and theorizing today in several different disciplinary areas. One contemporary line of inquiry for framing the phenomena associated with this general perspective on learning and knowing often goes by the name of "embodied knowing" (c.f. Davis & Sumara, 2000; Lakoff & Johnson, 1999; Johnson, 1987). Davis and Sumara (2000) sum up this perspective on embodied knowing as follows:

> Knowledge comes to be comprehensible only in terms of an active body. More specifically, knowledge is that which affords a body – whether a person, a social group, or a culture – a coherence through which that body maintains viability. Knowledge is the space of the possible. It is necessarily embodied. It is necessarily contextual (p. 835).

When I revisited the field of students' science learning some seventeen years later (Erickson, 2000), I again used the term "phenomenological", but this time to describe a family of learning perspectives (which would certainly include 'embodied knowing') that I considered to be an emerging research programme. While the

"constructivist research programme" is still dominant today, I argued that there are some serious shortcomings in the way in which 'constructivism' is being interpreted and used by both practitioners and researchers and that the phenomenological perspectives had much to offer the science education community[6]. The family of learning theories that I included under the 'phenomenological research programme' in the 2000 article included Marton's phenomenological perspective on learning[7] (Linder, Fraser & Pang, 2006; Marton & Booth, 1997; Marton & Tsui, 2003), enactivist theory (Sumara & Davis, 1997; Varela, Thompson, & Rosch, 1991) and complexity theory (Davis & Sumara, 2005, Davis, Sumara & Luce Kapler, 2000).

Interestingly this perspective on the transactional view of experience and knowledge has also evolved in the philosophical literature, where some contemporary philosophers have continued to develop some of insights from Dewey, the later Wittgenstein and Rorty to articulate a "Theory of Practice" (Brandom, 2000; Schatzky, 1996). Recently we have drawn upon some of these conceptions of practice to provide an account of what we call "ethically attentive practice" (Rogers, Erickson & Gaskell, 2007). We think that this work has considerable potential, particularly in the area of teachers' professional knowledge.

What Progress Has Been Made on These Issues? As noted above, my intent for this paper was not to undertake a thorough and extensive review of the field, but rather to identify what I consider to be fruitful directions for future research. Hence I will be necessarily brief and very selective in making these personal judgments about progress.

Application of student's science knowledge to everyday phenomena and assessing student's knowing-in-action

While we did not discuss this issue in terms of the STS, or a 'Vision II', research agenda, the issues that we were dealing with here – trying to make science learning relevant to students' everyday experiences – are similar in many respects. As my earlier discussion of Roberts' and Fensham's work (to name only two of the many, many science educators at this symposium who have made significant contributions to the field) would indicate, the curricular developments in this area have been far reaching and significant. As Roberts (2007) points out in his extensive review article there are curricular projects throughout the world that are engaging students with problems involving scientific knowledge and reasoning set in meaningful societal settings. In addition to the many school curriculum development initiatives throughout the world, the work originally undertaken by David Layton and his colleagues in the 1970's through the 90's on the 'Public Understanding of Science' also showed considerable promise. Layton, in his earlier historical work, demonstrated how science came to be part of the school curriculum on the promise that learners would benefit in a practical sense from understanding the natural world and that it would prepare them to do useful work in their adult lives. One project and accompanying book was given the title of "Inarticulate Science" (Layton, Jenkins, Macgill and Davies, 1994) and it examined how adults interpreted scientific explanations and information in contexts where that understanding had considerable salience for their lives, such as the care givers for children with Down's Syndrome

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[6] I reached a somewhat different conclusion about the continued viability and "progressiveness" of the constructivist research program than did Taber (2006) who undertook another review of the field of science learning.

[7] Marton and colleagues now tend to refer to his perspective as the "variation theory of learning".

and the survivors of the Chernobyl disaster. The field of the "Public Understanding of Science" has remained fairly active in the United Kingdom under the aegis of Science Studies (e.g. Wynne, 1991, 1992), but the empirical work in this area tends to be primarily with adults.

Have we made any progress in the difficult area of assessing students' "theories-in-action"? While practicing teachers still struggle with assessing large numbers of students who have engaged in some extensive project or practical work, the research community has made some progress by drawing upon a variety of qualitative research methods, particularly those naturalistic methods that focus on engaging learners in a naturalistic setting (c.f. Denzin and Lincoln, 1994; 2000). One aspect of my own work in this area took the form of developing a framework and analytical scheme for assessing students' approaches to experimentation with practical materials in a large scale student assessment program (Erickson, 1994; Erickson & Meyer, 1998). We argued that we were able to capture the student's 'theories-in-action' as they manipulated a variety of materials to test their hypotheses generated in responding to the following questions: "Which magnet is the strongest?", or in another problem context, "Which paper towel holds the most water?". However, this area of the assessment of students' understanding when engaging directly with phenomena is still in need of further conceptual and empirical study.

Fensham's and Tiberghien's work with the PISA project (see papers at this conference) holds considerable potential for looking at more innovative methods of assessment of student understanding of science knowledge in societal settings.

The need for developing learning programs and research studies that span years as opposed to hours or days

The issue of the paucity of longitudinal research studies remains problematic. Because of the funding cycle of many research projects and the fact that much of the research in education is still carried out by graduate students, carefully designed longitudinal research studies remain the exception rather the rule (Arzi, 1988). Of the exceptions those that stand out are the long term documentation of students' use of concept mapping to examine changes over time (Helldén, 1999; Novak & Musonda, 1991). While I have not done a systematic search of the literature in this area I still see only an occasional study reported in the literature (e.g. Sarantopoulos & Tsaparlis, 2004). Two of the more active, current researchers in this area in science education are Gustav Helldén from Sweden (Helldén, 1999, 2003, 2003a; Helldén & Solomon, 2004) and Russell Tytler and Suzanne Peterson from Australia (Tytler & Peterson, 2003, 2003a, 2004, 2005).

The proliferation of studies of student ideas or beliefs in the absence of any systematic and integrated theoretical/pedagogical framework

As we had predicted the short term studies of students' conceptual understanding became a dominant form of science education research and since the early to mid 80's right up to the present the science education journals continue to report on a wide range of studies about student understanding[8]. There were some early efforts to create a bibliography of this literature (Pfundt & Duit 1994; Carmichael et al. 1994) and to my knowledge only Reinders Duit has attempted to

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[8] While I now prefer to use the term 'understanding', following Schatzky's (2001) work on practice theory, the terms used in this literature are still almost as varied as those we reported in our 1983 article. "Misconceptions" unfortunately is still in frequent use in the literature.

maintain a bibliography in this area and he has added teachers' conceptions to the comprehensive listing of research studies (Duit, 2004).

The latter, and more important, part of this concern is more difficult to address as we unfortunately did not clearly distinguish between a theoretical perspective on learning and a pedagogical framework. The vast majority of the thousands of studies of student understanding that were undertaken in this 25 year period of time were informed by either a 'personal constructivist view of learning' or a 'social constructivist view of learning'[9] (Erickson, 2000).

Unfortunately many researchers and educators, as I think that we did at the time, seemed to slip easily from a constructivist stance on learning to the creation of curriculum materials and instructional programmes. Davis and Sumara (2002) have discussed this problem in some length as they point out:

> Since its first appearances in the literature, early in the 1970s, the term "constructivist" has risen to considerable prominence in several branches of educational discourse. Among theorists and researchers, it is most popular with those who are interested in processes of learning, especially the learning of mathematics and science. Among policymakers, curriculum planners, and classroom teachers, constructivism is not nearly so process- or domain-specific. Claims of constructivist classrooms, constructivist teaching, constructivist resources, and constructivist programs exist across subject areas (p. 409).

The problems associated with this move from any theoretical account of learning to a pedagogical position for educators is that it can lead to a large number of claims and prescriptions for teaching practices that bear only a tangential relationship to the learning theory itself, resulting in the unwarranted use of terms like 'constructivist' (as is the case in point above) to justify a wide range of educational practices. This situation is problematic for several reasons: first, the core commitments of learning theories are focused on theoretical accounts of human learning and knowing about "phenomena that are presented as complex events through which biological predispositions, cultural contexts, and idiosyncratic experiences are stitched together into interpretations that are adequate to maintain coherence with immediate situations" (Davis & Sumara, 2002, p. 417) and NOT on the practical matters of how one goes about nurturing student understandings of those phenomena[10]. A second reason is that a number of normative premises such as: What is of 'most worth' to teach? and What is an ethically acceptable manner of teaching this content? (c.f. Fenstermacher, 2001; Östman, 1998; Rogers *et. al.*, 2007) are neither made apparent nor deliberated upon in any systematic manner.

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[9] See Cobb (1994) and Driver et al. (1994) for a good discussion of some of the issues related to distinguishing between these two perspectives.

[10] This point was repeatedly made by Piaget in his many engagements with educators, particularly those in the United States who invited him to conferences aimed at applying Piaget's work to educational projects (c.f. Ripple & Rockcastle, 1964).

Research programmes should use a collaborative model involving researchers, teachers and students providing opportunities for all participants to appreciate alternative points of view, and to develop confidence in their own capabilities to act and construct knowledge of the phenomena under consideration

I have collapsed our last two points into one heading because they are closely related. I think in some important respects that this is another area where we can see some clear progress. It is clear that collaborative research and development work with teachers became very popular and the research and development programmes that both Ros and I developed, subsequent to writing our 1983 article, was completely dependent upon our collaborative work with teachers. (CLlSP 1987; Driver, Squires, Rushworth, & Wood-Robinson, 1993; Erickson, 1991; Erickson, Mayer-Smith, Chin, Rodriguez & Mitchell, 1994).

As was the case with the increasing recognition of the contextual and situational aspects of learning in educational research programmes, so too the notion of collaborative inquiry has become a mainstream approach for addressing issues and problems of curricular change and educational reform. One indication of this popularity is the extent to which the concept of collaboration has permeated the educational literature in all fields. So, if one does a Google search on 'collaboration and education' there are "about 164 million sites" that are identified; if you narrow the search considerably by using "Scholar Google" then 605,000 documents are identified. Of course there was no comparable search engine when we were writing this article in 1983, but the term was rarely used then in the journal literature. Furthermore, some of the more recent research designs have developed around the recognition of the importance of the close relationship between researchers, teachers and students. One such methodology is 'participatory action research' (Argyris & Schön, 1991) or as some researchers have called it the 'collaborative action research network or CARN – see the following website for more details: http://www.did.stu.mmu.ac.uk/carn/default.shtml

A second important research model that recognizes the importance of collaborative work between teachers and researchers is that of the 'design experiment'. This term was introduced to the mainstream educational community by Ann Brown over 15 years ago (Brown, 1992), and it has been increasing in popularity ever since. A whole issue of *Educational Researcher* (Vol 33, (1)) comprising nine articles was devoted to discussing the conceptual and methodological features of using design experiment research methods. This notion of 'design' bears some resemblances to the term used by the NLG, however, in this latter context virtually all of the focus is on process and methodological elements and does not have the rich connotations associated meaning making as is the case with the NLG.

In summary, some of the possible developments about which we expressed concern have indeed materialized, but at the same time, there has been considerable maturity in the nature of the questions being addressed and certainly the nascent theoretical perspectives on learning that we struggled to articulate have been elaborated in considerable detail. Even though there remain some significant challenges for the field, some of which have been discussed above, I think that over the past twenty-five years the overall research agenda on students' cognitive commitments has continued to evolve as new research questions and methods have emerged from our initial work in this field in the 70's and 80's.

As indicated in the Introduction to this paper I decided to draw upon two apparently disparate resources to address some of the issues around 're-visioning

perspectives on science education research and practice'. One might ask whether there are any significant connections or correspondence between these two sources and whether they provide any insight or guidance for future work in the field.

Relationship Between NLG Approach and Issues from 1983 Article

One of the most significant differences between the NLG article and our 1983 article was the approach that the NLG group took in developing a carefully argued approach to pedagogy, addressing both the 'what questions' and the 'how questions' and in the process identifying both their underlying normative commitments (premises) as well as the empirical principles that guided their pedagogical agenda. Working with the broad concepts of *changing social conditions and contexts* and the notion of *humans as designers of meaning* they generated six design elements in the meaning-making process and four components of pedagogy. It is this latter set of pedagogical components that I think offer some parallels to some of the above issues that I have discussed in earlier writings and that continue to be important problems facing the science education community.

The NLG pedagogical components identified above can be briefly characterized as "situated practice", "overt instruction in the metalanguage of Design", "critical framing" and finally "transformative practice". As discussed earlier, the importance of context or situated practice has been characteristic of both my own thinking for the past 25 years and it coheres with much of the current work in the field of science learning. Hence it is demonstrative of the broad scope and potential explanatory power of this broad perspective on learning and practice.

Their second component of teaching students the "metalanguage of design" represents their theorizing on what constitutes the nature of design in a pedagogical context and subsequently on the nature of the metalanguage for this design process. Teaching this metalanguage to students also generates a very interesting pedagogical strategy. Briefly summarizing their position, they point out the ambiguity of the term 'design' whereby it can refer to either the organizational structure resulting from some set of activities or the actual process of designing. They go on to argue that any semiotic activity, including the use of language, is a matter of design which describes the forms of meaning associated with those activities. They go on to describe three elements of the design process. Furthermore they conjecture that both teachers and students need a *metalanguage* for talking about and appreciating the "language, images, texts and meaning-making interactions" that constitute most forms of pedagogical practice.

Is there a comparable focus in the science education literature? Perhaps the closest efforts in this regard would be the efforts by some educators to create teaching strategies designed to encourage their students to become more metacognitive in their engagement with science content. The best known of these strategies would be Novak and Gowin's (1984) book on *"Learning How to Learn"* where they introduce and argue for the importance of 'concept mapping' and 'vee mapping'. There have been many other science educators who have argued strongly for the importance of teaching students a variety of metacognitive strategies (e.g. Case & Gunstone, 2006; Baird & Mitchell, 1986; White and Gunstone, 1992). An even closer example might well be the focus of the PEEL project on developing a "language for learning" by both teachers and students (Flack, 2002; Mitchell and Northfield, 1996).

The NLG third component of 'critical framing' implies that teachers should be assisting their student to better understand the "social, cultural, political, ideological, and value-centered relations of particular systems of knowledge and social practice"

(p. 86) such that the students are able to offer some critique of the content they are learning. This component closely mirrors many of the discourses underlying 'vision II' curricular initiatives discussed by Roberts (2007) and Fensham (2002). In fact the NLG use a science example to illustrate the nature of this type of pedagogical framing:

> For example, the claim "DNA replicates itself" framed within biology is obvious and "true." Framed within another discourse in the following way, it becomes less natural and less "true": Put some DNA in some water in a glass on a table. It certainly will not replicate itself, it will just sit there. Organisms replicate themselves using DNA as a code, but that code is put into effect by an array of machinery involving proteins. In many of our academic and Western discourses, we have privileged information and mind over materials, practice, and work. The original claim foregrounds information and code and leaves out, or backgrounds, machinery and work. This foregrounding and backgrounding becomes apparent only when we reframe, when we take the sentence out of its "home" discourse and place it in a wider context. Here, the wider context is actual processes and material practices, not just general statements in a disciplinary theory (the DNA example is from Lewontin, 1991) (New London Group, 1996, p. 86-87).

The final component is 'transformed practice' by which they mean the type of pedagogical activities where students are provided with the opportunities to design and carry out new activities based on their own goals and values in realistic problem settings. Interestingly, they again turn to a science example to illustrate the nature of this pedagogical component:

> In Transformed Practice, in one activity we try to re-create a discourse by engaging in it for our own real purposes. Thus, imagine a student having to act and think like a biologist, and at the same time as a biologist with a vested interest in resisting the depiction of female things - from eggs to organisms - as "passive." The student now has to both juxtapose and integrate (not without tension) two different discourses, or social identities, or "interests" that have historically been at odds (New London Group, 1996, p.87).

In some important respects this notion of being able to transform and reflect upon curricular subject matter in a manner which recognizes the 'real purposes' and autonomy of the learner, is a goal of education, writ large, not just language or science education. It entails the design of a learning environment where the students develop a sufficient degree of confidence and understanding of the subject matter that they are in a position to assess competing authorities regarding both scientific claims and the social and political consequences of such claims (c.f. Rogers, *et al.* 2007; Roth, 2002*).*

IV. Where to from Here?

In concluding this rather lengthy meander in the field (to return to the geographical metaphor in the introduction), I want to identify what I think are some issues/questions that require further attention and outline some possible directions for future work in the field. It seems to me that we still need to deliberate further on what role, if any, the concept of scientific literacy ought to play in developing: a) new, progressive curricular programs and accompanying teaching approaches; and b) fruitful research agendas.

Continuing Conceptual Issues around 'Scientific Literacy'

Given my analysis above, it seems reasonable to conclude that there is a general consensus within the science community that there is a desire to shift away from such a strong emphasis on the traditional delivery of disciplinary science content. In the language of Roberts' two Visions -- a shift away from the dominance of the Vision I perspective towards a Vision II perspective. Furthermore it seems to be generally agreed that such a shift would also signal a change in some of our approaches to pedagogy. Much of the current debate concerns the nature and dynamics of how one might bring about this shift in meanings of scientific literacy and who ought to be the dominant 'drivers' behind this process. This shift, be it partial or complete, does raise some questions in my mind.

- Is it possible that the community has created an unnecessary dichotomy between Vision I and Vision II approaches to 'scientific literacy' and that there may be some integrative approach that would address most of the concerns and values represented by both of these perspectives? If so, what would be the implications for curricular reform?
- In making a significant shift in the meanings we attach to scientific literacy, what are the implications for the kinds of pedagogies that should be considered?
- Would the NLG proposal of 'multiliteracies' apply equally well to 'scientific literacy'?
- Could we conceptualize some of these literacies in terms of Roberts' and Östman's (1998) work on "companion meanings"? Could these meanings be further elaborated in the manner of the NLG?

Continuing Pedagogical Issues around 'Scientific Literacy'

- The science education community needs to develop pedagogical models that make explicit the normative premises about aims and ethically responsible teaching practices as well as empirical premises about the nature of learning. Too often we try to simply derive pedagogical practices from theoretical positions on learning, or diversity, or language, or the latest research on the functioning of the brain, etc.
- Development of new curricular approaches and materials that are situated in contexts that both appeal to student and have some societal significance. In this regard could we explore the four "pedagogical components" from the NLG to see whether they provide any conceptual or methodological insights into changing pedagogical practices in the science education context? For example, we could take their concept of "transformative practice [where] students design and carry out new activities based on their own goals and values in realistic problem settings" and consider how it could be used in a science classroom. To illustrate this point one could imagine assigning a class a project to analyze the scientific and socio-political claims in Al Gore's documentary "An Inconvenient Truth". The next task would be to compare and contrast these claims with other scientific and political reports (e.g. the Kyoto accord or the proposed legislation from a relevant governmental agency) so as to critically analyze the various discourses of 'climate change'.
- What are our preferred theoretical models of learning and how do they inform the processes of curriculum development and pedagogy? I have argued for attending carefully to the emergent phenomenological perspective on learning, in contrast to the still dominant "constructivist research programme" (Erickson,

2000). As with all general learning perspectives much conceptual and practical work remains to move from theoretical propositions to design-like elements that can be incorporated into pedagogical practices. Thus we need to engage in the type of conceptual and empirical activities portrayed by the NLG in their article, drawing upon their preferred theoretical orientation of 'situated knowing'. While they don't describe their perspective in phenomenological terms, their notion of situated learning/knowing is very close to what we were referring to as 'embodied knowing' in our 1983 article. Like phenomenological perspectives, the NLG rendering of situated knowing has a strong relational character with its emphasis upon students as active designers of meaning. In passing I might note that these relational characteristics between learners and the phenomena that they are experiencing is also characteristic of a "transactional view of inquiry" coming as it does from Dewey (Clancey, 2004).

- How can we 'design pedagogical structures' (or components as the NLG called them) to translate the necessarily abstract propositions and assumptions of a general theory of learning/knowing into a structure that can be understood and used by practitioners? Marton and his colleagues have recently engaged in such an endeavour by taking their general "Theory of Variation" and developing a basic pedagogical structure that they call a "Learning Study" (Linder, Fraser & Pang, 2006; Pang & Marton, 2003). This structure not only draws upon Variation Learning Theory, but also incorporates features of two closely related pedagogical structures -- the frequently cited "Lesson Study" from Japan and China and the "Design Experiment", that I discussed earlier. Given that the focus is on improving student understanding in a particular content domain, it can be seen as both a teaching approach and a research design. The feature that I think is very powerful with the 'Learning Study' is its simplicity of design and language and in my recent experience of using it in a course with experienced teachers, they were impressed by its simplicity on the one hand, but with its effectiveness as a pedagogical tool on the other hand.

Continuing Research Issues around 'Scientific Literacy'

As we begin to systematically explore some of the issues raised in the above sections, it is clear that there are many research issues and agendas that still need to be addressed. While I discussed the importance of designing 'pedagogical structures' in the previous section, it could have just as easily been located in this section as it certainly does constitute a significant and important research activity. Some of the other more general types of research agendas that I think will be important in the years ahead as we look at the shifting sands of teaching scientific literacy are as follows:

- One of the central issues that we identified in our 1983 paper was the value of researchers engaging in collaborative research studies involving teachers and students. Both of us proceeded independently to engage in this type of collaborative work with teachers and students, particularly in the area of curriculum development (CLISP, 1987; Driver et al. 1993) and the generation of general pedagogical strategies (Erickson et.al., 1994). Unfortunately it is my sense from reading the literature and attending recent science education conferences, that in recent years the teachers have been somewhat 'sidelined' by the science education researchers in their various research endeavours. I think that sidelining teachers would be a large mistake and I would simply point out the very vibrant research and development programme that has emerged from

the PEEL project where several academics from Monash University worked with and supported a group of teachers in one secondary school more than twenty years ago (Baird & Mitchell, 1986). The focus of this group was around getting students to become more 'active learners', drawing in part upon the constructivist theory of learning and some other empirical work by Baird and White (1982) on students' learning behaviours in science classroom. The teacher inquiry model begun in this one school quickly spread to other schools who had heard about the interesting experiment the teachers were engaged in, and now 22 years later the PEEL project is still very active, generating a large number of "teaching procedures" based on short descriptive classroom-based stories (or mini-cases) written by the teachers (Mitchell, 2007). These stories are now located on the web and are coded not just by the 'teaching procedure' being illustrated, but by many other analytical categories (such as "principles of good learning" or "teacher concerns" or "teaching practices") that this group has generated over the years (see www.peelweb.org). This to me is a paradigmatic case of the value of collaboration between university-based educators and school-based educators.

- One of the issues that emerged in Fensham's (2002) analysis of the dominance of Vision I perspectives on scientific literacy and curriculum development has been the 'conservative' role played by university faculty members of the science disciplinary departments. This concern was further reinforced in Aikenhead's (2002) and Gaskell's (2002) contributions to this thematic issue on 'scientific literacy'. Roberts (2007) also points out the influential role played by academic disciplinary specialist, particularly in the United States where they were instrumental in the development of many curricular programs, initially in the 50 to 60's during the post-sputnik, revolutionary movement to create more rigorous, discipline-based science curriculum programs11 such as PSSC physics, BSCS biology and CHEM study in Chemistry; and more recently in major science education projects like Project 2061 (AAAS, 2001). While I think that these observations have largely been accurate, I think that there are some encouraging signs of change at the level of university science departments. In North America there are some important developments occurring in the priority given to changes in curriculum and models of teaching and learning at the university level. In particular, the Carnegie Foundation initiatives in the area of the Scholarship of Teaching and Learning have been widespread and influential in a number of major research institutions (http://www.carnegiefoundation.org/index.asp). To consider an example of a context with which I'm most familiar, the Faculty of Science at UBC has had a relatively long-term interest in improving and experimenting with the teaching of science at the undergraduate level. Close to 15 years ago they established a very innovative first year integrated science program for a cohort of around 75 students called Science One. This program integrates the subjects of biology, chemistry, mathematics and physics and "emphasizes and cultivates critical, independent thought as the basis of scientific inquiry" (http://www.scienceone.ubc.ca/home/). After a positive response to this

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[11] This is sometimes known as the 'alphabet soup' of science curriculum projects. See: http://www.chifoo.org/pages/programs/2004/support/01/AlphabetSoup.ppt. for a discussion of these curriculum reforms.

program by students and faculty members alike the Faculty initiated other innovative curricular programs (e.g. Coordinated Science) and then established a centre to promote the teaching and learning of science called Skylight in 2002. In keeping with one of the priority goals of the University, they recently hired Dr. Carl Wieman, a Nobel Prize winner in physics, who will head a major initiative to improve the teaching of science at the university (http://www.vpacademic.ubc.ca/CarlWieman/). While there is clearly an increased emphasis on the importance of teaching (perhaps less so on learning) at the university sector, much of this effort is focused on improving students' understanding of classical, disciplinary content. Not that this is inappropriate, since part of the mandate of the university science departments is indeed aimed at producing the next generation of scientists and engineers, but it is not yet clear whether this new found interest in teaching science in 'research intensive' universities will translate into support for changes in the way that we teach science in the elementary and secondary schools. One encouraging project in this regard at UBC is a curricular project in the planning stages for a first year physics course that will be organized and taught entirely around the two thematic areas of 'energy' and 'climate'. As university level scientists begin to realize that the kind of science that we teach to students at all levels must be both engaging and relevant, then perhaps we will be in a better position to recruit them in our efforts to bring about significant curricular changes at the elementary and secondary school levels. To sum up this lengthy point, I would encourage the science education research community to work in collaborative projects with university faculty of science members on the improvement of teaching and learning. From a strategic point of view, I suspect that it would be best to begin working at the tertiary level and then move to projects aimed at changing the curriculum and learning environments at the K-12 level.

While a number of other research agendas and perspectives on scientific literacy were discussed at the Uppsala Symposium, the above comments and reflections represent my current thinking on past and present issues facing the science education community writ large as we continue the important conversation on 're-visioning the goals and practices of science educators'.

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A Linguistic Perspective on Scientific Literacy

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During the past twenty to thirty years, the call for a language perspective on learning has increased. This is discussed in terms of a 'linguistic turn' in social sciences. The essence of this linguistic turn is also reflected in professor Roberts' summoning up of his paper submitted to the present conference on Scientific Literacy: "Clearly, more research is warranted about the development of SL and PUS through an examination of how discourse is understood, enacted by teachers and students, taken up in student learning, measured, and discussed in the science education community and beyond." (2007:88)

As early as 1978, the linguist Michael Halliday stated that "In the development of the child as a social being, language has the central role. Language is the main channel through which the patterns of living are transmitted to him, through which he learns to act as a member of a 'society' […]" (Halliday 1978:9). In such a social semiotic perspective developed within Systemic Functional Linguistics (Halliday 1978 and later), the semiotic systems which we live by, are considered to form a meaning resource. It is from this meaning resource that we choose when we articulate and structure meaning. By these choices, certain aspects are foregrounded while other aspects are put in the background or completely excluded. In that respect, the selected language forms are highly significant and coloured with ideology. However, the freedom to choose language resources and the explicit awareness of the importance of lexical choices may differ immensely between cultures and individuals. These issues will be further addressed later on in the present paper.

This paper thus focuses on what kind of knowledge a linguistic perspective and more specifically a social semiotic perspective can provide to the study of scientific literacy[1] in an educational setting. By using an example from a first grade classroom, we will highlight some dimensions that have proved to be central for the study of the language of science. We will also comment on the relevance of these dimensions to the study of scientific literacy.

Language dimensions

In the following example, some students in first grade are discussing their work on different animals together with their teacher.

1. Teacher — Thank you very much! I think that we found out a little bit about the ladybird. Yes? (*to Karl*)
2. Karl — May I, I want to tell you about my guinea pig.
3. Teacher — Yes, but we are not going to talk about *that* now, now we are going to . What does it say next? Which is the next animal?
4. Jeanette — A mouse.
5. Teacher — It is that table. Then it is your turn to tell us (*referring to a group of girls*). And then everyone else must be quite so that you can hear. (. . .) We are

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[1] In this paper we will not distinguish between scientific literacy and science literacy. We will use the former term.

		going to talk about what the animal looks like. What it eats, how it lives. If you know anything about its babies. What does it look like?
6.	Ulla	It has hair on itself.
7.	Teacher	It has hair. That is something the ladybird didn't have, so that is a difference. (. . .) What else!
8.	Ulla	Four legs.
9.	X	Hair on *itself.*
10.	Teacher	What about the tail? Is it long or short or thin or thick, or
11.	Girl	Short and thin.
12.	Rune	(*shouts*) Long and short.
13.	Girl	Thin, short, kind of round.
14.	Teacher	How does the mouse live? (*the children are restless*) Come on, you have to listen now! ……….

(The example is from Einarsson & Hultman 1984 pp. 134-136)

In a social semiotic perspective this event or context of situation is seen as one out of many instances of the practice or context of culture that is constructed by the languageing in these particular situations. All participants are looked upon as active participants and co-creators of these situations as well as of the evolving cultural contexts. This can be discussed in terms of having "agency". In other words, the students come from specific social backgrounds, they are boys or girls, and they have desires, special interests, goals and plans. By simply being, they instantiate their child and youth culture, its norms and values and are in this respect (together with their female teacher) ideological subjects of flesh and blood.

The real text and the produced text

The students in the example above are guided, or one might perhaps call it domesticated, in certain ways by their teacher. They are encouraged to focus the *real* text, i.e. the text about the animals they have studied. Karl tries to contribute something that is not congruent with the shared meaning previously discussed. He is thereby contributing a new relation that is not accepted by the teacher as belonging to the real text.

In his discourse analysis of classroom settings, Anward (1983:100-140) discusses how the norms for constructing a text on a subject matter in a classroom affects the students' ability to contribute to the text. He shows that depending on the pedagogical practices, these norms differ and as a result different contributions are accepted or not accepted. The text that is accepted is named *the real text*. This is only part of the actually produced text about the subject in focus. Contributions to the subject area which are not accepted by these norms belong to *the produced text*. In some pedagogical contexts the norms for the real texts are very strict and many contributions to the subject from the students are left out or ignored. For example, these norms concern what aspects of a subject that are judged to be relevant and adequate. The norms may also regulate very strictly the order in which these aspects can be given and in what language shape they are allowed to appear. In other pedagogical contexts more liberate and inclusive practices are used. In these cases the real text is extended in such a way that it more or less overlaps with the produced text.

Genre

The teacher in our example is working really hard to keep up with the tradition of how to organize facts about nature within natural science. The mouse should in this tradition be talked about from the perspective of a descriptive report. According to Veel (1997), the descriptive report is one among twelve different communicative genres typical of work within science. These genres are primarily found within four domains: 'Doing science',

'Explaining events scientifically', 'Organizing scientific information' and 'Challenging science'. Within the domain of doing science we find the procedure and procedural recount. Explaining events scientifically is fulfilled by using exploration or sequential, causal, factorial, theoretical or consequential explanations. The descriptive report together with the taxonomic report is used to organize scientific information. Finally challenging science is carried out in the form of expositions or discussions.

Everyday language and academic language

The language resources or wordings used both by the teacher and the students in the example above belong to the meaning resources of everyday language. However, by using the words in their generic sense, the mouse and its attributes, properties and behaviours are talked about in a generalized manner. In this sense, the language use exhibits traits found in the academic languageing that characterizes the science discourse. This discourse is in general very specific and distant from the discourses of everyday language (Schoultz 1998:30) as for example manifested in a large number of technical terms, often created through nominalisations (*Writing Science* 1993). By nominalisations we are referring to the process of expressing qualities and processes as nominal phrases instead of as verbs or adjectives. By doing this, processes and qualities can be treated as things in the text and thereby discussed without reference to participating actors or time. In general, nominalisations add abstraction to texts and, as previously mentioned, they are typical of the science discourse. However, sometimes abstraction comes into play also in everyday language. When generalizations instead of descriptions of "here-and-now" are used, the use of abstract language increases. Abstraction and concreteness could therefore be seen as a continuum where the first step towards abstraction goes through the use of generalized expressions (Edling 2006). In other words, there are no clear cut border lines between everyday language and academic language.

Technical terms are furthermore not just an unnecessary way of making science more difficult, but intrinsically linked to doing science and to science itself. They belong to the conceptual space of science. Just like technical terms in other areas, they are dense with information and to retrieve the information it may be necessary to unpack them. Nevertheless, packing up a word also entails that the new wording has another meaning. For example, to unpack 'solar eclipse' with 'eclipse of the sun' may not change the meaning significantly. But to replace it with 'the sun is darkened' or 'the sun gets dark' is much more questionable. It is uncertain if these last replacements actually include the reason why the sun gets dark in the same way as in the term 'solar eclipse'. These translations rather only scratch the surface of the meaning of the original term.

In educational settings in the primary grades (including reading material for the children) as well as in popular science, it is not uncommon to find these types of unpacked wordings. It could be seen as a launching pad for the technical term. A basic or surface conceptual structure is thus built through the use of everyday language.

In the discussion above, the sources of two possible marginalization processes within science teaching can be found. One type is when science is taught through the use of everyday language and on a superficial level only. Another type is when the teaching starts out on an abstract level using academic language, thus potentially leaving out all the students who are not acculturated into this type of discourse.

Foregrounding aspects of content

In our example from first grade, the generic mouse is foregrounded. This generic mouse is made the theme of the conversation. To put an aspect in the theme-position is one

important meaning making resource for foregrounding content. In some languages, like English and Swedish, this is done by putting this aspect at the beginning of each sentence. In some other languages the theme is marked by a special prefix or suffix.

Another way to foreground a specific aspect is to emphasize it in some way. This can be accomplished by expanding on the aspect of interest. However, this is not used to a large extent by the teacher in grade one. It is just when the hair of the mouse is in focus that she adds that this is in contrast to the ladybird. By this expansion she is actually using *difference* in order to scaffold the children's learning. Within Systemic Functional Linguistics Halliday and Matthiessen (2004, in af Geijerstam 2006) discuss three different types of expansive relations. 'Elaboration' is used when defining or clarifying an idea (expressed by e.g. 'for example', 'in other words', 'at least', 'actually'). 'Extension' on the other hand is used when joining two ideas by addition or variation (expressed by e.g. 'and', 'but', 'on the contrary', 'instead'). Finally 'enhancement' is used when qualifying something with more information such as time, place or cause (expressed by e.g. 'then', 'next', 'likewise', 'so', 'consequently', 'in that respect'). The use of expansions does not just support the foregrounding of an aspect. It also makes this aspect more comprehensible.

An aspect of the content can furthermore be emphasized by evaluation. Within Systemic Functional Linguistics Martin and White (2005, in Folkeryd 2006) have developed a framework for analyzing evaluation in discourse named the Appraisal framework. Within this system utterances are classified as 'Attitude' if they express positive or negative evaluation of a person, thing, situation or state of being (for example 'the situation is *dangerous'* or people are *suffering'*). 'Engagement' entails utterances that either accept or ignore various positions to what is discussed in the texts. These utterances thus react to what is presented, what has been presented or will be presented (for example '*Naturally* this is the way to go', '*Of course* this is the truth'). 'Graduation' is finally about turning up or down the volume of the evaluation (for example 'She was *very upset',* He was *a little bit hurt'*).

Meaning resources and scientific literacy

The teacher is a very important person in a student's educational life. He/she can be looked upon "as a creator of social man – or at least as a midwife in the creation process" (Halliday 1978: 9). In this position a teacher has the power to control the meaning resources being used in the class room. The teacher also governs both what aspects of a subject matter that is foregrounded and how this is done. But there are very few indications that the teachers of science are aware of her/his languageing power or have any knowledge about the meaning resources that are used in science languageing (af Geijerstam 2006; af Geijerstam & Liberg forthc). This is one very important reason why the students' freedom of choosing meaning resources is severely restricted.

In order to facilitate learning and the linguistic challenges posed on the students, there is thus a need for an orientation to language that allows all students to develop their linguistic resources as they enter classroom contexts. This includes a focus on the language dimensions presented above, i.e. the way language construes content, how a particular text type or genre can be structured and how certain lexical choices make one text more powerful than another.

The widening of the scope of scientific literacy also calls for new meaning resources that the science teacher has to be equipped with. Today this is not only a question of the verbal language discussed above. For example, there are recent studies of multimodality where

modality switches are discussed as transformations scaffolding the learning process (Knain 200X). An example of this would be doing lab work in science, talking about it and then writing it down in a lab-report, which is a process of at least two modality switches that can enhance understanding and learning.

In summary, this paper emphasizes that scientific literacy must include a component consisting of reflective competence and an awareness concerning the language and languageing of science as it is shaped in both Vision I and II.

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Scientific Literacy, Discourse, and Knowledge

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Proponents of scientific literacy often tie the goals of science education to broad societal ideals (e.g., AAAS, 1993). These ideals extend beyond reading and writing scientific texts and beyond understandings of scientific concepts and procedures. Rationales for scientific literacy include the economic well being of a nation, the perceived need for technological knowledge among citizens, and the value of scientific and technological knowledge for supporting social justice and taking actions in society (DeBoer, 2000; Hodson, 2003). Often lost in the discussion of what (or whose) knowledge is of most worth for citizenship is the central role communication plays in the construction and assessment of knowledge. A focus on scientific literacy can bring to the foreground the importance of language in knowledge production, in both scientific and education communities.

Discourse contributes in multiple ways to the production of scientific knowledge, from the banter in the process of discovery (Garfinkel, Lynch & Livingston, 1981) to the development of specific genres for persuasion (Bazerman, 1988). Similarly, in education discourse processes are central to the everyday activity of knowledge construction. Discourse is central to the ways communities develop community norms and expectations, define common knowledge for the group, build affiliation, frame knowledge made available, and provide access to disciplinary knowledge, and invite or limit participation (Cazden, 2001; Gee & Green, 1998). Thus, the learning of individuals is situated in the cultural practices and norms of a relevant community, a community that changes over time as members take action to change the social knowledge, norms, and practices. A central mediating feature of these communities is language. Knowledge is constructed and reconstructed as members of a community bring together their respective experiences, local knowledge, and ways of being (Wells, 2000). While discourse practices vary in purpose across professional and educational settings, uses of language are central to both the creation and communication of knowledge in each setting. Thus, the ties of language to knowledge construction merit a closer look at literacy and epistemology.

In this paper, I consider definitions of scientific literacy and how the use of language is related to learning and knowing. I begin by drawing from work in the field of literacy research, before turning to science studies and science education. Through the use of philosophy of science and various empirical studies of scientific practices across settings, I propose that the goals of science education include epistemic practices. From here I discuss how, when conceiving of language and knowledge as ideological, we need to consider how knowledge is legitimated through discourse.

Literacy, Language, and Knowledge

Language in Scientific Literacy

Norris and Phillips (2003) make a distinction between two senses of scientific literacy in the science education research literature. They define *fundamental* science literacy as coming from the ability to read and write on the subject of science and the *derived* sense of scientific literacy as encompassed in being knowledgeable, learned, and educated in science (Norris & Phillips, 2003, p. 224). Their argument continued to note that reading and writing in and about science do not stand alone as mere devices for the recording and communication of science (Norris & Phillips, 2003); but

rather, science literacy in the fundamental sense serves as a central component in building the conceptual, epistemic, and societal dimensions associated with a derived sense of literacy. Norris and Phillips argue that there exist connections between the broad citizenship goals of scientific literacy articulated in science education reform documents and the uses of written and spoken language in educational settings. While I agree with Norris and Phillips that the derived sense of scientific literacy is dependent on the fundamental sense of literacy, particularly as related to the social and discourse features of scientific practices, there are two ways that this distinction needs to be examined closely. First, learning literate practices in a fundamental sense entails acculturation to a broader set of ways of speaking, acting, and being in the world. Second, this acculturation involves the communication, and thus privileging, of some(one's) knowledge. Thus choices about which types of literate practices entail choices about types of citizenship.

Discourse practices, socialization, and literacy

Gee (2001a) offers some clarity to the notions of discourse and literacy. Although I will not follow his argument exactly, Gee's definition of literacy is useful for understanding issues of language use in science classrooms. I will use the term discourse to refer to ways of using language in social contexts. Gee's argument is that discourses are social practices that combine with ways of acting to form Discourses – "ways of being in the world … forms of life which integrate words, acts, values, beliefs, attitudes, and social identities as well as gestures, glances, body positions, and clothes" (p. 526). A key feature of Discourses is that they are not mastered through overt instruction, but rather, through participation as a member of a group exhibiting the practices of the particular Discourse. One learns a primary Discourse through enculturation and secondary Discourses through participation and acculturation[1]. Gee defines literacy as "the mastery of or fluent control over a secondary Discourse" (p.529). These secondary Discourses are powerful as they allow for analysis and criticism and, in particular, for critique of one's primary Discourse. This perspective has application in the design of science pedagogy, as the view suggests that students need time and opportunities to participate in activities that engage them in the new discourses – that is, language use needs to be connected to purposeful activity where students learn social meanings through participation with more knowing others.

Further extending Gee's view of literacy into social practice, Green and her colleagues consider literacy in terms of the "literate practices" of learning disciplinary knowledge (e.g., Santa Barbara Classroom Discourse Group, 1992). This view of literacy, derived from anthropology and sociolinguistics, examines ways spoken and written texts are embedded in social processes and cultural practices. Through the study of literate practices across disciplinary areas, the Santa Barbara Classroom Discourse Group (1992) defines literacy as socially constructed and situationally defined and redefined within and across different social groups as members engage with, interpret, and construct text (Castanheira, Crawford, Dixon, & Green, 2001, p. 354). This view suggests that literacy is not achieved, but rather can be viewed as literate actions members of groups take as they engage with texts in everyday life. This view is similar to that of Gee. In both cases literacy involves more than just

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[1] Enculturation typically refers to the learning that occurs in one's first culture and acculturation to the learning of a secondary culture. These notions may not be so easy to separate, as, for example, one's first culture may include the practices of one's family, neighborhoods, schools, churches, and other social organizations. For the purposes of this paper, it is clear that learning science is a process of acculturation and that the cultural practices of science may be aligned with certain first Discourses more than others.

reading and writing texts, but rather entails actions, beliefs, values, social practices, and identity formation (Gee & Green, 1998).

Viewing literacy and learning in this way suggests that the social practices of science interact with, and draw upon, and in certain circumstances are similar to, other specialized ways of talking, writing, engaging, and being in the world. This view of literacy suggests that social groups construct the semiotic systems, roles and relationships, norms and expectations, and rights and obligations that are signaled through the actions and interactions among members (Santa Barbara Classroom Discourse Group, 1992; Kelly & Green, 1998). Therefore, the study of how the discourses of disciplinary knowledge are constructed in educational settings needs to include examination of the ways social groups affiliate, build cultural practices through interaction, and establish common knowledge within the group or class (Edwards & Mercer, 1987). These ways of being suggest that learning to engage in the discourses of science requires developing new repertoires for interaction with people, texts, and technologies. The consideration of identity then becomes crucial for the understanding of the socialization processes of education and how affiliation or alienation might be occur through acculturation processes (Gee, 2001b; Brown, Reveles, & Kelly, 2005). This view suggests that identity is situational, contextualized, and becomes evident through discourse and interaction – members of groups make decisions about how to position themselves with discourse that draws from a repertoire of ways of interacting (Reveles, Kelly, & Durán, 2007).

The Ideological Nature of Language and Knowledge

The view of literacy that entails learning a secondary Discourse (Gee, 2001a), with all the associated values, beliefs, and ways of being in the world, suggests that learning to participate in a social context is not value neutral. This argument is made forcefully by Street (2001) in referring to the "new literacy studies." Street argued that initial studies of literacy often presupposed an "autonomous" view of reading and writing. This view suggests that literacy be conceptualized in "technical terms, treating it as independent of social context, an autonomous variable whose consequences for society and cognition can be derived from its intrinsic character" (p. 431-432). Street proposes an "ideological" model of literacy that views "literacy practices as inextricably linked to cultural and power structures in society and to recognize the variety of cultural practices associated with reading and writing in different contexts" (p. 433-434). Street uses ideological to refer to the social, cultural, and pragmatic dimensions of literacy practices – but not the "false consciousness" posited by Marxist views of ideology. The ideological model suggests that literacy practices are situated in some context with some set of purposes, uses, goals, and so forth. Street suggests moving away from only studies of literacy as an individual cognitive tool to consideration of the ways that language-in-use is situated in culture and power, in institutions, and in ideologies of communication in the contemporary world (p. 437). Thus, from the contemporary views of literacy educators, the study of literacy should include ethnography of communication, communities, and institutions. Such work applied to science education may entail investigations of the many ways that science is constructed – that is as interactionally accomplished through discourse and actions – both within schooling and in the many others contexts where local knowledge and practices involving the study of nature are evoked (Roth & Barton, 2004).

Directions for Research Concerning Scientific Literacy

In this section I propose two avenues for research in scientific literacy. I am not suggesting that research in scientific literacy be limited to these avenues, but

rather, that the views of literacy, language, and knowledge sketched in the previous section have implications for research. There are, of course, many other plausible ways to research scientific literacy and ways of going about such research. In the next two sections I discuss the importance of learning in epistemic practices of science as part of the secondary discourse of science and the need to consider how certain discourses come to count as science in schools.

Epistemic Practices and Science Learning

Duschl and Grandy (2005) propose to three knowledge domains of goals for science education: conceptual, epistemic, and social/communicative. These goals move science instruction beyond a traditional focus on the proposition knowledge of final form science. As much research has focused on conceptual learning, I shall focus on how the epistemic and social/communicative goals relate to scientific literacy. In previous reviews, I have noted that studies of epistemology in science education have tended to focus either on personal theories of knowing as related to learning or disciplinary views of knowledge that inform curriculum or assessment development, but that few examine the ways that disciplinary knowledge is interactively accomplished through discourse and actions in local settings (e.g., Kelly, Chen, & Crawford, 1998). My argument here is that the three knowledge domains outlined by Duschl and Grandy can be mutually supportive through a focus on the *epistemic practices* associated with assessing, producing, communicating, and evaluating knowledge claims (Kelly, 2005). While I do not believe that a focus on epistemic practices should be the only focus of research related to science pedagogy, it does offer some productive ways of examining the intersubjective nature of scientific literacy.

The focus on epistemic practices derives from a social epistemology. Developments in the philosophy of science have refocused the epistemic subject from an individual mind to a relevant community of knowers (Longino, 2002; for review, see Kelly 2005). The move to an intersubjective paradigm for epistemology is particularly relevant in the construction of scientific knowledge, as found in both professional and educational contexts. Community practices and values play important roles in empirical research. These practices and values have been well documented in science studies (e.g., Knorr-Cetina, 1999; Lynch, 1993). Social practices of epistemic communities in science fields govern research directions, control outlets for publication, define the socialization of new members, and formulate and assess knowledge claims through collaborative research endeavors (Jasanoff, Markle, Petersen, & Pinch, 1995). A social epistemology has relevance for education in many ways, but perhaps most centrally in ways that people are initiated into particular frames of reference through language and participation in cultural practices (Wittgenstein, 1958). Viewing science as social knowledge contrast with some paradigms for educational research, which have focused on how individual students learn particular concepts (e.g., Pfundt, & Duit, 1991). The alternative frameworks movement, conceptual change, various forms of constructivism, have largely focused on individual learners. This has been true even if the individual learners were learning in a social situation. In such cases, epistemology was often reduced to how individual learners conceptualized knowledge in their own personal, idiosyncratic ways. A focus on epistemic practices offers an alternative.

An emerging group of scholars are examining the knowledge building in everyday educational contexts (Jimenez-Aleixandre & Reigosa, 2006; Kelly, 2005; Kelly, Chen, & Prothero, 2000; Lidar, Lundquist, & Ostman, 2006; Sandoval, 2006; Wickman, 2004). The foci have been on discourse of students and teachers around the

practical investigations of science, as well as discourse around aspects of knowledge assessment and evaluation. A common characteristic of these studies is a centering of the epistemic subject as a relevant social group, or minimally within a social group. By focusing closely on the ways that knowledge claims are formulated and assessed through discourse processes, these studies offer ways to examine how evidence for changes in conceptual understanding, scientific reasoning, and science in sociopolitical contexts can be understood in everyday learning situations. This focus connects to theories of social epistemology, as we may think of pedagogy as providing opportunities to engage in the knowledge and practices of a relevant community. The focus on situated epistemic practices poses challenges for students and researcher.

A focus on epistemic practices situates science learning in social contexts and places a new set of literacy demands on students. The literacy demands entailed by the epistemic practices of science education suggest a need for studies of language in use in multiple settings. These studies need to account for the multimedia, interactionally accomplished nature of scientific reasoning situationally defined settings (Lemke, 2000, Roth & Lee, 2002). Such studies would need to examine uses of language in spoken and written forms across different temporal units – i.e., moments, lessons, science units and projects, histories of ideas (Kelly, 2005). What counts as science, who can participate, and how science is accomplished among members of a group, are all manifest in moment-to-moment interactions embedded in social histories and cultural traditions (Kelly & Green, 1998). Thus, the study of literacy demands of the many actors relevant to school science (scientists, activists, teachers, students, parents, among others) may shed light on the processes of representation, communication, and evaluation of the evidentiary bases of knowledge claims – often key features of the derived sense of scientific literacy. The pedagogical emphasis on evidence use suggests the need to examine ways that social practices are instantiated, communicated, appropriated, interpreted, applied, and change over time. Such a research focus may identify ways science pedagogy supports or constrains students' learning opportunities.

A focus on epistemic practices that situates science learning in social contexts places a new set of demands on researchers examining learning. A focus on epistemic practices suggests units of analyses that include multiple actors, the ways that roles are established and positioned, norms and expectations, the mediating artifacts, and local history of sociocultural practices. Activity theory provides a methodological approach that considers a distributed view of learning by taking into consideration the many dimensions of collective, culturally mediated activity (Engestrom & Miettinen, 1999). This unit of analysis thus requires that the study of inquiry examine these many dimensions, through systematic, careful analysis of the concerted actions of social groups.

The focus on epistemic practices and social knowledge presupposes an interaction of more knowledgeable others and students in dialogue. This perspective raises questions about who and what counts in the negotiation of (what is taken for) legitimate knowledge. I would be remiss to not consider some of the legitimation issues in science curricula.

Legitimation issues in science curricula

Whether considering the broad goals of science for citizenship, or the more narrow goals of the particular ways science texts are written and read, questions about what counts as science arise. A number of questions can be raised about scientific literacy from this point of view: How should a community decide which (whose)

knowledge is worthy of inclusion in the curriculum? Who can legitimately make such decisions? What ought to be the nature of debate regarding the processes for choosing knowledge worthy of the students' attention? Such questions are not easily answered. For example, Eisenhart, Finkel, & Marion (1996) suggested that important US-based reform documents (AAAS, 1993; NRC, 1996) while claiming the goal of scientific literacy broadly defined, emphasize on the theoretical and factual nature of science, at the expense of other goals related to the nature of science, understanding the societal impact of science, and a developing socially responsible science. In another example, Roth and Lee (2002) note that conceptions of scientific literacy often presuppose a view of knowledge acquisition on the part of individuals, rather than knowledge of, or for, a collective. By viewing literacy for a collective and assuming a distribution of expertise (Norris, 1995), Roth and Lee note that science education can be developed as and for sociopolitical action. Finally, Hodson (2003) noted that while documents such as Science for All Americans (AAAS, 1989), call for a more socially compassionate science, the authors did not suggest that scientific literacy include the "capacity and willingness to act in environmentally responsible and socially just ways" (p. 652). Hodson makes the case that, while notions of scientific literacy are of some value, there is a need to develop greater interest among young learners and to create a science for sociopolitical action.

Just as questions can be raised about the views of literacy underlying definitions of scientific *literacy*, educators continue to challenge assumptions about *science*. Critiques of science have come from feminist perspectives (e.g., Barton, 1998), multicultural education (e.g., Krugly-Smolska, 1996), critical theory (e.g., Kyle, 1991), and from the point of view of indigenous knowledges (e.g., Aikenhead, 1997, 2001). Science and scientific knowledge will continue to be contested (e.g., Barton & Osborne, 1998; Harding, 1993), whether framed under the banner of scientific literacy or not, and these challenges pose important questions for the future directions of research in scientific literacy. The contested nature of science leads to the need for careful consideration of knowledge legitimation issues (Habermas, 1990). For example, Aikenhead (2006) argues that in much of North American the "pipeline ideology" of science education orients curricular choices away from knowledge students may need toward knowledge of academic scientists.

Knowledge legitimation poses difficult questions for considerations of future direction for scientific literacy. Undoubtedly, there is a certain power in science and its contributions to technology for solving problems. Whether the science under consideration is the final form, de-politized often found in science textbooks (and sometimes articulated in recent standards-based reforms, e.g., Bianchini & Kelly, 2000), or science for sociopolitical action as suggested by Hodson (2003), there exists certain tensions between the value of students' voices in contributing to curricular decisions and the value of expanding the horizons of students through inculcation of certain knowledge, beliefs, and values. Decisions about whose knowledge counts have a long history and indeed are central to important debates in education (Apple, 1993). These debates are healthy; as a research community, we can continue to argue for legitimation of knowledge from different moral points of view. Nevertheless, such discussions are difficult. In an earlier paper I drew from Strike (1995) to propose a framework of critical discourse to consider how, given the epistemic plurality of modern societies, questions of importance can be discussed across differences (Kelly, 2006). The proposed framework involves considering a set of critical dialogues centered on building public reason, rather than defining *a priori* what counts as knowledge, science, literacy, and so forth.

Concluding Thoughts

In this paper I have argued for a view scientific literacy that considers the ways that language use is central to the development of community knowledge and practices. The purpose of the paper is not to provide a comprehensive review of all of the ways that considerations of knowledge and language might intersect with scientific literacy. Rather, I have examined some notions of literacy and how literacy focused on language in use (fundamental sense, following Norris and Phillips, 2003) is related to the scientific literacy for citizenship (derived sense of literacy, following Norris and Phillips, 2003). I have proposed a research focus on epistemic practices that consider the evidentiary bases of scientific knowledge claims: ways knowledge is framed, proposed, justified, evaluated, and legitimized. Furthermore, I have argued that framing reform in terms of scientific literacy presupposes notions of knowledge legitimation. Questions about *what counts as* knowledge and science remain and are part of a healthy on-going dialogue. Directions for future research might include examining how engagement in epistemic practices provides for learning opportunities, answering descriptive questions about what and whose science counts in given contexts, and considering normative questions about what and whose knowledge should contribute to creating a more just and responsible citizenry.

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Contributions from critical perspectives on language and literacy to the conceptualisation of scientific literacy

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Summary of the argument

In this paper I will try and contribute to the main goals of the seminar through a discussion of science literacy/scientific literacy (SL hereafter) with respect to two frames of reference: (i) a characterization of the 'language of science' based on Bakhtin's philosophy of language and on critical discourse analysis; (ii) a discussion of possible meanings for the concept of literacy, in particular, those derived from Paulo Freire's contribution to the field. This way, after situating both my personal socio conceptual horizon and implications on the subject of SL, I raise a number of questions, the discussion of which may lead to an expanded notion of SL which acknowledges the need to consider aspects such as: the adhesion to a critical agenda for SL research and practice, the need to overcome a split between activities in formal and non formal learning contexts, the relationships between natural and biomedical sciences and other fields of knowledge and the nature of the multimedia literacy demands.

On language and literacy

The 'language of science'

It was Bakhtin (1981) who first called attention to the existence of social languages, that is, the specific character of a given group's discourse as indicated by professional, generational, ideological or linguistic elements. Bakhtin (1986) also proposed the idea of discourse genre to indicate the regular patterns elaborated within different spheres of human communication. Indeed, the inextricable relationship between language and the social is marked in Bakhtins's choice for unity of linguistic analysis: the utterance. Being inherently social, any utterance is like a ring in a chain of communicative events, entailing and updating previous utterances and, at the same time, anticipating utterances to follow. This view of dialogism invokes the idea of the mixing of intentions of speaker and listener and defines the text as polyphonic (Vice 1997), that is, an arena where multiple voices, tied to different socio-conceptual horizons, elaborate, compete, complement or refute one another. This perspective takes us beyond a view in which language is a symbolic system of resources for communication to the realization of a conception in which language is constitutive of identities, of relationships between subjects and of relationships between subjects, institutions and knowledge.

Such views on language have been influential and instrumental for critical approaches to the study of language and discourse (Hodge and Kress 1998, Fairclough 1992). One essential contribution has been the recognition of the ideological nature of signs and their relationships with concrete forms of social interaction (Bakhtin 1986). Furthermore, for both Social Semiotics and Critical Discourse Analysis (CDA) texts contain traces of social and historical processes of meaning making and cannot be

conceived or understood without reference to the processes of their production, distribution and reception in social practices.

These considerations are important as one starting point to develop a notion of literacy is the very definition of the language domain it applies to. In our case we are especially concerned with 'the language of science'. Critical approaches to language and discourse can help us question the overrated importance given to discussions about which specific bits knowledge, technical terms or vocabulary scientifically literate people should possess. By considering the language of science as the result of a (semiotic) reconstruction of human experience (Halliday 1998), some of its characteristics, such as high lexical density, technical terminology etc., acquire new significance which has to do with the nature of scientific knowledge and of its social processes of construction. Also, an extension of such argument critical can help us reconceive the way we think about other science related texts which play a central role in SL research and *praxis*, such as science curricula, results from evaluation studies and media science, and to problematise their potential to promote learning and engagement with science. As they cease to be seen as just recommendations to be followed or contents to be learned and become instances of the materialization of discourses about science in society, we can ask to what extent these texts reflect the plurality of the perspectives needed to deal with SL.

Finally, understanding texts with respect to their social conditions of production does not mean to become trapped in the pessimism of deterministic approaches as Critical Discourse Analysis is equally interested both social effects *on* texts as well as social effects *of* texts, calling our attention to the fact that people respond to them in an active transformative and interested manner. Thus, it shifts focus towards the possibilities for meaning making and social action of the literate person and allows us to think which sorts of contexts are set out in society for participation and what are the individual and collective expectations for social action in science related situations.

Literacy as a metaphor

According to Soares (1995) the term literacy started to be used in a more widespread fashion around the end of the 19th century, that is, two centuries after the term illiteracy was coined. As the social demands concerning the use of language becomes more varied and complex there seems to be an increasing need to define the meaning of literacy. Authors like Soares distinguish two main contexts of use of the term literate, which relate to the communicative and to the constitutive dimensions of language respectively. The first designates the condition of people who are capable of reading and writing, that is, of interpreting texts and expressing themselves according to grammatical canons. The second one refers to those who not only master the necessary competences but who are fully integrated in social practices which demand reading and writing and, for this reason, being able to transform their social condition.

Thus, if we take the 'literacy' component in the phrase science/scientific literacy to be understood as a metaphorical appropriation from notions found in literacy studies, several interesting reflections occur. What counts as literacy? For a number of years, and consistently with quite a view of language as tool for learning, literacy was conceived as proficiency in the use of a code. Reading and writing were activities tied up to communicative needs and linked to the ability to understand and combine elements in a symbolic system. By analogy, scientific literacy would correspond to learning the building blocks of knowledge in order to be able to achieve more complex

levels of representation. Such view was quite influential in structuring traditional science curricula and in developing many large scale surveys of public understanding of science[1] conducted in the 1980s, which actually measured the ability to recall factual information. Such traditional views of literacy were gradually overcome and a growing interest in the social dimension of language enabled a shift in focus. Within this perspective, the social situation where reading and writing activities occur are emphasised and to be literate goes beyond knowing the bases of symbolic systems and means acting consistently on the bases of such knowledge in social practices.

Such expanded views on literacy have had an impact on how scientific literacy is defined. Brickhouse (2007) points out to at least four dimensions related to scientific literacy: civic, personal, cultural and critical. I would like to elaborate on this last dimension as it marks a transition from literacy as a pedagogic issue to literacy as a political issue, that is, as an investment in humanist and liberating *praxis*. An important source domain for developing the critical dimension in the literacy metaphor in SL can be found in the work by Paulo Freire (1970), a Brazilian educator who developed a critical pedagogical theory based upon concepts such as dialogue, consciousness awakening and emancipation. From this perspective, educators and those to be educated are subjects who engage in a world mediated mutual learning process. Commonsense and other forms of knowledge, including scientific knowledge, are never dichotomised but integrated in dialogical relationships. Education is conceived as a political act aimed at social transformation towards a more democratic and egalitarian society. His philosophy of education was materialized in a literacy method for young people and adults which had at its heart the identification of the subjects' cultural vocabulary universe and of the social political and existential situations in which these subjects took part in order to give meaning to these words and themes in a process that allowed the awakening of a critical consciousness which would lead to action and social change. For Freire, teaching involved ethical and political responsibility as well as professional knowledge. Teachers were authorized to teach by demonstrating both competence in their fields of knowledge and a lifelong commitment to learning. Teaching someone to read is defined by Freire as engaging in a creative experience of comprehending and communicating. This is why, for Freire, reading is never dissociated from writing.

To discuss the scope and complexity of Freire's ideas within the limits of a paper is clearly an unattainable task. Instead I wish to explore a bit further, from a Freirean perspective, what it means to teach a person to read. A key concept within Freire's framework, reading is constructed not just as a possibility of textual decodification but as a process which relates subjects' experience and world views with their potential to question and transform this world. It involves the articulation between reading the world, reading the word and, then, (re)reading the world. Thus reading is not repeating other people's words but being able to say one's own words. Being literate involves, therefore, the possibility to become aware of one's own socio-conceptual horizons as well as to relate individual and societal levels. Thus, from this perspective literacy is not defined solely by the nature of symbolic systems of representation and expression, and the answer to the question of why we should promote scientific literacy is not defined by the nature of science or of scientific activity but by the need to transform men and women into citizens.

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[1] For the relationships between scientific literacy and public understanding of science, see Rogers (2007).

Implications for thinking about SL

The ideas sketched above can be potentially useful to revise and expand the notion of SL in so far as they deal with a number of problematic issues concerning current definitions. What does it mean to be literate in science: to share knowledge about science products and processes or to be able to take part in social situations where scientific knowledge matters? Are these mutually exclusive possibilities? It seems that in the case of a social language as complex as science both senses apply, but how to relate them if social settings they apply to may seem quite diverse? What are the social practices which demand scientific knowledge? Which other kinds of knowledge do they demand?

Why should we promote SL?

Let us start with a question that has to do with how one deals with the tension between individual and societal levels in SL conceptualisations and with the reasons why we should be promoting scientific literacy. According to Roberts (2007), definitions of SL typically involve relationships between society and scientific knowledge though some of them will place a stronger emphasis on science's internal agenda (Vision I) whilst others will broaden the scope of what is to be considered relevant knowledge for a scientifically literate person (Vision II). However, both visions reinforce that science plays an important part in a number of matters with both private and public importance and quite often SL goals and actions are justified in terms of the need to prepare citizens for living and coping with the demands of an increasingly science and technology based society identified with preparation for work, informed decision making and responsible citizenship. In both cases, SL would respond to demands posed either by science itself or by society. SL would help achieve objectives consonant with functionalist approaches for education, which advocate the need for subjects to fit in, contribute to and participate in a (democratic) society.

On the other hand, based on critical approaches to education, one could argue that an awareness of scientific knowledge enables a different kind of participation in society, namely, one in which subjects not simply reproduce, reinforce or consolidate relationships already established but actively engage in questioning and transforming society. The argument is as follows. By expanding their consciousness of (scientific) knowledge as the product of social practices which are non neutral and marked by power struggles, subjects can situate themselves, as well as their knowledge systems and beliefs, with respect to such practices. Moreover they can expand their awareness about questions that matter to them and start finding their way into the debate of such questions. From this perspective, a more plural engagement in such dialogues might lead to a more democratic basis for social consensus. One example could be the controversy around using frozen embryos in stem cell research that could lead to treatment to incurable diseases. Public debate is needed in a matter that will be object of legislation and towards which we are to develop either a personal or a collective stance.

The argument could be further developed in the context of current debates and demands for individual action set out by other scientific matters with both private and public importance, such as nutritional education, teenage pregnancy prevention campaigns, global warming or rational management of water. Take the example of public health campaigns to prevent teenage pregnancy. A number of studies have emphasised that information about reproductive health and contraception is not enough to prevent girls and boys to put themselves at risk of having a child while in their teens. In most cases it

is hardly just an issue of rational conviction. Understanding risks may not lead directly to the adoption of responsible behaviour. The difficulties in this intended linear reasoning chain may not be cognitive, but social. To become a mother may signify, for a young girl who lives in a society that offers few opportunities, her only chance to become an adult and to occupy a different position in her community. One could question whether her choice would be the same if perspectives of both personal and professional growth were more widely available and then ask what is then to be reconsidered: the ways through which information can be conveyed or the opportunities and perspectives offered to younger generations?

Another step further would be to think about how critical perspectives could challenge decisions and objectives of science itself. Consider a decision to fund research on genetically modified crops that are more adaptable to the mineralised soils which result from the intense draughts predicted in global warming scenarios. Should financial resources be allocated to search for alternatives, which will just sustain what can be an economically profitable but environmentally predatory system? Or shouldn't we dismiss the fallacious claim that climate will inexorably change and focus on measures that minimise the impacts that, for instance, agriculture and industry have on the environment? Finally, critical as opposed to functionalist perspectives on scientific literacy would encourage citizens to debate and signify political choices, for example those made by some policy makers and governors to break patents of, say, antiretroviral drugs needed for treating HIV and AIDS in countries which are severely affected by this epidemic but do not possess enough resources to meet the high costs involved in importing them. The examples above reveal that SL entails not only cognitive but also political, economical, affective, emotional, moral and ethical dimensions which cannot be dissociated when thinking about scientific discourse.

Having said that it is important to stress that changes to the patterns and possibilities of public participation do not happen automatically as a direct consequence of improved scientific knowledge, that is, they presuppose a democratic systems in which people are free to express their aspirations and concerns. Again science cannot be disconnected from broader issues and institutions in society. But the point to be stressed here is that semiotic expression defines and characterises social practices as well as are the result of demands posed by social situations. The epistemological commitment involved in considering textual production as a social practice, that is, as a set of activities legitimated by a given community and that, as such, possess criteria for the inclusion, validation and exclusion of themes, participants, of processes of knowing, and of products of knowledge. As a result it is possible to see a relationship between, on the one hand, social structures and events and, on the other hand, languages and texts. Based upon Halliday (1978), Fairclough (2004) relates semiotic aspects (languages, orders of discourse, and texts) to social aspects (structures, practices and events) to problematise micro and macrosocial relations.

Aided by the scheme below we reject, together with Fairclough, the possibility that texts are just the result of language's meaning potentials (Halliday 1978). Similarly we can see that events do not correspond to direct effects of social structures. There are intermediate configurations that mediate and, to a certain extent, control the possible effects and influences between these levels. Social practices dynamically articulate ways of language use, actions and interactions, social roles etc. which correspond to forms of "organisation and social control of linguistic variations" named order of discourse (Foucault 1972; Fairclough 1992; Chouliaraki and Fairclough 2001)
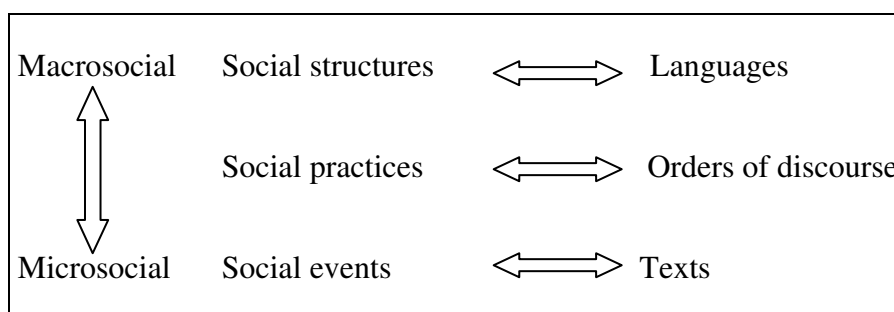
Figure 1: Relationships between semiotic and social dimensions (adapted from Fairclough, 2004)

This reflexivity (Usher 1996) allows the recognition that we are *part of* instead of being *apart from* discursive constructions.

Contexts and environments for learning science

Extensive research and practice on SL has indicated that it is can be conceptualised, amongst other things, as a teaching objective, as a learning goal, as a framework for curriculum development, as a basis to assess public understanding of science or as a research topic (Roberts, 2007). Such polysemic character and plurality of focus for SL foregrounds the need for a conceptualisation that allows a more integrated and coherent account of SL at different levels and contexts. A related relevant question is: *"How to conceptualise scientific literacy in a way that links different levels of science education?"* One possibility is to approach this issue from the perspective of curriculum developments, which articulates different learning experiences along the schooling continuum. Another possibility is to think about the actual scenarios for interacting with science as set out by contemporaneous media available for both adults and children, inside and outside school contexts, which end up conforming learning experiences[2]. I wish to argue that both SL research and practice cannot be conceptualised on the basis of a split between formal and non formal education especially now when it is acknowledged that 'media science' can help promote SL in society (De Boer 2000) and in schools (Halkia & Mantzouridis 2005).

A number of issues can be raised in a discussion about how to overcome the split without blurring the edges that confer identity to formal and non-formal contexts. Let us take the example of using media science texts in science lessons. To what extent are patterns of interaction with texts dependent on the nature of the social practices, which are typical of each context of reading? Is it the case to try and recreate the ethos for reading media science in schools? Or, alternatively, how should we think about the recontextualisation practices that are needed so that media texts can serve pedagogical purposes? How can we deal with questions of authority, legitimacy and credibility in scientific/school science and in media texts? In any case these questions must be considered against a background of current debates about the social function of school and schooling which defies traditional views of school as a (or the) place to acquire (scientific) skills to be later applied in life contexts to consider it as one (amongst other) life context which offer opportunities for learning of a certain kind.

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[2] In this paper I will assume that the media plays an educational role in providing up-to-date scientific information to the public and in constructing consensual views about science.

Finally, relationships between domain specific and contextual knowledge, discussed in a different way by the field of students' conceptions, could be further explored with respect to the conceptualisation of SL. It is increasingly difficult to think about SL, especially from a Vision II perspective, without making reference to the relationship between science and other domains of (scientific) knowledge. We must not forget that the S in SL stands for natural/biomedical sciences. In order to understand and act in an informed and responsible way in science related situations it is necessary to consider historical, statistical, ethical and moral arguments. There is a choice to be made as to whether knowledge related to these fields is to be considered as a relevant context to or as constitutive knowledge of science itself. That would of course depend on the ways though which science develops, but also on the ways we wish it to evolve.

Science and multimedia literacy demands

Another important, though often neglected, point related to SL concerns the inherently multimodal nature of scientific knowledge and discourse. From the early steps of conceptualisation to the final stages when consolidated research results are disseminated, science deploys a variety of semiotic modes. The need to cope with the variety of languages (verbal and visual, mathematical, computational, animation etc.) is already acknowledged as part of the multimedia literacy demands for the science curriculum (Lemke 2001) and for communication in general. Scientific texts, as well as their (didactically or popularised) authorized versions, are indeed semiotic hybrids (Lemke 1998) and efforts to achieve SL must involve dealing with their multimodal nature.

This debate takes place within a wider conceptual context that links Education Media and Communication studies and highlights a number of social, technological and economical factors that have had an impact on current discussions about literacy. In his book 'Literacy in the new media age' Gunther Kress (2003) points out to the shift from page to screen as one of such factors and discusses how it can change the ways literacy itself can be defined as well as the effects this might have in society and culture. With respect to science education, it is important to think about how formats and affordances of new media, such as role playing games, internet browsing, real time interfacing, remote sensing, modelling etc., will conform new roles for teachers and learners as well as what counts as knowledge and literacy in science.

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Expanding the Research Agenda for Scientific Literacy

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Explicitly or implicitly, research questions always relate to education policy and practice. The three interact. A fundamental research question for policy and practice is (Roberts, 1988): What counts as scientific literacy today? To help us address this question, Roberts (2007) created a heuristic framework for understanding the defining ideologies of scientific literacy (SL). His framework is a continuum between two extremes, which he calls Vision I and Vision II. At the one extreme, a Vision I policy is scientist-centred and focused on decontextualized science subject matter, with the aim to enculturate students into scientific disciplines (pre-professional training). At the other extreme, a Vision II policy is student-centred, context-driven, with the aim to enculturate students into their local, national, and global communities (as many other school subjects do).

The *enactment* of Visions I and II policies into practice (e.g., into classroom instruction or into the assessment of students' SL) is a somewhat different perspective than a policy perspective. Roberts (2007) points out that an enactment of a Vision I policy leads to a Vision I type of practice (e.g., a traditional status-quo school science, or assessments based on a narrowly defined SL), However, an enactment of a Vision II policy has conventionally led to a combination of Visions I and II type of practice. In the world of *practice*, therefore, the choice facing science educators is Vision I verses a combination of Visions I and II (i.e., Vision I-II).

Decades of empirical research unambiguously delineate the following dilemma for educators promoting SL (Aikenhead, 2006a): The choice between Vision I and Vision I-II is, in effect, a choice between (respectively): (a) most students playing school games so it appears as if meaningful learning has taken place yet little SL has been achieved; or (b) most students finding their school science somewhat culturally relevant, and therefore, developing their SL to a measurable degree. The latter choice (Vision I-II) seeks to enhance students' capacities to function as life-long, responsible, savvy participants in their everyday lives; lives increasingly influenced by science and technology. The former choice (Vision I) has consistently led to decreased interest and lower enrolments in school science. For example, after investigating in depth why so many science-proficient clever students no longer took optional science courses past grade 10, Lyons (2003, 2006) suggested researchers seriously ask: Why should they?

This key question (Why should students learn science?) seriously diminishes the significance of narrow research agendas dedicated to *how* students learn science (e.g., conceptual change). If school science enrolment and SL achievement are sinking like the Titanic, then let us refrain from conducting further behavioural, cognitive, or simplistic social constructivist research on how to rearrange its deckchairs. On the other hand, a learning theory that addresses students' "knowing-in-action" (Driver & Erickson, 1983) and that operates within a phenomenological type of research program (Erickson, 2000) is highly significant because it suggests an answer to "Why should students learn science?" – They learn science in order to create relationships with their world. This perspective harmonizes with the notion that learning science (in grades 6 to 12, at least) involves self-identity formation by students (e.g., Brickhouse, 2001, 2003, 2007; Case, 2007; Brown, Reveles, & Kelly, 2005; Kelly, 2007; Schreiner & Sjøberg, 2007). A phenomenological type of research program also harmonizes with "theories" of *non-learning*, such as cultural border crossing (e.g., Aikenhead, 1998), and

with investigations into cultural processes that extinguish students' interest in studying school science (Lyons, 2003, 2006; Osborne, 2007).

It is crucial to recognize, however, that the meaning of "science" and the *content* of school science necessarily and dramatically change when we embrace these new perspectives on learning and non-learning. Many authors have not discussed this implication. When conventional, academic, decontextualized science (a Vision I view of SL) changes to contextualized science (a Vision II view of SL), the context *and content* are mostly dictated by students' everyday worlds, rather than by scientists', teachers', or curriculum developers' ideas of appropriate contexts and content for school science (Aikenhead, 2006a; Deng, 2007; Fensham, 2002). Changing the meaning of "science" in the domain of school science takes us beyond policy and practice.

Beyond Policy and Practice

The interactions among research, policy, and practice do not afford a sufficiently comprehensive structure for a future SL research agenda. The present structure must be expanded. Some scholars have argued from an educational philosophy point of view that Vision I and Vision II are mutually exclusive in science classrooms, and that combining them is detrimental to students (Egan, 1996; Hughes, 2000). However, I concur with Orpwood (2007) and Roberts (2007) that educational soundness is only one consideration in the real world of science education; we also need to address political realities. Educational soundness and political realities are often contradictory (Aikenhead, 2006a).

Research, policy, and practice are all driven by *politics*. This political dimension includes elitism, inclusiveness, privilege, equity, prestige, funding, allegiances, self-identities, etc.; as well as science teachers' orientations to SL, students' expectations of school science, the culture of school science, the culture of schools, parents' opinions, university science departments' demands, university regulations, teacher education programs, professional scientific organizations' self-interests, assessment institutions, etc. (Aikenhead, 2006a; Fensham, 1992). The transformation of a Vision I policy or practice into a Vision I-II policy or practice is, first and foremost, a political event (Fensham, 1998, 2000, 2002; Hart, 2001; Roberts, 1988, 1995). Politics are central to Tiberghien's (2007) "legitimation by a community respected by society," where today each word (legitimate, community, respected, and society) is problematic and contested on political grounds, for both Vision I and Vision I-II types of SL.

Fundamental research questions of a political nature related to SL at the policy level include: Who decides on policy? How is the decision reached? How were participants chosen? What were their anticipated roles versus their enacted roles? What actor-networks (Carlone, 2003; Gaskell & Hepburn, 1998) did they bring to the deliberations and what networks developed as a result of the deliberation? Participants' roles and actor-networks could be a primary focus of research into who decides, and how the decision was reached. In short, worthwhile SL research in the political domain would investigate the influence of various stakeholders in the negotiations and decisions over what SL ideology will count as school science.

A preliminary study could evolve into a major R&D project that forges new roles and networks to enhance a clearer and more politically endorsed perspective on enacting a combination of Visions I and II. Such a study could be a "consensus-making R&D" (Aikenhead, 2006a, pp. 130-131). This is action research on the grand scale of deliberative inquiry accompanied by curriculum implementation and evaluation, within a large educational jurisdiction and drawing upon a broad array of stakeholders judiciously chosen

so the political elite is represented but its status quo SL ideology is actually discussed and renegotiated.

Scaled-up versions of investigations by Aikenhead (2005), Duggan and Gott (2002), Law (2002), and Symington and Tytler (2004) are needed to help establish a SL policy valued by politically positioned leaders and influential citizens (Elmore, 1996). This type of research will guide deliberations over a Vision I-II type of policy recommended by Roberts (2007).

Because the prevailing political climate of any educational jurisdiction determines political matters, another crucial R&D action research question for a future SL research agenda arises: How can the political climate of an educational jurisdiction be influenced to achieve a balance of Visions I and II in both policy and practice? How can political support for inappropriate and invalid assessment (Orpwood, 2007) be undermined in the public forum?

Research of a political nature at the level of practice belongs on a future SL research agenda. For example: How do science-proficient students actually use school science content in their everyday lives (if at all) compared with science-shy students, when both groups cope with similar situations? (This line of research converges with Brickhouse's [2007] "Who are scientific literates?") Who in the community is engaged with science and technology in some form or another? How can students and teachers become more scientifically literate through learning from these people, directly or indirectly? How do students, teachers, and administrators come to value a Vision I-II type of scientific literacy? and Who will allow students to learn science from this perspective?

In summary, it is critical to expand the present research agenda for SL to include a focus on politics. Historically, the politics of privilege and elitism, *not consensus*, has legitimated the ideology of Vision I endemic to science education (Aikenhead, 2006a; Hodson, 1994; Seddon, 1991). This legitimation in the Anglo world goes back to 1867, which is being contested at this symposium today by those who eschew the politics of privilege and elitism. Curriculum transformation to Vision I-II requires SL researchers to address *political* goals explicitly as well as educational goals. Defenders of a Vision I ideology are highly political in their response to attempts at curriculum transformation (e.g., Aikenhead, 2002). Therefore, proponents of a Vision I-II ideology need to be politically savvy by placing political research on their SL research agenda. The political success of Vision I-II research agendas will be measured, in part, by the degree to which defenders of a Vision I ideology are co-opted or marginalized in the process.

Vision III?

In addition to the competing interests between political realities and educational soundness associated with Visions I and II, Roberts (2007) discusses a different dynamic between Visions I and II. He draws upon Solomon's (1998) analysis of one version of Vision II she calls "popular scientific culture," which "refers to the concerns of the public, so important within their own local culture and often having a scientific and technological basis" (p. 170). In the context of contrasting popular scientific culture with academic scientific culture, Solomon asks, "Can [academic] science be taught so that it connects with attitudes, personal values, and political issues? This would indeed make [academic] science a part of popular culture. But would it still be [academic] science?" (p. 171). Roberts (2007) points out, "Such questions express the crux of the tensions between Vision I and Vision II" (p. 754).

Solomon has identified *cross-cultural* tensions arising between popular scientific culture and academic scientific culture. In academic scientific culture, scientists collectively work within a subculture that frames their thinking and practice (Pickering, 1992). For most scientists, this

subculture is Eurocentric in nature. I find the term "Eurocentric science" more descriptive than "academic science" because it expresses Solomon's cultural considerations more explicitly. Moreover, the term "Eurocentric science" encourages us to consider non-Eurocentric sciences in communities or countries that do not embrace a Euro-American culture. This consideration in turn draws our attention to a variety of long standing indigenous cultures worldwide that have developed ways of describing and explaining nature based on empirical and rational means, but much differently than Eurocentric science.

Conventionally, SL has been restricted to literacy in Eurocentric science (Roberts, 2007), thereby ignoring a world of other sciences (Battiste & Henderson, 2000; Maddock, 1981; McKinley, 2007; Ogawa, 1995). Aikenhead and Ogawa (2007) identify this pluralism of science by the following triad:

- *Eurocentric sciences*: the diverse enterprise of professional scientists, engineers, and people employed in science-related occupations; an enterprise based mainly on: particular values, a plethora of methodologies, Cartesian dualism, anthropocentrism, reductionism, rectilinear time, quantification, and predictive validity established through argumentation and consensus making by a group of practitioners (scientists within a paradigm); in short, one way of knowing nature. Professional scientists are people employed mostly in a social context of power and privilege associated with R&D, patents, economic progress, and globalization. These professionals are paid by their institutions to generate, transform, or use knowledge for the purpose of benefiting those institutions.
- *Indigenous sciences*: non-Eurocentric ways of knowing nature that have assured the survival of the first peoples who inhabited a locality or place, over tens of thousands of years; for example, ways of knowing nature held by the Sāmi of Scandinavia, the First Nations of North America, and the Mäori of Aotearoa New Zealand. These nations historically share experiences of repression and colonization (Battiste & Henderson, 2000; Niezen, 2003).
- *Neo-indigenous sciences*: non-Eurocentric ways of knowing nature held by long standing mainstream cultures that generally have not experienced Euro-American colonization, for example, Islamic, Bhutanese, and Japanese cultures; plus Euro-American commonsense cultures of everyday life (Linder, 1993; Semali & Kincheloe, 1999).

When we consider students in non-Eurocentric communities, we ask: Whose culture is being transmitted in school science in the name of scientific literacy?

When school science transmits only Eurocentric sciences as it does in both Visions I and I-II (i.e., in a singular-science ideological perspective – Eurocentric SL), students generally feel alienated by the cultural clash between their home culture and the culture of school science (Aikenhead, 1998; Costa, 1995; Maddock, 1981; McKinley, 2007; Ogawa, 1995; Phelan, Davidson, & Cao, 1991). In their resistance to feeling alienated from, or marginalized by, school science, students tend to reject instruction in Eurocentric SL. This state of affairs also applies to a large majority of Euro-American students whose self-identities do not relate to the culture of Eurocentric sciences (Aikenhead, 2006a; Cobern, 2000).

A pluralist notion of science proposed here is consistent with the OECD (2006) framework's description of science: "a process that produces knowledge and that proposes explanations about the natural world." For instance, Aikenhead and Ogawa (2007) offer the following pluralist definition of science: a rational empirically based way of knowing nature that yields, in part, descriptions and explanations of nature; where the term *rational* does not signify a

universalist rationality, but a rationality founded within the cultural context of use (Elkana, 1971).

The fundamental issue here, of course, is the politics of what counts as "science" in school science. I do not presume that scientists and their professional organizations will take up a pluralist definition of science because their identities seem to rest on their ownership of the word "science," an ownership expressed in terms of a singular universalist view of Eurocentric science (McKinley, 2007). Instead, I presume that a pluralist definition of science restricts itself to the domain of school science. A pluralist perspective for SL requires a careful articulation of several sciences: (1) relevant neo-indigenous sciences; (2) Eurocentric sciences (plural) found in the everyday working world of professional science and science-related occupations (not simply academic science); and (3) where applicable, Indigenous sciences.

Vision I-II policy and practice can be broadened to encompass not only a Eurocentric SL, but indigenous SLs (plural) – both neo-indigenous and Indigenous SLs. Thus, the conventional notion of Eurocentric SL (Roberts, 2007) is not rejected. Instead, it is held as one powerful way of knowing nature and understanding how Eurocentric sciences tend to operate in students' local, national, and global cultures. Indigenous SLs, related to local ways of knowing nature and understanding the community, will also be relevant for most, but not all, students. The exception here is a student whose personal worldview finds comfort in understanding the world as Eurocentric sciences describe and explain the world. These students comprise a small minority who tend to critique a Vision I-II type of classroom practice, a critique described by Tiberghien (2007).

To distinguish between the conventional, singular-science, Eurocentric SL and the proposed plural-science SLs, I suggest we call a plural-science SL ideology "Vision III," thereby adding a third dimension to Roberts's (2007) heuristic framework. Just as Vision II in practice becomes Vision I-II (Roberts, 2007), Vision III in practice becomes Vision I-II-III (Aikenhead, 2001). A Vision III ideology articulates a legitimate future dimension in an expanded research agenda for SL, and it connects with theories of learning (and non-learning) predicated on knowing-in-action.

The political agenda for a Vision I-II type of SL (outlined in the previous section) applies directly to a Vision I-II-III type of SL.

Conclusion

One of the cultural myths associated with a Vision I ideology of Eurocentric SL is the story line that school science accurately reflects professional (academic) science. Many science education researchers, however, lament the misrepresentation of professional science found in Vision I types of school science (e.g., Cross & Price, 1999; Gaskell, 1992; Kelly, Carlsen, & Cunningham, 1993; Knain, 2001; Larochelle & Désautels, 1991; Leach, Driver, Millar, & Scott, 1997; Linder, 1993; Östman, 1996; Solomon, Duveen, & Scot, 1994). "Is it really science?" they ask, which is the same scrutinizing question that advocates of Vision I tend to pose about Vision II (Solomon, 1998). Different questions need to be asked: What types of sciences (professional or academic Eurocentric, neo-indigenous, or Indigenous) are relevant to a particular context? and What political resources enhance researchers' ability to initiate the development and implementation of a Vision I-II-III type of scientific literacy?

School science is a negotiable enterprise, open to debate over what counts as scientific literacy today. Which sciences should be drawn upon in school science to make sense of human situations or events related to understanding natural phenomena? The question

assumes a context-driven pluralist-science perspective captured by an ideology of Vision I-II-III. The political realities arising from a Vision I-II-III sense of scientific literacy have already become part of some research agendas (e.g., Aikenhead, 2006b; McKinley, 2007).

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An Inclusive View of Scientific Literacy: Core Issues and Future Directions

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Introduction

In an extensive review of the science education literature on scientific literacy / science literacy, Roberts (2007) merges both terms (conceptual differences are pointed out in his review) and uses SL to refer to the holistic construct. However, Roberts makes an important distinction between two generalized views of SL: Vision I tends to stress functional aspects of academic content as they pertain to goals aligned within science, while Vision II emphasizes a functional approach that is broader in scope, involving personal decision-making about contextually-embedded socioscientific issues (SSI). The "heuristic device" (p. 775) employed by Roberts suits me just fine. We all realize that it is necessary to parse out components of a construct (such as SL) in order to think more clearly about its constituent parts, and we all acknowledge that any alternative heuristic we might invoke would, no doubt, frame the issue in a different light. Hence, for the sake of playing by the same rules, let me state that the argument I wish to advance can best be located in a more comprehensive, and necessarily more inclusive stance of Vision II. I have argued elsewhere (Zeidler, 1984; Zeidler & Keefer, 2003; Zeidler & Lewis, 2003, Zeidler & Sadler, in press; Zeidler, Sadler, Simmons & Howes, 2005) that any conceptualization of what it means to be scientifically literate falls short of the mark if moral reasoning, ethical considerations, and an eye toward character are not part of our understanding of SL.

The Socioscientific Issues (SSI) framework seeks to involve students in decision making regarding current social issues with moral or ethical implications embedded in scientific contexts (Sadler, 2004; Zeidler & Keefer, 2003; Zeidler et al., 2005). These issues provide students with the framework for actively reflecting upon an issue and examining how the issue relates to their own lives, as well as the quality of life of the community (Driver, Leach, Millar, & Scott, 1996; Driver, Newton & Osborne, 2000; Kolstø, 2001; Kolstø, (2006); Sadler, 2004; Zeidler, 2003). It is also equally as plausible that certain ethical issues become the context for embedded scientific content, as well as certain NOS tenets (Zeidler, Sadler, Callahan, Burek & Applebaum, 2007). To the extent that SSI can provide an epistemological context for students' conceptual understanding concerning matters of scientific and social importance, serve as a venue for the formation of character, provide opportunities for reflective judgment, a more inclusive Vision II stance of SL may be realized.

As I prepared for a recent symposium for the American Educational Research Association, I was asked to raise some questions connected with future directions of SSI. In a stream of consciousness (perhaps more akin to a trickle), several questions eventually came to mind because of their utility in moving our current understandings of SSI in new directions. Among the questions I listed most relevant to the wedding of SSI and SL were:

1) In what sense is the distinction between "scientific literacy" and "functional scientific literacy" meaningful?

2) How might argumentation play a role when implementing SSI and contribute to scientific literacy?
3) How can developmental frameworks inform our understanding of developing scientific literacy?
4) How can SSI best contribute to current or future notions of scientific literacy?
5) What does scientific inquiry look like within a SSI context?
6) Who controls (should control) scientific literacy?

Establishing a Research Driven Framework for SL and SSI

While these questions seemed at first blush to be reasonable, I began to realize that if a model of SL was to be advanced making sense to the greater science education community, then these questions would need to be gathered up and viewed in such a way as to show where they are positioned with respect to both a theoretical framework driven by the empirical research implied by each question, as well as how that framework influences its counter part in practice. Accordingly, I have sought to embed these core questions, based on our current understanding of the research on SSI, into a framework that connects theory to practice in a manner that will, I hope, move our discussions of SL in what may be radically new directions. A caveat, however, is in order. What may be new is often not radical, and what is radical may not be any better than our current state of affairs. It is my argument, that the following core questions have the potential to contribute and impact our field by virtue of bringing to the forefront more inclusive, relevant, and subsequently more meaningful visions of SL. If such visions are to be realized, then many of our current mainstream conceptualizations of science education will be significantly affected. In this sense, what I am proposing may be considered by some, to be a radically different conceptualization of the pedagogical strategies necessary to promote a robust notion of SL. Table 1 below, presents these core questions which represent, to my way of thinking, seminal issues of the interplay between SL and SSI affecting current research and practice.

Core Questions	*Theoretical Issues*	*Pedagogical, Curricular, & Policy Issues*
1) In what sense is the distinction between "scientific literacy" and "functional" scientific literacy" meaningful?	1) a. Conceptual distinctions between technocratically functional and humanistically functional. (Vision 1 vs. Vision 2, Roberts, 2007) b. Investigate how SSI may develop both SL and character via experiences that maximize opportunities for "citizenship."	1) a. Evaluate how SSI may be informed by data driven discourse (argument) and ethical considerations. b. Explore how real-world issues become relevant to the lives of students.
2) How might argumentation play a role when implementing SSI and contribute to scientific literacy?	2) a. Conceptualize transactive discussions and group discourse. b. Develop better understanding of informal argumentation / reasoning. c. Develop better applications of "Practical Reasoning."	2) Identify issues-driven curriculum where natural points of critical discourse will arise.

3) How can developmental frameworks inform our understanding of developing scientific literacy?	3) Conceptualize development interdependence with: a. Sociomoral discourse b. Epistemological bases of NOS in SSI contexts. c. Reflective Judgment	3) a. Identify age-appropriate experiences and curriculum that are both student relevant and challenging. b. Plan opportunities to create cognitive and moral dissonance.
4) How can SSI best contribute to current or future notions of scientific literacy?	4) Investigate to what extent does conceptual understanding of scientific content occur when SSI inquiry is implemented in the classroom?	4) a. Identify pedagogical strategies necessary to facilitate discourse in SSI. b. Evaluate the conditions under which issues may provide context for subject matter understanding. c. Assesses "functional" SL by indicators of conceptual application of scientific content in the context of personal / social ethical decisions.
5) What does scientific inquiry look like within a SSI context?	5) a. Examine inquiry strategies students use to seek and evaluate empirical data & other forms of information. b. Evaluate factors associated with classroom ecology under which inquiry may occur.	5) Provide opportunities for students to: - raise their own questions - analyze claims from varied sources - evaluate empirical evidence - test ideas - form tentative conclusions about issues
6) Who controls (should control) scientific literacy?	6) Analysis of the political hegemony surrounding scientific literacy.	6) Identify aims, needs or goals of: a. associations b. organizations c. groups (e.g., districts) d. individuals (*including teachers and students*).

Table 1. Core Questions for Scientific Literacy and Socioscientific Issues in Theory and Practice.

It is important to recognize that these core questions are not independent from each other, nor are the theoretical and pedagogical connections orthogonal to the core question to which they have been ascribed. While it is best to think of them as a holistic network of conceptual ideas stemming from the research on SSI, it is, nonetheless, helpful from a research perspective, to investigate how component parts may be examined for their contribution to the whole. The core questions have been derived from a conceptual model of "functional scientific literacy" suggested elsewhere (Zeidler, 2003; Zeidler et al., 2005). The theoretical framework was proposed both because of its utility in addressing SSI in terms of the psychological, social, and emotive growth of the child, and its flexibility in being sensitive to multiple perspectives of science education research as it relates to SL (see Figure 1

below). In this conceptualization, functional SL is dynamically mediated by personal cognitive and moral developmental considerations. These considerations may be accessible within key areas of science education likely to be the most promising in terms of impacting character, cognitive and moral development and include (but may not be limited to): cultural issues, discourse issues, case-based issues, and NOS issues. And while the whole notion of advocating the SSI framework, with its focus on moral and ethical factors in relation to SL, may be radically different from other conceptualizations of SL, I would suggest that the assessable science education areas listed above are now recognized, even by the mainstream science education community, to be important pedagogical factors in science teaching. The difference lies in how these areas are orchestrated together with an eye toward providing developmental conditions necessary for the formation of responsible, evidence-based reflective judgment, conscience and character. Hence, shaping students' epistemological belief systems may be a bit of a novel consideration in contemporary science education practice.
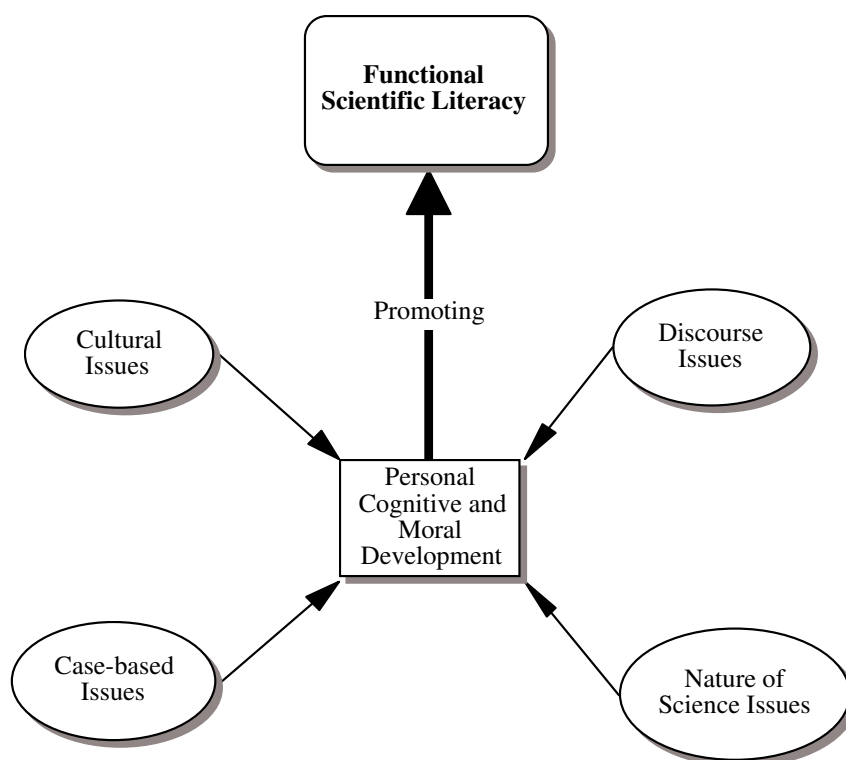

Figure 1. Socioscientific Elements of Functional Scientific Literacy.

What may not be in the mainstream view of science education is the argument that contextualized argumentation in science education should be understood as an instance of education for citizenship. If one accepts this premise, then it becomes essential to present to students the humanistic face of scientific decisions that entail moral and ethical issues, arguments and the evidence used to arrive at those decisions. Separating learning of the content of science from consideration of its application and its implications (i.e. context) is an artificial divorce (Zeidler, Applebaum & Sadler, 2006; Zeidler & Sadler, in press). This is essentially an analogue of the same position that Erickson (2001) advances when he stresses that Phenomenological Research Programmes view the distinction between individuals and the context in which they thrive "… is a spurious one, as is the body-mind dualism." (p. 21). Aikenhead (2006)

also presents a humanistic perspective of science education that highlights and integrates features of moral reasoning, cultural considerations and citizenship preparation in school science. However, my colleagues and I have pushed this argument a good deal further out of the mainstream SL view in science education with our emphasis on the fundamental importance of attending to how the cultivation of cognitive and moral reasoning enhances features of character, and subsequently features of decision-making inherently connected to SL.

Issues and Factors Related to Core Questions

In attending to the core questions, I do not mean to imply that the corresponding theoretical and pedagogical issues are the *only* issues relevant to those questions. Nor do I mean to suggest that I can supply the details necessary to fully answer those questions. My purpose here is to initiate a dialogue to address those ideas, perhaps reframing the questions and matrix components as the dialogue unfolds. Inasmuch as the matrix, as mentioned previously, is derived from current areas of research connected to our functional view of SL, it is helpful to keep in mind that our aim here is to advance the development of character and the quality of reasoning through social discourse as we press forward with each core question.

1) *In what sense is the distinction between "scientific literacy" and "functional" scientific literacy" meaningful?* As suggested in the introduction, the heuristic distinction between Roberts' (2007) conceptualization of Vision 1 and Vision II for SL becomes meaningful when one wishes to locate between the extremes where pedagogical and policy emphasis will be placed. Aikenhead (2007) ups the ante by further distinguishing traditions of Euro-American Science that describes a type of academic science that is transmitted through dominant culture from other indigenous cultures that do not share the Euro-American norms of science. Thus, he suggests a variant perspective of a Roberts' scheme; Vision III for SL that entails issues, needs, and norms that fall outside the Vision 1 – Vision 2 continuum. I have suggested that the vision of SL I wish to advance is more aligned with Vision II – but pushes the envelope a good deal further along Robert's original continuum. I decided to call this -- Vision 10.4.1 (not to be outdone be Aikenhead's Vision 3 – I am anticipating Vision 4 through 9 being developed in the future and I just wanted to get a jump ahead of the pack). Borderline levity aside, the rationale behind my use of the term *functional* scientific literacy is one that would be sensitive to both dominant and alternative normative views of SL. To the extent that the emphasis on moral growth and reflective reasoning and the formation of character is part and parcel of a radically different notion of SL (fundamentally different from Vision 1 and distinctly different from Vision II) functional SL in the sense that my colleagues and I have advocated necessarily is context and culturally sensitive to the needs of the learner. This perspective is the sociocultural perspective of SL that Sadler (2007) advances; it is one that "prioritizes enculturation and practice" (p.4). In such a view of SL, the activity of science as practiced in any culture is legitimized – and students have access to the norms of that culture wherever it may be found. Kelly is certainly sensitive to this view inasmuch as he recognizes that the selection of goals for scientific literacy with particular outcomes of citizenship. The question for him, given the pluralistic nature of societies, is whether a focus on "building public reason" with its focus on critical discourse should trump a focus on selecting a priori outcomes of what students should know about science. Under our functional view of SL, a priority is given to

investigating how SSI may develop both SL and character through experiences that maximize opportunities for citizenship.

2) How might argumentation play a role when implementing SSI and contribute to scientific literacy? Argumentation and pointed discourse between students and among class members is the sine qua non of sociomoral discourse. When exchanges are aimed at resolving conflicts through evidence-based reasoning, the raw power of SSI becomes harnessed in science classroom practice. The place of argumentation in science education to enhance thinking and mirror scientific discourse is well established in science education (Kuhn, 1993; Osborne, Erduran & Simon, (2004). However, when argumentation is used to advance understanding of the human condition (Arendt, 1958) then such discourse may be said to be aimed at the promotion of functional SL, and all aspects of social, political, ethical nuances that it necessarily entails. Fensham (2007) and Aikenhead (2007) appear to tip their hats in recognition of the assertion that discourse in the science classroom is inherently connected to social and political systems. Kelly shifts the focus further toward an epistemological framework of scientific knowledge construction rooted in dialogue and social negotiation – fundamental for both the enculturation and critique of norms rooted in all social sectors of institutions (e.g. science, religion, family, marriage, etc.). The defining moment, to my way of thinking, where the notion of argumentation moves us from something interesting to do with our students to facilitating the advancement of functional SL comes when such pedagogy is deliberately directed toward issues embedded in the crossroads of cultural, ethical and personal norms. It is one thing (and a very important thing) for students to distinguish pseudo-science from scientific claims, but it is quite another to realize the utility of using argument to advance moral reasoning and enhance character through the practice of citizenship (Zeidler, Osborne, Erduran, Simon & Monk, 2003). To the extent that better moral decisions (in the sense that such decisions better align with formalistic criteria of impersonality, ideality, universalizability, preemptiveness) are ones that correspond to higher developmental levels, the role of informal argumentation (Sadler, 2004; Sadler and Zeidler; 2005) to promote functional SL becomes of paramount importance. Of future importance will be for science educators to identify issues-driven curriculum where natural points of critical discourse are likely to arise.

3) How can developmental frameworks inform our understanding of developing scientific literacy? Much of the developmental implications about promoting argumentative discourse to promote functional SL (see above) is, of course, the result of buying into a cognitive-developmental framework whose purpose is not the acceleration of cognitive or moral stage progression; rather the aim is to provide the social contextual conditions in our classrooms necessary to assure the eventual attainment of higher forms of reasoning. It is this conviction that lies at the heart of the conceptual framework in Figure 1 above. We have viewed this framework as a tentative, working model that points children in the direction of functional scientific literacy because it allows for a plethora of research and pedagogical perspectives related to the developmental needs of the child. That children naturally progress through general stages of cognitive and moral development are supported by empirical work. That higher stages of reasoning have a leg-up on less mature stages in searching for evidence, allowing for multiple perspectives, understanding with empathy the nuances of short and long term decisions, and resolving competing claims in a just manner, is consistent with the criteria of reversibility and universalizability, philosophically more robust forms of decision-making. (A detailed analysis of these claims can be found in Zeidler & Keefer, 2003.) Hence, if we accept

the premise that scientific literacy involves, in part, the capacity to utilize critical analysis and discourse to make rational decisions, developmental frameworks become a useful guide to better inform our goals, curricula design (particularly in the arena of SSI) and pedagogy. Clearly, the epiphany that Sjøberg (2007) describes, as he transitioned from a pure scientific research field to that of science education, entailed the realization that neo Piagetian developmental ideas help to inform constructivist epistemology (in its variant forms) – which has bearing on the quality of cultivating an informed populace capable of engaging in issues with critical discourse. Further, Abd-El-Khalick (2003) has suggested that epistemological stances and Nature of Science (NOS) aspects may be developmentally linked to meaningful critical discourse regarding controversial SSI. Since most would assent to the claim that NOS understanding is a key consideration in the pursuit of scientific literacy, the advantage of embedding NOS into a SSI framework, suggested by our research (Zeidler et al., 2007) seems to be that SSI instruction may have the added benefit of embedding NOS into a scientific context that is, de facto, theory laden, driven by data, as well as socially and culturally embedded. The context of the SSI-driven curriculum provides an anchor on which reason may be exercised. Reasoning about ill-structured problems requires that students care to exercise reasoning. If structural development shifts in epistemological orientations are to occur, then reasonable opportunities need to be created for the type of social interaction necessary to advance solutions to issues that need to be sensitive to new evidence, perspectives or modes of inquiry. Accordingly, age-appropriate experiences and curriculum that are both student relevant and challenging need to be identified with purposeful opportunities built in to create the conditions necessary for cognitive and moral dissonance.

    4) How can SSI best contribute to current or future notions of scientific literacy? In order to best understand how SSI contributes to current (or future) notions of scientific literacy, it may be instructive to point out that Hurd (1958) first conceptualized SL as a *goal* of science education about a half century ago. While the idea that science education ought to have something to say about the quality of public life certainly predates this benchmark, Hurd (1998) also noted that by the late 1990's science was becoming more holistic and transdisciplinary tapping both the natural and social sciences. He presents a venerable "laundry list" of personal, social and cognitive concepts that students need to grapple with in order to gain a foothold on becoming scientifically literate. Upon inspection of that list, a common theme emerges; SL is intricately tied to cultural, ethical and moral issues connected to "science-social problems" (p.413). I no longer believe the case must be made for the inclusion of SSI to foster SL; rather, the question properly raised is how can we utilize SSI to best meet the needs of current and future students? Brickhouse (2007) suggests that by focusing on civic (engaging in public life), personal (making personal decisions based on scientific information), cultural (appreciation of scientific ideas for their unique eloquence) and critical (how people position themselves in relation to new scientific-based claims) dimensions of SL individuals will have a leg-up on resolving normative dilemmas based on scientific argument and evidence. Such dilemmas are part and parcel of the SSI framework. Case (2007) argues that, at least for tertiary science and engineering education, a focus on the emergence of new identities as students become enculturated into new academic communities is necessary so they can reflect on how they best fit (or not) into the normative expectation of those new professions. And Sjøberg (2007) has been working on a curriculum project (ROSE: Relevance of Science Education) with an eye toward enhancing cultural diversity and gender equity, personal and social relevance, and

democratic citizenship. Again, a SSI framework provides opportunities to subsume such goals and experiences inasmuch as our presuppositions to SSI education suggests that contextualized argumentation in science education may be understood as an instance of education for citizenship. It follows that it is essential to present to students the humanistic face of science decisions about moral and ethical issues, arguments and evidence used to arrive at those decisions. Separating the learning of the content of science from consideration of its application and its implications is an artificial divorce (Zeidler & Sadler, in press). Thus, SSI can best contribute to SL when it is structured in a way that allows for personal reflection and introspection of the norms for both the scientific community (which we understand to be varied among and within disciplines) and the normative expectations of social and cultural groups within the students' community. Identifying meaningful contexts for students under which SSI provide conceptual clarity of subject matter is imperative to achieve this end.

5) What does scientific inquiry look like within a SSI context? While it may be the case that we could argue the finer points of what inquiry in science education entails, most science educators would likely assent to the stance that we want to provide the kinds of opportunities that allow students to raise questions, address issues, generate investigative methods to evaluate data, evidence and claims. Fostering inquiry in a SSI context includes that description, but has an additional key element. Through this process, arguments are also advanced through argumentation, social negotiation and discourse. Jorde (2007) uses a description of inquiry suggested by Linn, Davis, & Bell (2004) that is useful here: "Inquiry is the intentional process of diagnosing problems, critiquing experiments, and distinguishing alternatives, planning investigations, researching conjectures, searching for information, constructing models, debating with peers, and forming coherent arguments." The web-based projects Jorde works with utilize a Scaffolded Knowledge Integration (SKI) framework that is embedded within SSI so that political, social and economic factors become central considerations in students' ability to formulate arguments and making decisions while exploring contemporary science issues. Given that students are often unclear as to what constitutes empirical data (Sadler, Chambers & Zeidler, 2004), students need to be more explicitly directed in what constitutes scientific data and evidence and how to formulate sound arguments. SKI frameworks hold much future potential in this regard. One indicator of this may be found in a study by Walker & Zeidler (in press) where the overarching goal was to implement a unit of study embedding SSI in the context of a well-designed SKI inquiry activity where students were engaged in deliberating a current science issue of controversy including explicit connections to relevant science content and nature of science scaffolds. This approach enabled students to sort and integrate their preinstructional beliefs with the content presented in the curriculum. Students were engaged in the inquiry process by exploring background information provided by the conflicting viewpoints, used evidence to support their own viewpoint, debated and discussed the issues, and made more informed decisions. In related work, it is important to highlight that a concerted effort was made for the SSI drove a content-rich curriculum, and provided a *context* for student-centered inquiry to develop conceptual understanding of scientific content (Zeidler et al., 2007). In this case, the issues were carefully selected and crafted in a manner that aligned students' interests with the course content embedded in the SSI, challenged core beliefs and applied new content knowledge to the appropriate scientific context in a manner that was personally relevant and meaningful. The curriculum was intentionally designed to consistently challenge deeply held core

values by offering opportunities to confront and defend or reject new information. Thus, the curriculum included multiple activities that required students to evaluate claims, analyze evidence and their sources, come to a decision on a personal position, make moral decisions, and present the information within a group of peers to negotiate a consensus opinion. Certainly, rich opportunities exist for researchers to examine and better understand the inquiry strategies students evoke to seek and evaluate empirical data and alternative forms of information, and to evaluate curricula and strategies under which scientific inquiry flourishes. This, I believe, is an important route to SL.

6) Who controls (should control) scientific literacy? There are many threads to scientific literacy; each one connects to different levels of social entities (i.e., political reform agendas, organizations, groups, researchers, teachers, students). Unfortunately, no heddles exist to guide these threads into a uniform social fabric on which all groups can reach consensus. Many have recognized that what counts as scientific knowledge may be at loggerheads from what counts (or should count) as scientific literacy (Bulte 2007; Erikson, 2007; Fensham, 2007; Kelly, 2007; Roberts, 2007; Tiberghien, 2007). Orpwood (2000, 2007) makes it quite clear that schools must function in a political climate, often at the mercy of high stakes assessments which miss the mark, because of their monolithic focus of SL I, of any notion of SL II or other novel, robust or perhaps humanistic conceptualizations of SL. He cites three fundamental threats to "richer" conceptualizations of SL and suggests an appropriate response to each worth repeating here:

- Political threats require a preparedness of members of the SL community to advocate for their vision of SL and for correspondingly valid assessments;
- Professional threats require members of the SL community to become involved in projects to disseminate appropriate assessments of SL into the classroom as well as into national and international projects;
- Conceptual threats require more creativity from the SL community in generating new approaches to SL assessment. (Orpwood, 2007, p.4)

In all cases, the implication of who *should* control scientific literacy is clear; it is those of us in the science education community who are engaged on the forefront of SL that must exercise judgment through our research and participation in assessment and curriculum development projects. Martins (2007) embeds her framework to discuss SL from Bakhtin's (1986) orientation stressing the relationship between language and social discourse to social (group, professional, etc.) identity. If social discourse is indeed tied to social identity, it begs the question: "Who is doing the talking?" Osborne (2007) reaffirms the normative power the transmission model of group identity holds in our schools and political consequences it entails. While Aikenhead (2007) perceptively points out that a research agenda entailing any "pluralist notion" of Vision II (or his advocacy of Vision III) would likely marginalize advocates of Vision I. From a Bakhtin perspective, this is tantamount to displacing those voices, or at least having those voices fall upon deaf ears. Perhaps the counterpoint to understanding who speaks for science education is to ask at the same instant, "Who is listening?" We, in the science education community, must do more to understand the political hegemony surrounding scientific literacy, including identifying the needs of those closest to the task at-hand (teachers and students), if scientific literacy is to be transformative in nature.

Closing Thoughts

It is clear that that the very idea of achieving scientific literacy is a phantom image; it is too much a moving target and its make up constantly morphs because human needs and knowledge are in constant flux. We, of course, do not sit passively with grim expressions, because our role as science educators is to find a means, based on our best research and practice, to attend to current and what we believe to be future imperatives of scientific literacy in our field. Living with a degree of ambiguity concerning our mission is par for our course.

It is rather fitting that above the entrance to the Grand Auditorium in the Main Building at Uppsala University where this symposium was held, the words of the 18th century philosopher Thomas Thorild are inscribed which read: "It is a great thing to think freely, but it is greater still to think correctly." I would like to bridge his thought with that of a contemporary of Thorild's across the Atlantic where a new democracy was unfolding. Thomas Jefferson, in reference to the moral commitment those entrusted with power should exercise for our youth, believed their aim was:

> To develop the reasoning faculties of our youth, enlarge their minds, cultivate their morals, and instill into them the percepts of virtue and order: … And, generally to form them to habits of reflection and correct action, rendering them examples of virtue to others, and of happiness within themselves. (Honeywell, 1931, pp. 248-260)

It is in these contexts, science educators need to make a compelling case that the future of and quality of life within our social institutions is indelibly linked to the quality of educative experiences we provide for our children.

I have attempted to identify core questions connected to scientific literacy within a SSI context, and initiate salient points of theoretical and pedagogical discussion surrounding them. This view pushes Robert's (2007) Vision II of SL further out along edges, and certainly taps Aikenhead's (2007) view of Vision III along the way. What seems clear to me, is that our perspectives are aimed to develop future citizens who will more likely consider the moral, political and environmental aspects of scientific concerns that shape public policy. These future citizens are, of course, our current students. My hope is that they are able to develop a modest degree of functional scientific literacy, and in doing so, cultivate a healthy skepticism regarding the ontological status of scientific knowledge. I have stated in the past, that if we, as science educators, wish to cultivate future citizens and leaders who serve their community with a sense of care and commitment, then we have a moral imperative to delve into the realm of virtue and character as we look to a future where scientific literacy and clear thinking has its day.

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The Aims of Science Education:
Unifying the Fundamental and Derived Senses of Scientific Literacy

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There is about as much consensus regarding what constitutes scientific literacy as there is in defining constructivism or delineating inquiry-based science instruction. Teachers, researchers, and policy makers frequently invoke these terms; and yet, each falls short of representing a unified construct. The diverse interpretations of scientific literacy (see Roberts, 2007) present challenges that the field of science education would not necessarily have with a more clearly-defined and widely accepted construct capturing its aims. However, these challenges afford opportunities for practitioners and theorists to carefully reflect on the purposes of science education. With the rest of this brief piece, I will outline a version of scientific literacy framed by three overlapping dichotomies. In building my case I will focus first on competing notions of literacy and proceed to a discussion of contrasting theories that frame scientific literacy.

Literacy: Fundamental or Derived

One of the chief challenges for negotiating scientific literacy as a conceptual resource is the varied senses in which the term "literacy" is applied. Literacy can be positioned in both *fundamental* and *derived* senses (Norris & Phillips, 2003). In the fundamental sense, literacy refers to the use of language as in reading and writing. In the derived sense, literacy is more broadly construed to denote knowledgeability, learning, and education. In terms of scientific literacy, the fundamental sense refers to use of language in science contexts; whereas, the derived sense deals with understandings or abilities relative to science. With few exceptions (e.g., Fang, 2004), scientific literacy has come to exclusively represent what students should know, understand, or be able to do relative to science (Laugksch, 2000). The construct is typically invoked to characterize the goals of science education; that is, educators define scientific literacy in terms of the normative goals they have for science instruction. However, Norris and Phillips (2003) have provided a compelling argument for the significance of fundamental literacy. In doing so, they draw an important distinction between "simple" and "expanded" views of fundamental literacy.

The Fundamental Sense Scientific Literacy: Simple or Expanded

The simple view of the fundamental sense of scientific literacy, which certainly transcends the boundaries of science education, equates reading to text decoding. "Even today, there is strong reason to believe that teachers are unwittingly fostering this simple view of reading, despite over five decades of research showing that skilled word recognition is not reading" (Norris & Phillips, 2003, p. 227). An expanded view of literacy, more consistent with current trends in reading education research (e.g., Pressley & Wharton-McDonald, 1997), positions reading as inferring meaning from text. In the excerpt below, Norris and Phillips (2003) explicate the processes involved in inferring meaning and distance this view of literacy from those which correspond to simple decoding.

> Inferring meaning from text involves the integration of text information and the reader's knowledge. Through this integration, something new, over and above the text and the reader's knowledge, is created—an interpretation of the text (Phillips, 2002). It is crucial to understanding in this view to recognize that interpretations go beyond what is in the text, what was the author's intent, and what was in the reader's mind before reading it. Also crucial is the stance that not all interpretations of a text are equally good, but usually there can be more than one good interpretation. (p. 228)

Whereas simple fundamental literacy highlights the recognition of vocabulary, the expanded sense of fundamental literacy invokes broader processes of constructing meaning relative to a variety of texts. A substantial difference exists between knowing what specialized terms mean and actively interpreting those terms within larger contexts. These varying perspectives on literacy have important implications for the relationship between language and science. When literacy is cast simply, language bears a merely functional relationship with science. Language is a tool for science; however, an expanded view of literacy frames the relationship between language and science as constitutive. Language is a constituent, a fundamental element, of science. When language is positioned as a tool of science, science itself can be construed independent of language. In contrast, if language shares a constitutive relationship with science, then literate practice is essential to science. That is, science can not be independent of language; without language, there is no science (Norris & Phillips, 2003).

The Derived Sense of Scientific Literacy: Cognitive or Sociocultural Perspectives

Although most articulations of scientific literacy share a focus on the derived sense of the construct, there is substantial variation across these variations. The epistemological perspectives which frame particular notions of scientific literacy serve as an important grouping heuristic for the various views. My discussion focuses on cognitive and sociocultural perspectives: cognitive perspectives tend to prioritize cognitive entities such as concepts or attitudes as the intended outcomes of science instruction; whereas, sociocultural perspectives prioritize the appropriation of practice as the intended outcome of science learning experiences. I will argue that cognitive perspectives on scientific literacy encourage the disarticulation of science and language while sociocultural perspectives situate language centrally with respect to science practice.

Cognitive perspectives, based on individualistic psychologies, have dominated discussions of education generally and science education more specifically for the past 30-40 years (Kirshner & Whitson, 1997). These perspectives undergird much of what exists as the common practices and goals of modern science classrooms. Cognitive perspectives tend to conceptualize the aims of education as the development of cognitive attributes. These attributes may be transmitted or constructed; in either case, the goal of instruction is for learners to come to possess certain knowledge structures or attitudes. Desired knowledge structures may include declarative or conceptual knowledge (i.e., knowing the meaning of target concepts) and procedural knowledge (i.e., knowing how to perform given tasks). Scientific literacy has frequently been defined in terms of these kinds of knowledge and attitudes (Jenkins, 1990). Viewed in this way, learning is synonymous with acquisition of cognitive entities. In science learning, students acquire science concepts, abilities to complete certain tasks often referred to as process skills, and positive attitudes regarding the contributions of science.

When scientific literacy is framed in this manner, the role and significance of language are minimized. Scholars can reasonably argue that conceptual formation or acquisition is mediated by language (i.e., concepts exist only inasmuch as they can be identified or described through language) (Munby, 1976), but the real focus of cognitive views on scientific literacy is concept acquisition, not the interactions of learners, ideas and language. Language becomes a medium through which knowledge can be communicated, and its significance is derived through its utility. This perspective on language use is consistent with the simple view of literacy in its fundamental sense. In fact, adopting a simple view of fundamental literacy enables and encourages a cognitive perspective of scientific literacy in the derived sense. Furthermore, this combination (i.e., simple fundamental literacy and cognitive derived scientific literacy) makes the distinction between the fundamental and

derived senses of literacy most pronounced. In essence, conceptualizing fundamental literacy in a simple way promotes a view of derived literacy which prioritizes abstracted cognitive entities. When scientific literacy is articulated in the form of cognitive entities without much attention to language, then it remains significant to draw the distinction between fundamental and derived senses of literacy.

Sociocultural perspectives offer a competing framework for conceptualizing the goals of science education, that is, scientific literacy in its derived sense. Whereas the cognitive perspective just elaborated positions knowledge as abstracted entities that ideally can be transmitted to students (or constructed by students), sociocultural perspectives on learning emphasize the significance of context, enculturation and practice. *Enculturation* refers to processes by which individuals come to be a genuine part of a community. Through these processes, an individual comes to understand, appropriate, and appreciate the values, norms, and practices of the group. Viewed from the sociocultural perspective, learning is enculturation. In their seminal work on the topic, Brown, Collins, and Duguid (1989) effectively demonstrate the link between learning as it has been historically conceptualized relative to disciplinary knowledge and culture:

> To talk about academic disciplines, professions, or even manual trades as communities or cultures will perhaps seem strange. Yet communities of practitioners are connected by more than their ostensible tasks. They are bound by intricate, socially constructed webs of belief, which are essential to understanding what they do…The culture and use of a tool act together to determine the way practitioners see the world; and the way the world appears to them determines the culture's understanding of the world and the tools." (p. 33)

When learning goals are abstracted from the culture in which the practice was originally situated, as I have suggested is the case in cognitive articulations of scientific literacy, students do not have access to the broader framework which supplies meaning and significance. If one accepts the argument that all learning is situated, then the abstract learning goal becomes an aspect of the culture of schooling and not of meaningful scientific practice.

Enculturation does not occur at a distance or in the third person; it occurs by personally engaging in the *practices* (i.e., the regular activities) of the community (Greeno, 1998). Therefore, if learning is enculturation and practice is an essential aspect of enculturation, then learning must involve practice. The goal of learning defined by sociocultural perspectives is to move the learner from a naïve position beyond the boundaries of a community of practice ever more central to the community. Ideally, the learner progresses from an outsider to an active participant. Learners do not become immediate experts, nor do they engage in the full spectrum of practices characteristic of the community; learning starts through *legitimate peripheral participation* (Lave & Wenger, 1991). Participation is legitimate because the learner engages in authentic activity, that is, practices that are genuinely significant for the community. It is considered peripheral because the novice does not immediately assume the complex activities most central to the discipline or craft. As learners come to understand the knowledge base and practices of the community through peripheral activities, they are prepared to take up more central responsibilities.

While most students participate in school activities, they typically do not engage in practices consistent with the scientific community. "Many of the activities students undertake are simply not the activities of practitioners and would not make sense or be endorsed by the cultures to which they are attributed" (Brown, Collins, & Duguid, 1989; p. 34). What then does this mean for classroom science instruction? It is both unreasonable and impractical to

expect all students to work in apprenticeships that lead to professional science; however, in order to learn science, students need more than just exposure to abstract concepts. Students need to experience science concepts and tools in authentic practice, where authentic practice represents developmentally appropriate contexts that invoke similar processes as those used in research labs or other settings in which "real science" takes place.

Given a sociocultural perspective which prioritizes enculturation and practice, the articulation of scientific literacy in its derived sense takes on a new character. The goals of science education shift from the acquisition of cognitive entities, as defined by a cognitive perspective, to becoming a member of a scientific community. Again, this is not meant to imply that all learners should ultimately become professional scientists, but the statement reflects the view that learning science involves being engaged in the culture and activities of science.

In some respects, recent emphases on inquiry-based learning experiences have moved the field of science education closer to the desired goal of actively involving students in scientific practice. Inquiry based approaches encourage students to engage in some elements of scientific practice such as manipulation of variables, experimental design, and the confirmation of hypotheses. However, they typically fail to accurately account for the social nature of science or highlight the significance of discursive practices which enable students to make sense of their findings, apply their understandings of science to personal decision-making, and engage in public discourse about issues related to science (Duschl & Osborne, 2002). Language use, broadly construed to include written, spoken and symbolic discourses, is central to the culture and practices of modern science (Gee, 2005; Lemke, 2004), and attempts to promote sociocultural versions of scientific literacy must attend to this reality. Language use, as it is applied here, refers not to just simple decoding and deciphering vocabulary or sentences. Language use as scientific practice is consistent with the expanded view of literacy in its fundamental sense. Doing science is a social process through which meanings and conclusions are negotiated via written and spoken language. This involves creating and interpreting text and an inter-play between authors/speakers, the words and figures they inscribe, and the readers/receivers of the material (Norris & Phillips, 2003).

At the outset of this work, I contrasted the fundamental and derived senses of literacy. This contrast is significant particularly when the fundamental sense of literacy is cast simply and the derived sense is framed with a cognitive epistemological framework. These frameworks allow and even encourage the separation of language from science and create situations which marginalize language in science learning contexts. However, when scientific literacy in its fundamental sense is framed with the expansive view and the derived sense of scientific literacy is conceptualized from a sociocultural perspective, the distinctions between the fundamental and derived senses become blurred. Scientific literacy comes to represent the appropriation of authentic scientific practice (i.e., practice meaningful within the culture of science) which, in large part, is defined by the use of language.

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Scientific Literates: What do they do? Who are they?

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In this paper I will attempt to be responsive to the papers by Erickson and Roberts, as well as to articulate a somewhat different view of scientific literacy. Any rigorous account of scientific literacy must also address the issue of what counts as learning. My own perspective on learning has been strongly influenced by scholarship in situated cognition. I will then describe who scientific literates are and what we know about how they are made. Finally, I will describe why I believe scientists are a bad model for scientific literacy and where we might find better models.

What counts as learning?

From a situated cognition perspective, learning is the result of participation in particular social practices. Learning happens as individuals become particular kinds of people. Learning is the acquisition of Discourses of thinking, acting, valuing, interacting, feeling that makes you a particular kind of person.

As Knobel and Lankshear (1997, p. 96) describe: "By participating in Discourses we take up social roles and positions that other human beings can identify as meaningful (cf. Gee, 1996), and on the basis of which personal identities are constituted. It is in and through Discourse that *biological* human beings are constituted as ("identified") *social* human beings." Thus, learning includes not only knowledge and skills, but also feelings, attitudes, dispositions and all other aspects of ourselves that may be brought to bear on the way we participate in science-related activities.

From this perspective, then, the question is not what science content must be known for one to be deemed scientifically literate. The question is "who are scientific literates and what do they do?"

What do scientific literates do? Who are they?

There are (at least) two ways of addressing scientific literacy. One way privileges the first question (what do scientific literates do) and is answered normatively. A second way privileges the second question and is answered empirically by finding scientific literates and describing what they do. I will take each of these approaches in turn

The normative approach: What do scientific literates do?

Traditionally, discussions of scientific literacy have focused on what it is we think the Discourse of scientific literates ideally ought to be. This requires a social analysis of science, its place in contemporary society and it influence on individual lives.

There are several dimensions to being a scientific literate. Some of these will sound familiar as they are relatively commonplace in the literature on scientific literacy. A *civic* dimension is related to participation in public life in ways that supports, critiques, and directs professional science in ways that are good for society as a whole. It would also include decision-making on public matters about which scientific knowledge may be brought to bear. A *personal* dimension would include

making good use of scientific information to make personal decisions such as health, home maintenance, and consumption of goods and services. A *cultural* dimension would include the appreciation and understanding of scientific ideas for their own sake.

While these dimensions are well-known and often cited in the literature, I would also like to add a fourth: a *critical* dimension, influenced by scholarship in critical theory and new literacies. This dimension would have scientific literates not only reading scientific texts but also understanding why the text was written, what the authors are trying to do with the scientific text, how science is being positioned in the text (e.g. as the voice of expertise, as the source of controversy, etc…), and how readers are positioned by scientific texts (e.g. as intelligent decision makers, as ignorant individuals in need of simple instructions, etc….) The term "text" is used broadly here to mean the full range of ways (e.g. written, oral, visual, etc…) in which science is communicated between and by people.

This approach to defining scientific literacy has the appeal of a high degree of idealism and completeness. The difficulty in this approach, however, is that it may also result in standards that are not humanly possible to achieve simply because the analysis is not informed by evidence of what real people do. It acknowledges few limitations.

How do people acquire these competencies?

In science education, much of the work using situated cognition (or socio-cultural research more broadly) as a framework for understanding learning seeks to enculturate students into the practices of professional scientific communities. Researchers have often drawn upon studies of scientists, such as that of Nancy Nercessian, Bruno Latour and others to inform our views of what it is scientists do presumably so we can design instruction that teaches school children these same competencies. Researchers and curriculum designers attempt to design classroom environments that emulate the characteristics of scientific environments and introduce problems into classrooms that will require students to acquire scientific competencies. Others have attempted to design instruction to teach students scientific argument, using the work of philosophers such as Stephen Toulmin to set the normative criteria for evaluating the quality of arguments. We have a growing research base on students' acquisition of scientific competencies such as reasoning with evidence, argumentation, model-based reasoning. While all of these competencies seem important and may indeed be tools used by scientific literates, our understanding of how these resources might be deployed by scientific literates is not well understood. While one can easily see how this research can inform the *cultural* dimension of scientific literacy, it is harder to ascertain how they would contribute to the other dimensions of scientific literacy. Teaching students to reason in the way that scientists reason does not map easily onto the components of scientific literacy listed above. I know of no evidence that scientists are better citizens or make better personal decisions or are more critical of science texts than the rest of us. In fact, Bell & Lederman (2003) provide some evidence that scientists reason no differently than the rest of us in the context of personal decisions.

Both the *civics* dimension and the *personal* dimension of scientifically literate practices have been recently reviewed by Glen Aikenhead (2006). This exhaustive review provides guidance in the kinds of scaffolds and instructional approaches likely to improve students' decision-making regarding both social and personal issues.

On the *critical* dimension, I know of no research that addresses how students develop a critical competence. Although Lottero-Perdue and I (2007) have begun working to elucidate what this critical competence look like and how we might provide opportunities for it, this is an area that has for the most part not been attended to by science educators. While there is some research on how students might learn to critically evaluate the content of science texts, (e.g. Keselman, Kaufman & Patel, 2004) what we are suggesting is a different meaning of what it means to be critical, one that includes understanding of how scientific texts are used in positioning readers, science, authors, etc…

While this line of research has been very productive in many regards, I wonder if what we are teaching and assessing will produce more scientific literates. We assess student learning based on norms that are formed analytically, but not empirically. I wonder if this line of work needs to be more substantively informed by what it is that scientific literates actually do.

Who are scientific literates?

If scientists are a bad model for scientific literacy, then where might we find good models? Or where do we find scientific literates? A few researchers have responded to this challenge by looking in their communities and in the activities of everyday people.

For example, Layton, Jenkins, MacGill and Davies (1993) describe "workshop science" as places where ordinary people are engaged in solving personally significant problems for which science is potentially useful. They found that formal scientific knowledge needed to be transformed in order to be used in practical settings. In other words, scientific information did not always provide simple solutions for the problems they faced. Similarly, Aikenhead (2005) found that nurses made frequent judgments regarding the quality of the evidence they collected, but made little use of formal science concepts typically taught in school. Eisenhart and Finkel (1998) have examined the way in which science is employed in a variety of settings that they describe as marginal to mainstream scientific practices. In cognitive anthropology, Kempton, Boster & Hartley (1995) studied cultural models of the environment and how these models shape both reasoning and decisions regarding actions toward the environment. They found widely held models of pollution, the ozone hole, and photosynthesis were misapplied in an attempt to understand global warming. Environmental decisions were also strongly affected by other kinds of values such as religious values and commitments to their children. Pamela Lottero-Perdue (2005) examined the ways in which women in a nursing mothers' support group engaged with scientific texts about breastfeeding. Like the prior research, this study supports the finding that scientific information often could not direct action. This study also highlighted the ways in which women selected texts that supported their beliefs and rejected those that did not. Within this group there was a small number of experts (with more advanced medical/scientific training) who engaged in critique of scientific texts while the majority deferred to the experts.

These are all cases that describe activities related to the *personal* dimension of scientific literacy. I believe they may provide some guidance in helping us understand what kind of knowledge is relevant to personal decision-making as well as the nature of the reasoning required for resolving dilemmas. For example, scientific knowledge rarely dictates decision-making. Everyday decision-making is fraught with the need to manage uncertainty and in being able to make decisions between

competing sets of values. In other words, this everyday reasoning is a form of practical reasoning (Brickhouse, Stanley, & Whitson, 1993).

Lottero-Perdue's study is perhaps unique in that it also examines the *critical* dimension of scientific literacy. In addition to judging the credibility of scientific texts against their scientific knowledge of how breastfeeding works and their own experiences, they also examined the way that scientific texts positioned mothers and the practice of breastfeeding.

The dialectical relationship between the empirical and the normative in understanding scientific literates

In empirical studies of scientific literates, the first problem is also the biggest problem. One still has to make a judgment regarding who to study. One cannot make this judgment without at least having some initial norms or ways of identifying scientific literates. I think this work is important to do because it has the potential of helping us figure out what competencies seem to develop effortlessly when individuals are thrown into situations where they must figure out how best to act, and of course what competencies might be missing and thus lead to poor decisions. The descriptive could help us begin to set more realistic goals for science literacy, yet there is a danger that one could set standards too low by taking the everyday activities of people as the best we can hope to achieve. Much like the naturalistic epistemology program in the philosophy of science (e.g. Solomon, 2001), the descriptive can inform the normative, yet it cannot prescribe it.

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Rethinking identity at the core of scientific and technological literacies:
Insights from engineering education research and practice in South Africa

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Perspective

The predominant focus of science education research on scientific literacy has been the context of school science, with related work around informal science education activities (Roberts, 2007) and this is also reflected in the papers presented at the symposium. My primary focus in research and teaching over the last ten years has been in an engineering programme at a South African university and I therefore come to the notion of scientific (and technological literacy) with a a somewhat different perspective. My concern has been explicitly with those students who wittingly or unwittingly have elected to study engineering and science at a tertiary level, and who (hopefully?) will be going on to forge careers in these areas. One might therefore assume that my approach to scientific literacy would be firmly located in the Roberts (2007) 'Vision 1' which can be described as 'looking inward at the canon of orthodox natural science' (p. 2). In fact, as will be outlined below, my work on student learning in science and engineering has led to a position on learning which strongly resonates with Roberts' 'Vision 2', in which the focus is on real world situations which have a scientific component. If such a perspective on scientific literacy is desirable even in the 'heartland' of educating scientists and engineers at an 'elite' institution, then this certainly adds weight to the call for a broader notion of scientific literacy for application in the school context.

In the South African context of a general 'skills shortage' there is growing concern to improve the (generally dismal) 'throughput' in tertiary studies in general, and in engineering degrees in particular. Furthermore, many of our students come from school and family backgrounds that have not provided an easy starting point for tertiary study. My concerns as a teacher and a researcher have therefore centred on improving student learning in tertiary engineering and science. My initial research efforts followed a similar line to the mainstream 'Constructivist Programme' in science education research outlined by Erickson (2001). My early work focused on conceptual change, and this soon broadened to include a focus on metacognitive development (Gunstone & Mitchell, 1998). A particularly powerful framework in the tertiary context has been provided by the theory on 'approaches to learning' which emerged from Phenomenographic Programme' also described by Erickson (2001). Notwithstanding the more 'socio-cultural' directions that the Constructivist Programme has taken, nor the accounting for 'context' in the Phenomenographic Programme, I have come to the view that these perspectives remain limited in terms of radically addressing the challenges of tertiary science and engineering education. In Sfard's (1998) terms all of these perspectives are drawing on what can be termed an 'acquisition metaphor' and in Säljö's (Säljö, 2002) analysis these would be fall under what he has termed a 'things ontology'. In other works, despite their differences, all of these perspectives focus on learning as the *acquisition* of some*thing*, be it constructs, concepts, etc.

An alternative perspective on learning can be characterised by what Sfard (1998) terms a 'participation' metaphor. In Säljö's (2002) ontological analysis here the focus is on activity. In his paper Sadler has provided an analogous categorisation when he compares sociocultural to cognitive perspectives on the derived sense of scientific literacy. Learning is now a process

of doing, of participating. Importantly though, these are no random activities: the sorts of things you do fundamentally determine the person that you are. In her paper Brickhouse has written that "Learning happens as individuals become particular kinds of people". In other words learning becomes characterised as a process of *identity* development.

In his paper Osbourne makes some important points about identity. He notes that "identities are discursively and contextually produced" (p.2) The role of discourse will be discussed further below, but the word 'produced' is useful in that it signifies action, a dynamic process, not something that you 'have' or don't have (i.e. acquisition). Importantly, Osbourne also states that identities are 'shaped' in relation to aspects of race, gender and class, and therefore link to a sense of "what is appropriate for a person like me". This resonates strongly with the South African context, but it is important to note that the post-apartheid social context has provided an opportunity for the disruption of historical aspirations. Massive numbers of first generation university students have entered these institutions over the last decade, a portent of radical social change in the class landscape in South Africa. From interacting over many years with these students I have noted that they are anything but constrained by traditional working class expectations (cf. situation in the UK), and importantly also there are few constraints regarding expectations of appropriately gendered careers. For academically successful black [1] school leavers there is a sense of a wide world of possibilities. This links with Osbourne's observation (p. 3) that aspirations can change quite dramatically over time.

Osbourne also points to the importance of understanding career choice as a process of identity formation. In previous research (Jawitz & Case, 1998) we found that many South African students explained their choice to study engineering in terms of a desire to improve the quality of live for fellow South Africans, and also in terms of setting out to change stereotypes around traditional careers for black and/or female students.

In order to build a a theoretical perspective that focuses on identity development, I have drawn on work in the areas of situated cognition, and discourse and academic literacies. In a highly 'expanded' sense this move could be considered a revisioning of the vision of scientific and technological literacy at a tertiary level. I am aware that Erickson places these theoretical frameworks under his Constructivist Programme, but following Sfard, Säljö and others I think it is important to note that these theoretical frameworks rest on a very different set of basic assumptions about how learning can be characterised.

Using situated cognition: identity as entry to a new community

In searching for an expanded theory on learning that could better serve the context in which we research and teach, I was drawn to the theory of 'situated cognition' (Lave & Wenger, 1991). As noted above, this theory involves a dramatic shift from cognitive perspectives on learning, with a focus no longer on the building of individual (or even collective) mental models but rather a reconceptualisation of learning as participation in a community of practice. In a statement echoed in the work of Osbourne referred to above, in earlier work Brickhouse (2001) has noted that "Learning is not merely a matter of acquiring knowledge, it is a matter of deciding what kind of person you are and want to be and engaging in those activities that make one a part of the relevant communities." (p. 286). In this theory, learning

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[1] The use of racial terminology in this paper assumes race as a sociological not a biological construct, and recognises the need to make these distinctions in order to be able to understand the legacy of apartheid on current South African education realities. The term black refers inclusively to people previously classified as African, coloured and Indian.

then is seen as the development of identity, through the medium of legitimate participation in a community. There is the possible confusion on whether one is talking about the scientific community or an educational community; but Lave and Wenger (1991) suggest that this theory could equally be applied to either context even though the workplace context seems a more natural application of their original research.

In work with my colleague Jeff Jawitz, we used situated cognition as a theory to explore students' first experience of the engineering workplace as they engaged in compulsory industrial 'vacation training' as part of their engineering studies (Case & Jawitz, 2004). This theory proved a productive perspective particularly for illuminating the way in which this experience could be profoundly empowering or distressingly disempowering. The race and gender dynamics of the engineering workplace were found in some instances to impact on students' levels of access to legitimate peripheral participation, and therefore on their learning. In other instances we found mentors in industry who had gone out of their way to provide 'legitimate' experiences for their students, and who had thereby facilitated extremely meaningful learning experiences which had clear outcomes in the development of new identities.

A focus on academic literacies: identity as acquisition of a new discourse

One of a range of limitations of situated cognition theory is that it does not adequately account for the way in which practice is embedded in a wider institutional context and enacted through linguistic means (Contu & Willmott, 2003). At this point it has been productive to incorporate a focus on discourse, with a focus on learning as the acquisition of new discourses. In the work of Gee (2005) , acquiring a new discourse refers not only to learning new grammar and vocabulary, but rather to a way of being in the world, a combination of 'acting-interacting-thinking-valuing-talking-(sometimes reading-writing)' (p. 26), in other words, the development of a new identity. Brickhouse writes in her paper that "Learning is the acquisition of Discourses … that makes you a particular kind of person" (p. 1). In this symposium there are also helpful elaborations of the value of the 'discourse' perspectives in the work of Kelly and Martins. In assessing the value of Gee's framework, it is maybe worth raising for discussion the emphasis he places on the acquisition of secondary discourses. He stresses that these discourses can *only* be obtained through acquisition, not through formal teaching. I would be interested in the perspectives of the symposium participants on this point.

Working together with another colleague, Delia Marshall (Case & Marshall, 2006), we were interested in understanding the learning experiences of senior engineering students. Here, we drew on Gee's (2005) notion of 'Discourse models', 'the "theories" (storylines, images, explanatory frameworks) that people hold, often unconsciously, and use to make sense of the world and their experiences in it' (p.61). One such Discourse model that we identified amongst students we termed the 'no problem Discourse model', in that this involved students constructing an upbeat portrayal of their experience of a course, despite experiencing crises induced by assessment events. Through a process of justification the seriousness of the crisis is denied, and this Discourse model therefore arguably did not help students to overcome their learning difficulties.

In this study we were particularly interested in the possible origins of such a Discourse model, and we noted how teachers unwittingly might shore up this model in their encouragement to

struggling students, for example in telling them not to worry, that everything will ultimately be all right.

In the above study our focus has been very much on the development of an appropriate/productive *student* identity, with an interest in how students approach their learning. The more usual focus in research on 'academic literacies' has been on students' engagement with the specialist discourse(s) of the discipline (Lea & Street, 1998). Of course these are overlapping interests, and in fact in our identification of 'Discourse models' we also noted different extents to which students engaged in the specialist discourse of engineering when discussing their learning in a course. Nonetheless this is an important area for future work in science and engineering education.

A case study of teaching practice

Educational research with no practical value in the real world is most probably of limited value. I have had the fortunate situation in being able to try to build the insights that have emerged from this research into the chemical engineering undergraduate programme at UCT. Here I will focus on my work at the first year level. For the last seven years I have convened a first year course in which students are introduced to the discipline and profession of chemical engineering. In an interactive and reflective manner I have attempted to incorporate into this course a focus on learning as the development of identity, the incorporation into a new community, and the broadening of scientific and technological literacies.

Drawing on early notions of 'academic development' in the South African context, the course had inherited a module entitled "Introduction to the Study of Engineering", which had similar content to many 'study skills' courses, with a particular focus on engineering. This module had been plagued by poor perceptions amongst especially some students who felt that they did not need this sort of help. In reworking the course I have reworked these elements to focus rather on career development, and the initial building of an engineer identity. The new module entitled "Studying and Working in Engineering" involves (surprisingly popular) talks by engineers, as well as a range of tasks that are billed as developing one's career prospects. Importantly, a key objective of the course is to show that there is an incredibly diverse range of careers that are taken up by chemical engineers, and the focus is on helping individuals start to conceptualise their own 'niche'. One task which has been very well received by students involves them having an email 'conversation' with a working chemical engineer.

Building a community in the class is a particular challenge in the South African context, but also something that most students strongly support in principle, even though this takes them out of their comfort zones. A key focus here is to build networks in the class that cross racial boundaries. The course involves afternoon problem-solving sessions which are held in randomly assigned groups, and a range of group projects are also held in such groups. There is ongoing support from tutors and lecturers towards good group functioning. In the latest initiative – hot off the press – we have just recently taken the first year class on a 'camp' which has been designed to be focused primarily around this objective.

One key objective of the course is framed as the development of scientific and technological literacy. The core content of the course is focused towards basic chemical engineering concepts as well as the development of computer modelling skills. In addition, students are taken on plant visits, after which they have to reflect on what they have obtained from the

visit. A new initiative in 2007 involves a 'book review project' which requires students to read and review a book from the popular literature with some relevance to the course.

In conclusion then I would like to argue for a rethinking of learning in tertiary science and engineering education to focus on the development of identity, including the entry into new communities and the acquisition of new discourses. This has proven a productive route both for research and practice.

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Challenges for science education: A personal view

Synopsis of Contribution to Uppsala symposium May 2007

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A personal story

This symposium is supposed to be about taking stocks of where we, as an international research community, are -- and to share some ideas and visions about where we want to go in the future. One way of doing this might be to describe your own journey and shifting academic and personal priorities. I take the liberty to do so[1]. I know that many other science educators in my generation have a similar story, and this also justifies taking such a perspective.

I entered the field of science a long time ago, early in the 1970's. I was then a young and newly educated nuclear physicist. For many reasons, I came to realize that I would not spend my professional life in a research laboratory. When I got the offer to be responsible for the building of a group in science education in my university, I grasped the possibility. I then entered a field that did not exist in my country. (I did not even know that there was such a field anywhere else!)

In hindsight, I can see how my initial research interests were coloured by my 'pure' scientific training. My research concerns were with pupils' learning of correct and accepted science contents, and also about finding the best and most efficient way of teaching such concepts, laws and theories. I entered into research in the field myself, and found theoretical frames that appealed to my own background.

The inspiration from Piaget

Like so many other, I found this in the Piagetian stage theory. His theories had a strong appeal to science educators, his own background was a PhD in biology, and he used a perspective and terminology based on science (adaptation, accommodation, assimilation, self-regulation etc.) Moreover, most of his examples on cognitive development were drawn from science: the earlier books (1920s to 1940s) were about children's conceptions of the world, of force, movement, velocity, on causality, numbers and quantities etc. When Piaget later (from the early 1950's) developed the details of his stage theory, he used evidence based on children's grappling with more or less classical school experiments from physics and chemistry (balance, water pressure, mixing of liquids etc.) Moreover, Piaget formulated his stage theory in mathematical terms, even using his own versions of group theory. As a summary: It was very understandable that Piagetian stage theory became a research paradigm (or at least a progressive research program, to use Lakatos' terminology) among science educators who came directly from the sciences. My own PhD (in 1982) was based on this theory, but also incorporating the new perspectives that were emerging; constructivism and the stress on the actual contents of children's thinking. I got inspiration (as well as personal friendship) with key persons in the field, like Rosalind Driver and Andrée Tiberghien, later also with Gaalen Erickson, Peter Fensham, Glen Aikenhead and others – also contributors to this seminar! As we all know, constructivism soon emerged as a new research programme, and the stage theory gradually lost its domination. The literature in this field exploded and a recent bibliography (Duit 2997) now covers 7700 studies in this category.

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[1] A detailed account is given in English in Sjøberg 2007and in Norwegian in Sjøberg 2006, both available from my web site http://folk.uio.no/sveinsj/

It should be noted that the constructivist turn in science education is not a rejection of Piaget, but rather a re-discovery of the earlier Piaget, as well as of the constructivist epistemology and psychology that remained his perspective through his 5 years of academic writing.

My own research interests, like so many others in the field, followed the path described above. I was from the beginning inspired by Jean Piaget. I corresponded with him, and had an appointment with him to discuss my PhD-theses. In 1980 I went to Geneva to meet him. He fell sick and died that week, but I did meet all his co-workers.

Constructivism: many faces, many phases

As noted, the term constructivism is currently used very widely in educational literature, in academic papers as well as in books used for teacher training, curriculum development and assessment. The level of precision is often rather low, and the term is seldom clearly defined. This has led some critics (e.g. Matthews 1994) to consider the term to be empty of meaning, and that its use is purely ideological. It seems to be used to distinguish the good guys (constructivists) from the bad guys (traditionalists). The label 'constructivist teaching' seems to be used by many authors as more or less synonymous to any teaching that is somewhat 'child-centered', caring, inclusive, or based enquiry, discovery or any kind of active involvement from the learners . The literature abounds with lists of aspects that characterize constructivist classrooms, constructivist teachers, constructivist curricula and constructivist assessment. Most of these articles and books have a low precision on the definition of the term, but they all seem to associate the term with something unquestionably positive.

Based on such observations, many critics argue that constructivism as a meaningful concept has lost its power. Some call constructivism a new orthodoxy, a fad and a fashion, a movement (Erickson 2001) or even a religion with different sects (Phillips 1995). But there is, of course, also serious theoretical writing and research that strongly oppose such characterizations. Many academics claim that there is a strong theoretical underpinning of constructivism. But they also disagree with one another about the epistemological and theoretical status of constructivism.

One should also note that even within the field of education, there are there are several varieties over the theme of constructivism. Many scholars use qualifiers when they refer to constructivism. Hence, we find *individual* and *cognitive* constructivism (often with reference to Jean Piaget), *social* constructivism (often with reference to Lev Vygotsky). Some use the term *simple*, *mild* or even *naïve* constructivism with reference mainly to some interpretations of Piaget, and with a contrast to *radical* constructivism, used by Ernst von Glasersfeld (e.g. 1984). Other widely used version include *contextual* constructivism (Cobern 1993), *sociotransformative* constructivism (Rodriguez 1998), *sociocultural* constructivism (Tobin 1998; Branco & Valsiner 2004). The list can be made longer, and many of the above qualifiers are used in new and inventive combinations. It is beyond the scope of this paper to go in detail on differences and similarities behind this flourishing terminology. The point is simply to warn about the possibility for misunderstandings, as well as for real and false disagreements. It is my conviction that many of these debates emerge from the mixing of different perspectives, different types of claims.

Constructivism: The construction of what – and by whom?

As science educators, we are mainly interested in how people construct meaning and knowledge. It is important to distinguish this from epistemology of scientific knowledge, i.e. the growth, development and status of public, scientific knowledge about the world.

We may ask: What is constructed?

1. Is it our individual knowledge about the world? ("Children construct their own knowledge.")
2. Is it the shared and accepted public scientific knowledge about the world as it exists in established science? ("Scientific knowledge is socially constructed")
3. Or is it the world itself? ("The world is socially constructed")

The first of these questions is a problem of psychology and educational or learning theory, while the latter two are part of philosophy and epistemology. Question no 2 is also addressed by the sociology of knowledge and sociology of science.

Analytically, it is important to keep these questions apart. One may, for instance, be a strong supporter of constructivist learning theories, while at the same time reject the two other stances, in particular the last and most extreme one. This latter kind of constructivism is criticized for being a subjectivist and relativist post-modern attack on the rationality of science, a stance that runs against any suggestions from for instance Piaget and Vygotsky, to be discussed later in the final version of this paper. It is also my impression that some authors slip between the different meanings of constructivism in their writing.

From learning science to learning about science

When science is communicated to the learners, through classroom teachers, textbooks etc., they do not only learn the science contents per se (concepts, laws, theories). They also learn what science is all about; they develop views on the nature of science and the status of scientific knowledge. Similarly, the learners develop impressions on how scientists are as persons, the nature of scientific work and occupations, the relationship of science and technology to society etc. It is likely (and it is my conviction) that these more or less hidden and implicit messages are as important as the overt and intended curriculum.

The values that are communicated through school science (and through other media) are probably more lasting and more important than most of the actual science contents that is learned. In rich, highly developed countries (like the Nordic countries and many other OECD countries) the perceived values of a field, a discipline or an occupation are likely to be strong determinants if we want to understand the choices made by the younger generation.

It is my conviction (and it can be backed up with theory and evidence) the search for personal meaning and relevance are key elements for young learners when they decide on their future career in countries like ours, where they are not driven by material needs and the need for a decent job and income.

Also for those who do not enter into careers in S&T (i.e. the great majority!) the affective aspects of science learning is of crucial importance. They are the voters and decision-makers of the society. Given the enormous importance of S&T for present society, it is crucial that we have a population that understands key aspects of S&T, for good and bad. A working democracy is dependent upon its citizens to be well informed, and to have a critical and realistic perception of what S&T is really al about.

This might be called my vision of what we may mean with Scientific literacy. (Although the term in itself is not the important issue, we may just as well use other terms.) Many definitions of scientific literacy seem to stress only the cognitive side of S&T. (Also definitions used by PISA, although it is interesting to note how this definition has been broadened and changed from 2000 to the 2006-version) (More on this in the final paper?)

Current research: attitudes, values and the ROSE project

The main project I have worked on for the last years is called ROSE (The Relevance of Science Education). ROSE is an international comparative project meant to shed light on factors of importance to the learning of science and technology (S&T) – as perceived by the

learners. International research institutions and individuals work jointly on the development of theoretical perspectives, research instruments, data collection and analysis. The informants (the target population) are pupils towards the end of secondary school (age 15).

The lack of relevance of the S&T curriculum is probably one of the greatest barriers for good learning as well as for interest in the subject. The outcomes of the project are be empirical findings and theoretical perspectives that can provide a base for informed discussions on how to improve curricula and enhance the interest in S&T in a way that

- respects cultural diversity and gender equity
- promotes personal and social relevance
- empowers the learner for democratic participation and citizenship

The key feature of ROSE is to gather and analyze information from the learners about several factors that have a bearing on their attitudes to S&T and their motivation to learn S&T. Examples are: A variety of S&T-related out-of-school experiences, their interests in learning different S&T topics in different contexts, their prior experience with and views on school science, their views and attitudes to science and scientists in society, their future hopes, priorities and aspirations, their feeling of empowerment with regards to environmental challenges etc.

ROSE has, through international deliberations, workshops and piloting among many research partners, developed an instrument that tries to map out attitudinal or affective perspectives on S&T in education and in society as seen by 15 year old learners. We have tried to make an instrument that can be used in widely different cultures. The ROSE instruments taps into the diversity of interests, experiences, priorities, hopes and attitudes that children in different countries bring to school (or have developed at school). The focus is to stimulate research cooperation and networking across cultural barriers. An underlying hope is to stimulate an informed discussion on how to make science education more relevant and meaningful for learners in ways that respect gender differences and cultural diversity. We also hope to shed light on how we can stimulate the students' interest in choosing S&T-related studies and careers – and to stimulate their life-long interest in and respect for S&T as part of our common culture.

The ROSE project is based on cooperation. The intention is that participants learn from each other. The data that are produced will be made available for participating researchers. In several countries the research groups involved in ROSE are also engaged in the large-scale comparative achievement studies like TIMSS and PISA. It is expected that the two kinds of studies will complement each other, both providing information about the status of science education in the country.

PISA and TIMSS focus on students' achievement, and they provide 'standards', 'indicators' and 'benchmarks'. However, they say little about how children feel and think about S&T. Results are often published in the form of country rankings that may not always provide clues to what one should try to do to improve teaching and learning – not to say students' interest! The purpose of ROSE is not testing of achievement and understanding against universal standards, but rather to address attitudinal and motivational aspects of S&T and open up for discussions of cultural diversity and how S&T education can be made relevant in different contexts. In contrast to studies like TIMSS and PISA, ROSE is low-cost and less rigorous in its logistics etc. It is also organized 'bottom-up' from interested researchers, and not from Ministries and Governments.

The ambition of ROSE is to try to see these challenges from the perspectives of the learners, and to provide information of a different nature than the dominating achievement

studies. We hope that data and perspectives based on ROSE may provide an additional voice in the debates about curricular choices and priorities.

There are now more than 40 countries taking part in ROSE, and more than 10 PhD students will base their thesis on ROSE data. Two have completed, Camilla Schreiner (2006) in Norway and Ishmael Anderson in Ghana. The participants have met at conferences like ESERA and IOSTE, and special ROSE workshops have been hosted in Oslo and Helsinki.

Articles etc are put on our web site at http://www.ils.uio.no/english/rose/

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Engaging Young People with Science: Thoughts about future direction of science education.

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A considerable body of evidence now exists that, by age 15, compared to other school subjects, science is failing to engage young people (Jenkins & Nelson, 2005; Lyons, 2006; Osborne & Collins, 2001; Sjøbeg & Schreiner, 2005). Yet, student interest in science at age 10 has shown to be high and with little gender difference (Murphy and Beggs, 2005). Research also suggests that the point of decline begins in the final years of primary school (C. Murphy & Beggs, 2005). Moreover, a recent analysis of longitudinal data collected in the USA would suggest that, by the age of 14, students' interest in pursuing further study of science has been largely formed (Tai, Qi Liu, Maltese, & Fan, 2006) – to the extent that at age 14 students *with* expectations of science-related careers were 3.4 times more likely to earn a physical science and engineering degree than students *without* similar expectations. This effect was even more pronounced for those who demonstrated high ability in mathematics – 51% being likely to undertake a STEM related degree. Indeed Tai et al's data analysis shows that the average mathematics achiever at age 14 with a science-related career aspiration has a greater chance of achieving a physical science/engineering degree than a high mathematics achiever with a non-science career aspiration (34% compared to 19%).

Further evidence that children's life-world experiences prior to 14 are the major determinant of any decision to pursue the study of science comes from a survey by the Royal Society (The Royal Society, 2006) of 1141 SET practitioners' reasons for pursuing scientific careers. A major finding was that just over a quarter of respondents (28%) first started thinking about a career in STEM before the age of 11 and a further third (35%) between the ages of 12 -14. Likewise Lindahl's (2007) concluded from her longitudinal study, which followed 70 students from grade 5 to grade 9, that, if students were to engage with science in any significant way, then they must have sustained positive experience of science from the beginning of elementary school. Once they lose interest the likelihood of re-engaging with science is low.

Such data demonstrate the importance of the formation of the aspirations of young adolescents, long before the point at which many make the choice about which subjects to study further. Thus, rather than plugging the leaks in the STEM science pipeline (Jacobs & Simpkins, 2006), research effort would be much more productively expended by: (a) understanding what are the formative influences on student career aspirations between the ages of 10 and 14; and (b) attempting to foster and maximise the interest of this cohort of adolescents in the role and value of science in society from age 10.

In most developed societies, the lack of student interest in STEM related careers in is well documented (Haste, 2004; Jenkins & Nelson, 2005; Roberts, 2002; Sjøberg & Schreiner, 2005) and of rising concern amongst industrialists who perceive it as a threat to the economic competitiveness of their societies (European Commission, 2004; National Academy of Sciences: Committee on Science Engineering and Public Policy, 2005; Roberts, 2002). However, whilst students recognise the importance of science, they perceive it to be less engaging than other school subjects and 'not for

them' (Jenkin & Nelson, 2005). Girls are also significantly more negative about the physical sciences than boys (P. Murphy & Whitelegg, 2006; Osborne & Collins, 2001; Osborne, Simon, & Collins, 2003). Data collected by the Relevance of Science Education (ROSE) Project (Schreiner & Sjøberg, 2004), using a standard survey administered in over 20 countries, show that the decline of student interest in school science is an international phenomenon with girls, in the overwhelming majority of countries, liking school science less than their male counterparts . Indeed, there is a 0.92 negative correlation between students' responses to the question 'I like school science more than other subjects' and the UN index of Human Development (Sjøberg, personal communication, 2006) suggesting that the phenomenon is deeply cultural – a product of youths' values in advanced societies.

An analysis of the 1999 TIMSS data shows a similar negative correlation between high attainment in school science and student attitudes to school science (Martin et al., 2000).
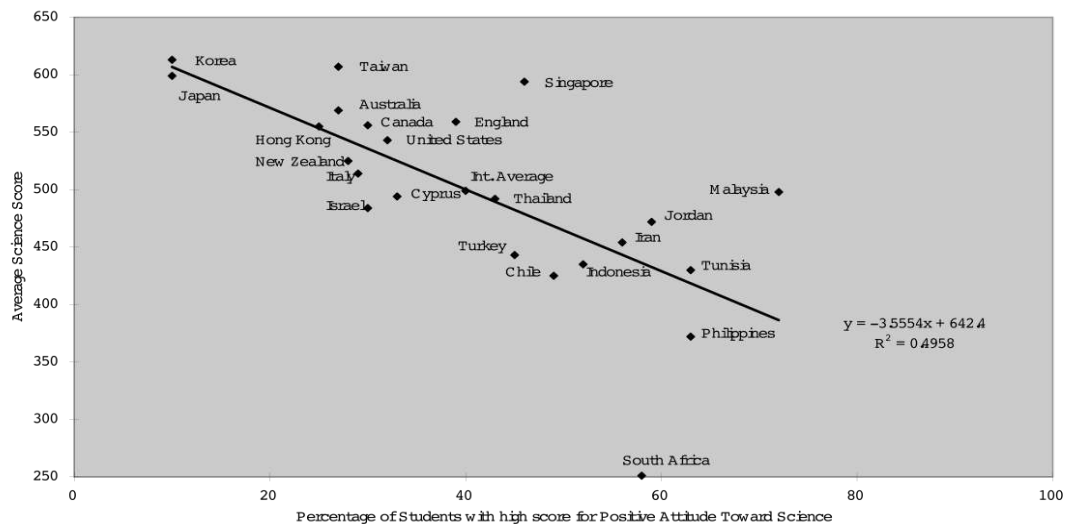

Fig 1: Relationship between student achievement and student attainment for TIMSS data

Taken together such data shows that traditional approaches to science education with their emphasis on basic foundational concepts are failing to engage the majority of young people. In short, that developing a mass system of science education on a curriculum that was designed for the minority of able students simply does not work.

Lack of interest in school science may be, in part, a product of the mismatch between the values communicated by science, the manner in which it is taught, and the aspirations, ideals and developing identity of young adolescents. Ever since the work of Goffman (1959), social life has been seen as a performance with agreed rules for behaviour in which every facet of people's public choices and behaviour, such as language, actions, values and beliefs, are tacit symbols or codes of social identities. Identity is both an embodied and a performed (Butler 1990) construction, that is both agentically constructed by individuals and shaped by their specific structural locations (e.g. see Archer 2003; Archer & Francis 2006). Identities are understood as discursively and contextually produced (i.e. produced through relationships and

interactions within specific sites and spaces) – and as profoundly relational. That is, a sense of self is constructed as much through a sense of what/who one *is not*, as much as through the sense of who/what one *is* (Said 1978). Importantly, notions of identity are multifaceted and complex, being shaped in relation to intersecting axes of gender, \ethnicity, social class, and so on, which can generate powerful notions of what is/not felt to be appropriate or normal for 'people like me' – which in turn can profoundly shape individuals' educational choices and trajectories (Bourdieu & Passeron 1977). A notable feature of contemporary society is also the growing range of interactive technologies and media that young people have access to for constructing their identities and engaging in creative and autonomous self expression (Buckingham, 2000; Sefton-Green, 2007).

In contrast, school science is arguably one of the last surviving authoritarian socio-intellectual systems in Europe (Ravetz, 2002) with a teaching style which is over-reliant on information transmission (Lyons, 2006) and, until recently, curricula whose primary social function was that of training and selecting a future generation of scientific research workers. Presenting, as it does, a body of unequivocal and unquestioned knowledge with little opportunity to explore discursively the nature of what is offered, its relevance or applications, such a cultural practice does not naturally fit with the normative practices and goals of young people. This is particularly true for students whose career aspirations lie outside of science, many of whom are female and who do not see science qualifications as a means of realising their personal goals (Fielding, 1998).

Indeed the problem of girls uptake of the physical sciences is chronic and enduring (Cronin & Roger, 1999; Kelly, 1981; P. Murphy & Whitelegg, 2006). Despite a host of attempts since the 1980s to address the issue, girls uptake of physical science in most countries still hovers somewhere between 15-30%. The exception to this is in Southern and Eastern European countries (OECD, 2006). Blickenstaff (2005) has examined the multiple theses advanced to account for this phenomenon demonstrating that those explanations couched in biological terms are simply not sustainable. Rather the problem is complex and cultural requiring a multi-faceted solution. Those factors which are amenable to intervention e.g. the nature of the curriculum, access to teachers and resources, and the nature of classroom pedagogy need to be adapted if the problem is to be addressed.

The problem of student interest in science is compounded further by the finding (Munro & Elsom, 2000) that teachers do not perceive themselves as a source of career information for year 9-11 pupils (let alone year 11-14), but rather, regard it as the responsibility of the careers advisor. However, only a small minority of careers advisors have any science background and, in addition, the compulsory nature of science means that there is less incentive for teachers to sell either careers *in* science or careers *from* science. As a consequence, few young people are offered a vision of the value of either careers in science or careers from science (Munro & Elsom, 2000).

Nevertheless, whilst school experiences are significant, school students spend only 18% of sixteen waking hours per day between the ages of 5 and 16 in formal education (Bransford, 2006) – see Fig 2.
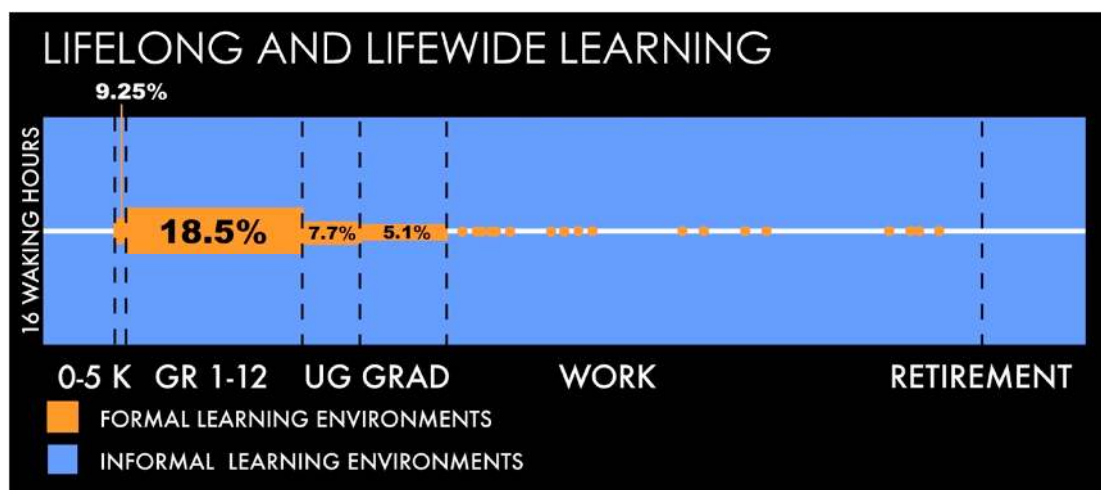
Fig 2: Time spent in Formal Education across an Individual's Lifetime

Therefore, young people's attitudes to the study of science and mathematics needs to be understood as much, if not more, within the cultural contexts outside school in which students are situated and where these attitudes produced. It is this context that shapes and frames their sense of self-identity and their aspirations for their adult life. Indeed there is a large body of work which would indicate that students' sense of self-identity is a major factor in how they respond to school subjects (Head, 1979, 1985; Schreiner & Sjøberg, 2007). A central concern for research, therefore, is to develop our understanding of the cultural *processes* at work in the formation of young people's aspirations. In particular, how and why they refuse or 'choose otherwise' the further study of STEM subjects.

To do this we need to bring together sociological and psychological research on 'aspirations' (particularly gender and aspirations). From this we know that, in general, girls' career aspirations are becoming less gender stereotypical over time (e.g. Francis 2000), and that single/mixed sex schools can shape the gender-traditionalness of aspirations (Archer 2004). This work has not, however, been applied within the context of school science and mathematics. Furthermore, whilst existing work details what pupils' aspirations are, it fails to show how they evolve over time and how they are affected by particular events and influences.

It is also necessary to recognise that students are also culturally, economically and ethnically diverse; that minority groups are under-represented (Jones & Elias, 2005); and that there is much to learn from comparing selected sub-groups. Research conducted to date (Archer et al., 2003; Archer & Yamashita 2003; Reay et al., 2005) has shown that different social groups use information differently when making educational choices and decisions. Working class young people and their families tend to privilege 'hot' (interpersonal) knowledge gained from people judged to be 'like me' and/or impartial as opposed to the middle classes who make more use of 'cold', formal and official sources of knowledge (Ball & Vincent 1998). Hence there is a need to examine the situatedness of young people's formations of aspirations and the role of the social and cultural in the formation of ideas about mathematics, science, scientists and STEM careers and their appropriateness to their own selves.

Should societies, for instance, develop a proactive approach to the promotion of STEM careers with children of age 10-14? This could be achieved through a programme of diverse activities and strategies devoted to highlighting and considering the role of science and STEM careers in society. The work of Haste (2004) and the ROSE project (Schreiner & Sjøberg, 2007) has shown, for instance, that the interests of girls lie much more with people and environmental concerns. Thus, in developing any programme of work, is there not a need to focus on how science, and those working in science, can contribute to solving the enormous environmental and social challenges faced by society – food production, water supply, the control of disease, energy production and climate change? In short, working with teachers, is it not necessary to create a new vision of why working in science is a means of fulfilling the idealistic aspirations of youth. And, in so doing opening students' eyes to the range of careers in science, and that working in science is a means of serving humanity – a vision which is more likely to address what is currently known about the interests of girls?

Nevertheless, none of this can be achieved if the experience of teaching and learning science is not transformed to one which allows students greater opportunity to engage discursively with science (Osborne & Collins, 2000). Considerable evidence exists that the lack of space for critical engagement with the ideas of science and their implications is what alienates many students. In addition, the foundationalist basis of many traditional science courses means that the underlying coherence and the major explanatory themes of science are only grasped who stay the course to the end. School science needs to find a mechanism of presenting the major stories that science has to tell in a readily understood form. For instance, that you look like your parents because every cell in your body contains a chemically coded message which enables it to reproduce itself; or that, apart from hydrogen, all the atoms in your body were manufactured millions of years ago in a distant star; or that all the materials that surround us are made of just 92 stable substances. Only by presenting a vision of the story that is to be unfolded, creating what narrative theorists commonly call 'narrative appetite' (Schank & Berman, 2002) can we hope to sustain student engagement with material whose relevance to them seems questionable.

Transforming the pedagogy of school science is another major challenge. Research to date has shown that the dominant pedagogy is one where teachers lack a good understanding of the nature of their own subject which limits their ability to engage in the reflective meta-commentary that the language arts teachers commonly use (Lederman, 1992). In addition, teachers commonly operate as if they are dispensers of knowledge rather than facilitators of learning (Aikenhead, 2005; Bartholomew, Osborne, & Ratcliffe, 2004) using a discourse which is dominated by IRE dialogue (Lemke, 1990) and where students undertake activities which seem contrived and inauthentic (Duschl, Schweingruber, & Shouse, 2006).

However, such pedagogy is a consequence of two features – one is a collective culturally embedded notion of what it means to teach science which is difficult to shift or transform. The second is an assessment system which overwhelmingly values the reproduction of factual information as the best measure of a knowledge and understanding of science rather than the ability to critically evaluate scientific evidence, to gather and research information necessary to answer scientific questions, and to apply scientific knowledge in meaningful contexts (Black, Harrison, Osborne,

& Duschl, 2004). Teachers are as much a product of the structures and agencies to whom they are held accountable as any other professions (Giddens, 1984). Politicians need to realise that the values embedded those systems are resulting in an experience of school science which leads to the very effect that most concerns them – the flight of contemporary youth from school science. In short, that it is killing the goose that lays the golden egg. Given the weakening of the authority of schools as the sole source of knowledge in society, and given the effect that these are having on young people's ways of engaging with society, does school science require a revolutionary change? That is rather than tinkering with the system at the edges, is it time to start with a blank piece of paper and ask what should be the outcomes of a science education for all, and what kinds of learning experience is required to attain those goals?

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Competences, from within and without: new challenges and possibilities for scientific literacy

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Preface

The direction for scientific literacy and research I pursued in my initial summary has obvious relations to the thrust of the language-oriented summaries of Gregory Kelly, Isobel Martins, Troy Sadler, and Dana Zeidler. Several less direct relations to other summaries have also emerged. For example, Jennifer Case's suggestion that students would be better prepared for university studies in science-based fields if they had acquired the discourse of their new communities, made me aware that the research into the teaching of scientific competencies (discourses) that I am promoting may, indeed, bridge Douglas Roberts' two visions of SL.

In order to highlight the sources that have led to the press for the teaching and learning of generic competences compared with the scientific competences that are now being associated with SL, I was unable in this short summary to include the issue of the place of affect in scientific literacy –an issue the urgency of which, for most of our countries, transcends the debates about the more cognitive aspects of SL. To my surprise, only Jonathan Osborne and Svein Sjøberg make any mention of *interest in*, and *support for science* and none of us have referred to SL as including *personal and social responsibility for science and technology*.

Introduction

Science for All emerged in the 1980s as the slogan that signalled the recognition in UNESCO and many other countries that school science needed to be reconceptualised. It was no longer enough for Science in schooling to be aimed at the minority in need of Doug Roberts' *Vision I* of SL for their science-based careers, because the majority of students not so headed now had urgent societal needs to have access to the *Vision II* of SL. In one of the more perceptive national report on Science for All (in which both Doug Roberts and Graham Orpwood had more than a hand), four purposes for science education were set out.

1. one was *preparation for science-based careers (Vision I).*
2. the second was *for participation in socio-scientific decisions (Vision II).*
3. the third was *preparation of all students for the world of work*, and
4. the fourth was *for their moral development*.

In the twenty year interim almost no attention has been paid to Nos. 3 and 4, either by any of the new science curricula or by the research community for science education. The first of them is now, as I argue in this paper, pressing quite new and urgent demands on schooling and science education need to be part of the response. The second points to social responsibility of science and technology as a SL research agenda, that has, in fact already begun, although more in studies with the general public than within schooling. Since PISA Science for 2006 will provide important base line data on these matters as well as on personal interest in science, I shall try to expand on these affective issues in a third pert of my larger paper.

The slogan, ***Science for All,*** had a challenging ring; but it was far from a definition of how science in schooling should now be conceived, and even further from what it should be like in practice.

The term, *scientific literacy*, became popular in the 1990s as a new term for the intended reconceptualisation of school science. It had a more operational ring about than *Science for All*. It also seemed to link science education with the high status and priority in primary schooling that the basic literacies of *Language* and *Number* everywhere enjoyed.

Scientific literacy, however, did not have an obvious operational definition. Unlike language and number that have always been established priorities in the primary years of schooling, science had no such history of establishment in these years. Science had no obvious counterparts to the basics of reading, writing and operating numbers
.

Scientific literacy was soon being associated in a number of countries with an amount of content for learning in school science that was patently absurd (e.g. AAAS, 1993), exceeding what had hitherto been the science content for elite groups of secondary students in academic streams that had chosen the sciences. By the later1990s and into the 2000s this impossible level of science education for all students has resulting in a serious decline of interest in science, in science-based careers, and in the learning of science as other than rote recall of dogmatic information. It is urgent that science education yet again be reconceptualised.

In this paper two quite separate initiatives of the OECD will be examined as pointers to a direction that science education must now consider, as it faces these failures of *scientific literacy* as its curriculum organiser.

PISA Science
In 1998 the OECD set up the *Programme for International Student Assessment, PISA*, a project to provide information to its member countries on how well their 15 year olds were prepared for life in 21st Century society. This information was to be about the three domains, Reading, Mathematics and Science. The project had a six year cycle with testings in 2000, 2003 and 2006 when in turn each of these domains would be the major focus with the other two being minor foci. Expert groups were set in each domain to plan that part of the overall task.

The PISA project as a whole uses a language of literacies as its indicators of the students' preparedness. The Science Expert Groups have, for each of the three testings, taken a view of *scientific literacy* that enables it to be defined in terms of a number of scientific competencies (skills) that are intimately connected to conceptual content. In this sense they strongly endorsed the argument by Driver and Millar (1987) against the separation in school science curricula of conceptual content from processes that had grown up following the major reforms of the 1960/70s.

For 2000, these competences were:
* *Recognising scientifically investigable questions*
* *Identifying evidence need in a scientific investigation*
* *Drawing or evaluating conclusions*
* *Communicating valid conclusions*
* *Demonstrating understanding of scientific concepts. (OECD, 1999)*

These seem to include both of what Troy Sadler refers to as fundamental and derived sense of SL. To ensure that all of these are active skills in the students, the PISA Science tests take the form of presented real world contexts involving science and technology, about each of which the students are asked a series of questions that reflect these competencies. The use of novel

contexts means students in responding to these questions are never simply recalling knowledge, but rather are having to apply their knowledge of science in a transfer of learning sense. McGaw (2002) contrasted *PISA Science* with the other, concurrently occurring international project, *Trends in Mathematics and Science Study (TIMSS)*, by saying TIMSS set out to measure *what students know*, while *PISA* is concerned with *what they can do with the knowledge they have.*

There was great scepticism that students anywhere would be able to succeed, '*because in none of the participating countries were such competencies being taught in school science"*. In fact the students' performances were better than this gloomy prediction, while leaving much scope for further development.

By 2006 when Science was the major domain in PISA these competencies had been rethought and refined to be:
- *Identifying scientific issues*
- *Explaining scientific phenomena*
- *Using scientific evidence* (OECD,2006)

It will be evident from both sets of competencies that the PISA project has pushed the balance in science learning from *Knowledge of Science* to a combination of this with *Knowledge about Science*. In its emphasis on the latter, it has given considerable prominence to the *Nature of Science*, a current area of great interest among science education researchers who see this as a weakness in how national curricula were presenting their intentions for scientific literacy.

The Knowledge Society
If science education has not taken seriously education its role in preparing students for the world of work, the OECD began to do so, just a little earlier than the PISA project, when it launched studies on how the world of work was changing (OECD, 1996a&b). At the same time a similar study was initiated in Britain by the Royal Society for the Arts, Industry and Commerce (Bayliss, 1998). These studies found that the nature of work in developed countries is changing in three ways - *in kind*, *in the requirements for performance*, and *in the permanence of one's engagement.* These changes in the world of work and employment are driven by new forms of information transfer, ICT, (itself an outcome of science and mathematics). The resulting new knowledge enables innovation of new processes and products, and the globalization of their production. This new knowledge is increasingly the primary source of economic growth – *the currency of the economy.* Together these changes are known as the *Knowledge Society*.

In the manner that education has always been linked to the world of work and its knowledge demands, so the next step from these recent studies was to explore the educational implications of this changing nature of society (see Gilbert, 2005).

The following comparisons indicate some of the differences between the educational implications of the *Knowledge Society* and those that exist in most, if not all, educational systems.

- "Knowledge" is to be a verb *rather* than a noun
- Knowledge is about acting and doing to produce new things *compared with* Knowledge made up of stored bits of established knowledge

Value is to be associated with:

♦ Knowing how to learn and Knowing how to keep learning *compared with* Knowing many bits of a subject's contents.

♦ Knowing how to learn with others *compared with* Individually accumulating knowledge.

♦ Seeing possibilities for solutions to problems *rather than* Knowing the right answer

♦ Acquiring important competences (skills) *rather than* storing Knowledge

Change is now presented as the norm in the new society and it follows that the learnings for its wellbeing should have a dynamic character that equips students *to adapt to change, to generate new knowledge* and *continue to improve performance* (Fraser and Greenhalgh, 2001).

Lest I seem to be talking about abstract and academic analyses of modern or postmodern society, I can refer you to a string of active projects about these issues in the countries making up the Council of Europe, in Canada, the USA and Australia. In these projects there are constant references to the acronym ***DeSeCo*** which stands for ***Definition and Selection of Competence***, within which three broad types of competence are recognized – *communicative, analytical* and *persona* – as important.

The reports from these studies usually conclude with a longer or shorter list of competencies to describe the learning outcomes that will be increasingly needed. It is clear that these lists are messages from employers and policy makers that young people, regardless of their relative success in formal education, are emerging lacking knowledge and skills that are important for today's personal, social and economic life (OECD, 2000). It is disturbing to note that while science and technology are often referred to as instrumental in these changes, education in science and technology (other than IT skills) is not mentioned.

Prominent in these lists of the new competences are *Thinking, Communicating, Problem Solving, Inquiring, and Working with Others.* The statements of *Values and Purposes* that accompany these lists commonly refer to Connectedness, Resilience, Achievement, Creativity, Integrity, Responsibility, and Equity.

For science educators and science teachers, this language of the *Knowledge Society* and what it means for education is almost entirely foreign. Furthermore, there is such a dearth of connection between these competences and subject matter, that they seem to be essentially generic in character. Even problem solving is not elaborated in discipline specific terms, but in generic strategies of various types.

Discussion

So we have two developments (from the same OECD source) that are emphasising "competences" as the direction education should move, and move rapidly. Both relate to the argument Kelly espouses that these are fundamental to the way in which knowledge is constructed in science and education respectively. In education systems at present these competences are being quite independently defined and encouraged – one set highly subject specific and the other widely generic. It is not surprising that schools and subject curriculum developers are confused about responding.

In **Catching the Knowledge Wave?** Jane Gilbert (2005), one of the New Zealand body responsible for a response, sets out very clearly the contradictions between these two very different paradigms of knowledge and its learning. To bridge the gap she tries to make a case for competencies and traditional learning by suggesting the new worker will need "*to put

elements from one knowledge system together with elements from another, arranging them so that they work in new ways and do new things" (p.156). Such an integrating and interdisciplinary intention is hard to comprehend, let alone to practice in schooling.

I would rather explore an alternative solution. The idea of generic competences clearly has an appeal, and it is to these we refer when we ask people in every day situations *to think outside he square, to communicate more clearly, to consider alternative ways of doing things*, and *to find out more about a topic*. Probably all our school systems have been remiss in giving enough weight to developing these general abilities in students, and new emphases to do so will be necessary. However, this should not be at the expense of those other sets of competences that are subject or domain specific.

Hence, I propose as the next task for science education research, in close conjunction with teachers and students in real classrooms, is to extend our understanding of appropriate scientific competences to aim for at each stage or level of schooling, and to find how contexts, content and pedagogies, will make them learnable by large numbers of students.

PISA Science has made a big contribution by defining, for one important level of schooling, some competencies that can only be developed in science education, and furthermore it has shown that these can be validly and reliably be assessed. *PISA Science* is not, however, a curriculum. It is a piece of evaluative research that has defined wanted outcomes, and shown how to measure them authentically. These achievements are familiar as essential starting and end points for the design of curriculum.

As researchers we have already begun this task with the work on *nature of science*, on *modelling* and on *argumentation in science*. Interestingly, the three PISA scientific competences above for 2006 map fairly well into these three issues of research.

In extending science's competences I have found it useful to look at what has scholars outside of science find interesting about it. Outsiders can notice features that have become implicit for persons like ourselves, who have been heavily socialized into science.

Many years ago Barnes and Todd (1977) were intrigued by the transmissive manner in which teachers and students in science classrooms communicated with each other about science topics, and how this contrasted with the communication in other subjects. More recently Kress, a socio-linguist, and colleagues in London brought that discipline's analytical skills to bear on science teachers' talk in classrooms and found that its dominant character was an attempt at scientific explanation (Ogburn, Kress, Martins and McGillicuddy, 1996).

Other linguists like Halliday and Martin(1993) have been interested in the written communication of science and how particular grammatical constructions, like nominalisation are so commonly used – very complex processes are subsumed into a single phrase. Latour and Woolgar (1979).were intrigued by the retrospective stylistic writing of science reports and how it contrasts with the scientists' day-to-day oral accounts of the same research. Mason (2005) describes this communication is so about an orderly "outer" research that it completely excludes the messy "inner research" that is the heart of the nature of science.

Olson ((1994) has made the provocative claim that to understand a discipline means to be able to engage in its discourses. So what are the distinctive discourses of science? Toulmin (1967), a philosopher, began the answer when he set out to distinguish between the characteristics of

argument in linguistic contexts (of which science is one) and its use in the contexts of mathematics. The former has inspired the pioneering of a new frontier of research in science education by Driver, Austin and Osborne (1998), Kuhn (1997), and others, its practical use by PISA with its competences relating to scientific claims and the evidence for them.

Ohlsson (1995) has gone further by listing a number of epistemic activities- *describing, explaining, predicting, arguing, critiquing, explicating* and *defining* - each of which has a distinctive character and importance when used in the sciences. Marton, as a psychologist, was attracted by the notion of *scientific intuition* and, with Fensham, explored its meaning among 88 Nobel Laureates (Marton, Fensham and Chaiklin, 1994). The Woods Hole Conference recognised, almost 50 years ago, the importance of *intuition* for science education, but we have singularly avoided it, like *creativity*, in school science. (Bruner, 1967).

Here then is an agenda for research and practice on competences (or what Gregory Kelly calls *epistemic practices)* that innately belong to our subject field of Science and its application in the form of technologies. These scientific competences are important knowledge tools for engaging with the S&T contexts that are part of the real worlds of our students and of the society in which they are, and will be, future citizens. They also complement almost on a one-to-one basis the generic competencies that the Knowledge Society is demanding from education. This repositioning of science education will not be easy for many science teachers, who have so often simply been required to be transmitters of established knowledge.. They will need much help in the form of professional development. The fourth issue in Gaalen Erickson's paper recognises the need for research into how best science teachers in pre- and post-service can be helped to reposition their practice. It will have to give heed to both these teachers' <u>science</u> education and science <u>education,</u> and to the conditions that determine these as constraints to this repositioning (examples of Glen Aikenhead's educo-political dimension). For this research to keep pace with the demand for school practice to change will not be easy, but programmes of this sort, as Erickson hints at, may be science education's best hope for retaining meaning for SL among students, and SL as the established vision for science teachers. Otherwise we shall find the traditional view of teaching students to store abstract science knowledge becoming less and less attractive.

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Assessing Scientific Literacy: Threats and Opportunities

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I have been a keen observer and, in my own context, a dedicated participant in what we might call the scientific literacy (SL) "movement" for some 35 years. And while the concept has grown richer and more profound with each passing decade, as the papers at this conference demonstrate well, I am now fearful about its future. I believe that the prospect of implementing a significantly new and richer vision of SL is under serious threat. In fact I would argue that it is under a series of threats, from both inside and outside the science and science education communities.

The source of these threats in practice is from the field of assessment, an area of educational policy and practice that has attracted (in my view) inadequate attention from the SL community. And I fear that, if this inattention continues, richer deeper visions of SL will be hijacked by more prosaic, less intellectually and educationally satisfying visions of SL.

I have argued this point elsewhere (Orpwood, 2001) and Roberts has commented on it in his review paper (Roberts, 2007). Here, I want to reflect on the variety of threats to richer visions of SL and propose some ways in which we – as a community dedicated to furthering both the concept of SL and its implementation in schools through research – might move forward.

1. Purposes of assessment in nations and schools

Assessment is playing ever more important roles in education throughout the world, serving not only its traditional educational and social purposes with respect to students (Broadfoot, 1996; Gipps, 1999) but also new and significant political purposes in relation to schools and governments. One way to classify these varieties of purpose is as follows.

- *Assessment for educational accountability*

The public, media and politicians in most western democracies are increasingly demanding that both the overall education system and individual schools provide evidence of their effectiveness, productivity, and "value" for taxpayers' investment (whatever that means). In some countries, this has resulted in "league tables" of schools based on the results of examinations that were themselves designed for other purposes (such as A levels in England or provincial assessments of math and language in Ontario, Canada). Elsewhere, international assessments such as Trends in Mathematics and Science (TIMSS) are used as proxies for school and system effectiveness. Finally, in some countries, special tests are designed with this accountability agenda explicitly in mind (in Canada, the School Achievement Indicators Program (SAIP) was a case in point).

- *Assessment for student certification and selection*

This is perhaps the most traditional role for assessment – originating centuries ago in China as the basis for a merit-based system for recruitment to the public service – and examinations are still used in the majority of countries throughout the world for the purposes of certifying students' completion of one stage of education and for selecting them for subsequent opportunities either in education or employment.

- *Assessment for school improvement*

It follows – at least in a commonsense (though somewhat misguided) view of schools – that schools whose students achieve well in examinations are good schools and that, correspondingly, schools with lower aggregate results are in need of "improvement". Assessment is therefore increasingly providing the basis for assessing individual schools and for measuring whether they are improving. In Ontario, where I am most familiar with the school system in relation to assessment, a whole new government bureaucracy has been developed at huge expense with a view to improving school performance to meet government-set targets.

- *Assessment for learning*

In recent years, Black & Wiliam (2001) and others have argued eloquently that the most important purpose for assessment – dubbed "assessment for learning" – is also the most neglected; it certainly tends to have the least support financially. This purpose aims assessment squarely at the individual student's learning and is designed to have immediate impact. It represents the antithesis of most other approaches to assessment: individual in focus; classroom-based; designed and practised exclusively by teachers; lacking secrecy – indeed, the sharing of assessment criteria with students is key to its success – and its results require no documentation or reporting. It truly implements the vision articulated by Grant Wiggins (2003) that assessment is something we should do *with* students rather than *to* them.

This variety can and often does lead to a contest between different and sometimes incompatible purposes for the assessment of student achievement. One test cannot serve several purposes equally well. For example, the final examinations at the end of primary school – that determine whether students progress to secondary school and, if they do, which they will attend – are designed to facilitate student selection. The psychometric characteristics of assessments that perform this task most efficiently are unlikely to be the same as those of an assessment designed to determine if students have generally mastered the concepts and skills set out in the curriculum or to discover what kind of remedial instruction might be required. Yet we often see tests or exams being expected to serve more than one purpose and not necessarily equally appropriately.

Power over Purpose

The classification of purposes also forms an approximate hierarchy, based on the power of those controlling each level of assessment, which suggests the likely outcome of any conflicts. Senior levels of government typically have the power and resources to invest more in assessment than lower levels, senior bureaucrats more than junior bureaucrats, and school principals more than classroom teachers. It follows therefore that the needs and interests of the more senior levels will tend to take precedence over those below them. It is likely that international and national assessments designed for system accountability or student certification/selection will

"trump" those designed locally for the purposes of promoting school improvement and that all of the first three purposes of assessment out-rate assessment designed to support student learning.

For example, in Ontario, the results provincial mathematics and language assessments are used to make judgments about schools as a whole and the content of these tests have a significant steering effect on the teaching and assessment carried out by teachers, whether or not this is appropriate (Sinclair, Orpwood & Byers, 2007). This hierarchical competition among purposes also means that reliability-related criteria – critically important in large-scale and high-stakes assessments – are likely to be of more significance than validity-related criteria – usually of much greater significance in the curriculum-related assessments of the school and classroom levels. Since teachers and schools operate in a political environment, this represents an important source of inertia in any attempts at assessment reform based on reforms to the curriculum.

The power hierarchy also influences debates over such matters as "what counts as scientific literacy" where the definitions of the concept adopted by politically high-profile assessments such as TIMSS and PISA can out-weigh those developed by more scholarly or reflective research. When politicians see that their country's performance in international studies reflect their own views of their schools, they are hardly likely to question the validity of the measure. Furthermore, when "spooked" by what they perceive as poor results on international or national assessments, politicians can and do react in predictable ways. They – like teachers when their students are faced with high-stakes tests – will encourage "teaching to the test."

Ontario has seen its share of just such political responses to international assessments. Following TIMSS, a detailed analysis of test items done poorly by Ontario students led to the publication of a guide published on how to teachers should change their teaching. Later, also in Ontario, the government insisted that the new science curriculum match exactly directions proposed in a Pan-Canadian Framework, whose development was led by Alberta and British Columbia – two provinces whose TIMSS performance had far outstripped Ontario's.

2. Assessment and Science Curriculum Reform

I have argued elsewhere (Orpwood, 2001) that the development of the science curriculum over the past 100 years can be seen in Kuhnian terms as a sequence of (political) revolutions and new paradigms (Kuhn, 1962). The question of the *content* of the science curriculum – "what" should be taught and learned – is given new answers and debates over content are part and parcel of what can be described as "normal curriculum change".

Overlaying this normal curriculum change, however, have been two periods of what I argue can be thought of as "curriculum revolutions" where the very purposes and goals of the science curriculum have been changed. Like the paradigm shifts Kuhn invented to explain the growth of science, these curriculum revolutions fundamentally changed the way that the science curriculum content should be taught and learned. Roberts (1982) has used the concept of curriculum emphasis to capture different purposes for which science should be taught and learned. My argument now adds a

second dimension to his by suggesting that a period of radical change among the array of emphases in the science curriculum can be seen as a revolution, which influences not only curriculum policy and teaching but also textbooks, curriculum debate and research.

The first revolution began in the late 1950s and early 1960s when the combined focus of the science curriculum moved from a focus on science content for its own sake (Roberts's "firm foundations" and "correct explanations" emphases) to include attention to the nature and processes of science ("scientific skill development" and "structure of science" emphases). This was the period during which major projects funded (in the US) by the National Science Foundation and (in the UK) by the Nuffield Foundation attempted to redirect the teaching of science.

The second period of revolutionary change began in the late 1980s and early 1990s and added the emphasis on science, technology, and society (STS) and (later) the environment (STSE). Once again, the science curriculum field was to be fundamentally transformed and made relevant not only to those who would be future scientists[1] but also to future citizens and to those who were entering the world of work. Once again, science literacy was redefined, teacher education transformed, textbooks rewritten, and new agendas for research developed. Many countries have national reports on science education dating from this period that articulate one or another version of this new vision of SL.

However, throughout the past 50 years, as these two revolutions have changed much in science education, assessment in science education has developed at a much slower rate. The first significant performance assessments – matching the emphasis on skills and processes that were fundamental to the first curriculum revolution in the 1960s – did not appear until the early 1980s in England (APU, 1983) and it was not until the late 1990s before performance assessment became relatively common in North America. Indeed, such assessments are still only now making their way into many countries for the first time.

Performance assessments are still not welcomed by assessment purists as they are hard to design, expensive to implement, and complex to score. The first round of the Third International Mathematics and Science Study (TIMSS) included what was initially a required performance assessment component though, as the project developed, it first became optional, then was published separately a full year after the reports of the written tests (Harmon et al. 1997), and it was finally dropped entirely from subsequent iterations of TIMSS.

Assessments appropriate for the second curriculum revolution and that correspond to the latest visions of SL have yet to be developed on a systematic scale. There have been attempts by specific curriculum projects to incorporate appropriate assessments but these have not been widely adopted by schools. There are notable exceptions (e.g. AQA, 2003) but these are far fewer than the "curriculum talk" would suggest.

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[1] The motivation of the funding agencies supporting the curricula in the first revolution was to increase the numbers of scientists and engineers, a goal that was somewhat achieved, but at the price of losing the interest of many students who did not wish to pursue a scientific career.

On the international front, TIMSS tried and largely failed (see Orpwood & Garden, 1998; Orpwood, 2000). A few items in the Science Literacy component of the TIMSS tests of students in their final year of high school addressed STS topics but most were of a very conventional variety and called for simple analysis of data about a scenario set in a social context. Only one question was of the variety where there was no one right answer – at least, no one answer was equally correct in all countries – and there was considerable resistance to its inclusion. It dealt with the social consequences of technological change and, not surprisingly, the results emerging from this item from across the participating countries proved fascinating to analyse (Bartley and Orpwood, 2005). The OECD's Programme for International Student Assessment (PISA) is making a bolder attempt to incorporate STS items into its assessment and it is to be hoped that this project will see success where TIMSS did not.

As Roberts has shown in his analysis of the development of scientific literacy (Roberts, 2007), the concept – or at least the second of the two visions of it that he describes – has historically been an elastic one, flexing and growing to include many different facets. Yet when it has come to assessments, we have too often seen what Roberts describes as a "retreat to Vision I" (the traditional science content view of scientific literacy).[2] And the richer the conception of scientific literacy has become, the more uncertain have educators been to embrace the task of its assessment.

3. Thinking about Assessing Scientific Literacy

In order to get a conceptual handle on the problem of assessing aspects of SL, one must choose between two ways of conceptualizing the relationship of science content itself (Roberts's Vision I stuff) to the other, richer components of SL (the Vision II aspects).

SL as Course Content

One way is to see these aspects as extensions of the *content* of a science course. In such a view, the STS aspects of a science course – or the science process skills, or the nature of science, or any other aspects of SL (Vision II) – would be seen as additional course content requiring, of course, additional instructional time and additional assessment. This view is implicit in the complaint of a teacher who, when faced with a new curriculum incorporating, say, scientific investigations, science and society, or aspects of the history of science, says: "I don't have time for all of that! A retreat to Vision I is necessitated, in this teacher's mind at least, by the view that scientific literacy (Vision II) is like Vision I but with more "stuff" to teach but no more time to teach it.

This view of SL is one that was embraced by the TIMSS frameworks and by several other assessment frameworks. In a particularly interesting one, Keeves & Aikenhead (1995) developed a framework whose categories are differentiated by the degrees in which "science content" is integrated with "STS content" (see Table 1). They used this framework successfully for distinguishing a variety of curricula that incorporated STS to some degree.

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[2] Aikenhead (2007) also discusses the politics underlying this retreat

Category	Description	Assessment
1. Motivation by STS content	Standard school science is taught together with mention of STS content to make lessons more interesting	Students are not assessed on STS content
2. Casual infusion of STS content	Standard school science is taught together with a short study of STS content attached to the science topic. The STS content does not follow cohesive themes.	Students are assessed mostly on pure science content and only superficially on STS content
3. Purposeful infusion of STS content	Standard school science is taught together with a series of short studies of STS content integrated into science topics in order to explore systematically the STS content, which forms cohesive themes.	Students are assessed to some degree on their understanding of STS content.
4. Single discipline through STS content	STS content serves as an organizer for the science content and its sequence. The science content is selected from one discipline.	Students are assessed on their understanding of the STS content but not to the same degree as on the pure science content.
5. Science through STS content	STS content serves as an organizer of science content and its sequence. The science content is multidisciplinary.	Students are assessed on their understanding of STS content but not as extensively as they are on the pure science content
6. Science along with STS content	STS content is the focus of instruction. Relevant science content enriches the learning.	Students are assessed equally on the STS and pure science content.
7. Infusion of science into STS content	STS content is the focus of the instruction. Relevant science content is mentioned but not systematically.	Students are assessed primarily on the STS content and only partially on the pure science content.
8. Pure STS content	A major technology or societal issue is studied. Science content is mentioned but only to indicate an existing link to science.	The students are not assessed on the pure science content to any appreciable degree.

Table 1: Range of Integration of STS and Science Content (Keeves & Aikenhead, 1995)

In another paper that addressed assessment of STS, Tony Bartley and I used this framework as the means for analysing some of the TIMSS items designed to measure scientific literacy and, in particular, for reviewing some of the assessment challenges involved the use of items that were high on STS content (Bartley & Orpwood, 2005). This proved useful, as an analytical tool, as far as it went. However, subsequently, it has not proved as useful for developing new and interesting STS assessment items. I have concluded that this problem is the view of STS (or any SL goals) as "course content" comparable to the science itself.

SL as Contextualized Goals
In the first paper in which he outlined the concept of science curriculum emphases, Roberts (1982) made the point very clearly that an emphasis was not additional course content but, rather, the expression of purpose or goals through the contextualization of the science content in a distinctive way. Yet, this is not as easy a conceptualization of curriculum to grasp or to implement as its lucid description suggests it is. Developing a second "contextual" dimension for the science content in such a way that the goals of both Vision I and Vision II material are carried along together is a hard thing to do, whether one is a teacher, a textbook author, or a test developer. It is much easier to

treat STS (for example) as additional content to be taught and assessed either with or instead of the science content. But I am increasingly convinced that this is a mistake.

One of the most useful concepts underlying the development of the TIMSS assessments was the idea that all TIMSS items be thought of in terms of at least two dimensions: *content* and *performance expectations* (Robitaille *et al.*, 1993). An item's content refers to the topic from math and science that the item is drawn from, while its performance expectation refers to the cognitive skills with which students are expected to employ in relation to the specific piece of math or science content. Lower levels of performance expectation included knowledge and understanding, and higher ones included analysis, problem solving, and investigation. Every TIMSS item was classified with respect to both of these dimensions and the goal of the development process (sadly, less than fully realized) was to achieve a balance among items according to both dimensions. The point is that the performance expectation provides an assessment context for the science content much as a curriculum emphasis provides an instructional context for it. And the results of the assessment can (in principle, at least) be analysed on each of the two dimensions.

In some cases, the performance expectation dimension of an item may be of more significant than the content. In our paper about the TIMSS SL items, Bartley and I reviewed one item in particular, which became known as "The Bridge" item:[3]

> It takes 10 painters 2 years to paint a steel bridge from one end to the other. The paint that is used lasts about 2 years, so when the painters have finished painting at one end of the bridge, they go back to the other end and start painting again.
>
> - Why MUST steel bridges be painted?
> - A new paint that lasts 4 years has been developed and costs the same as the old paint. Describe two consequences of using the new paint.

It is interesting to note that this item initially included the second question – clearly an STS issue – on its own, but the overall item was accepted into the overall TIMSS tests only after the first question was added, as some of the scientific critics claimed that otherwise it was "not a science item." Its inclusion was also opposed by countries whose curricula lacked an STS component and by some psychometricians since the second question lacked a universally correct answer. The struggle to avoid a total retreat to Vision I is documented elsewhere (Orpwood, 2000) and the item was finally retained.

As our subsequent analysis of students responses to the second question showed, the pattern of how students thought about the implicit STS issue varied in interesting

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[3] The original version of this question derives from a real-world context. The Forth Bridge in Scotland used to occupy twenty-four painters painting on a continuous twelve-year cycle to keep the entire structure covered with five coats of paint. The vastness of the endeavour was so well known that "painting the Forth Bridge" became a metaphor (in the UK) for an endless task (Petroski, 1995, p. 381).

ways across countries and even, within Canada, across provinces. Three questions in particular emerged from our analysis of the Bridge item:

What is the scope of STS in science education? If STS means that students should learn science in a broad social context, we would argue that this broader context should include social, economic, technological, political, and environmental aspects. The TIMSS results suggest, and many STS materials confirm, that STS often refers to the social and environmental impacts of science and technology—these being most familiar to teachers—while technological and economic impacts are given less emphasis.

What counts as STS Assessment? Science educators must match STS curricula with appropriate assessments. As performance tasks with hands-on investigations are now used to assess the inquiry skills that are part of science education, so new forms of assessment with tasks and questions drawn from the real world need to be incorporated into STS programs at classroom, local, national and international levels.

Part of the challenge in developing such assessments is the variety of contexts in which students live and the variations of "right answer" that frequently are apparent in real-world situations. At stake here is not so much the definition of a "right" answer but rather how to enable students (and teachers) to consider feasible solutions to real problems. Reliability concerns have caused some psychometricians to feel uncomfortable. More work in this area is essential.

How do students' own contexts affect their responses? Responses to items like the Bridge item show that students draw on their personal experience and social context. This is appropriate, but presents problems for scoring. In TIMSS, local scoring teams were instructed to use their own judgement concerning what "made sense" in their national context. For example, in a country with provisions for guaranteed employment, consequences for the painters might be very different from one in which there were no such provisions. Such differences need to be taken into account by all involved in test development and use.

Ways Forward?
In this paper, I have outlined three types of threat to implementing a richer vision of SL:
- Political threats from governments seeking simple measures of student achievement;
- Professional threats from educators being too slow to adopt new forms of assessment;
- Conceptual threats from researchers not being creative enough to develop new approaches to assessment.

Each of these types of threat requires an appropriate response.
- Political threats require a preparedness of members of the SL community to advocate for their vision of SL and for correspondingly valid assessments;
- Professional threats require members of the SL community to become involved in projects to disseminate appropriate assessments of SL into the classroom as well as into national and international projects;

- Conceptual threats require more creativity from the SL community in generating new approaches to SL assessment.

This conference has seen some new and conceptually rich visions of SL articulated. If we are to see these become reality in the classroom and in students' lives, then we must not continue to ignore the assessment realities.

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Legitimacy and references of scientific literacy

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The idea of scientific literacy is shared among a large number of politics, science educators and scientists. However there is no consensus on the content of scientific literacy at secondary school level (Roberts, 2007). The agreement to which, during the first half of the twenties century, the democratic societies reach consisting of recognizing that all citizens should learn to read (advice, notices, newspapers), to write (letters, etc.) and to calculate does not exist for scientific literacy; the situation is more complex.

In this short paper, I will address mainly the question of the curriculum transformation and some consequences on teaching difficulties according to choices for scientific literacy.

Visions of scientific literacy and variety of types of knowledge

Working for a long time on types of knowledge involved in science curricula, teaching, and learning, it appears to me that the question of scientific literacy introduces multiple ways of tackle knowledge. The characteristics or qualifications of knowledge and its use are very diverse and then I use a theoretical framework to characterize it.

This framework is based on the theory of ecology of knowledge (Chevallard 1991), which states that knowledge content and its meaning depends on the community where this knowledge "lives" (is elaborated and/or used). The complexity of scientific literacy curriculum is that it involves different types of knowledge, not only sciences, but also epistemology of science including argumentation, and moreover in cases of socio-scientific issues, it involves sociology, history, ethics, etc., and everyday knowledge. Each type of knowledge is associated to a given community (scholar, professional, social, etc.). Vision 2 of scientific literacy proposed by Roberts (2007) involves several types of knowledge. Whereas Vision 1 corresponds to "science subject matter itself" (p.729), vision II corresponds to "situations in which science can legitimately be seen to play a role in other human affairs" (p.729) or "character of situations with a scientific component, situations that students are likely to encounter as citizens" (p.730). In the case of Pisa framework (OECD 2006), the two visions are involved. To the question "as citizens, what knowledge is most appropriate?", in the first part of the framework the answer is "certainly includes basic concepts of the science disciplines, but that knowledge must be used in contexts individuals encounter in life. In addition, people often encounter situations that require some understanding of science as a discipline – that is, as a process that produces knowledge and that proposes explanations about the natural world. Further, they should be aware of the complementary relationships between science and technology, and how science-based technologies pervade and influence the nature of modern life."

Then, like in vision 2 proposed by Roberts or in PISA vision, scientific literacy includes relationships between scientific knowledge and society or everyday knowledge; such relationships lead the curriculum developers to include other types of knowledge than scientific and epistemological knowledge. How are these compulsory level curricula based on these different types of knowledge legitimated in society eyes? I propose two different cases of legitimacy.

Legitimacy of scientific curricula involving a variety of academic disciplines (case A)

Following Chevallard (1991) in the theory of ecology of knowledge, the processes of elaborating a curriculum and teaching materials include three main aspects.

First an element of a curriculum *should have a referent elsewhere than in the educational system* (for example the referent of physics or any scientific discipline taught at school is knowledge or practice of the scientific communities, or in the case of vocational training, professional societies are referent).

Second, there is a process of transposition from the referent knowledge to the curriculum knowledge. The referent knowledge and the school knowledge "live" in different communities, then they are necessarily different; even if same terms and sentences (force, energy, etc.) are used, their meaning is not exactly the same.

Third, the curriculum (called "knowledge to be taught") *should be legitimated by a community that is respected by the society*.

In traditional curricula, where disciplinary elements of knowledge like biology, chemistry, physics, etc. are involved, the legitimacy of these elements is done by the scholarly communities that are usually respected by the society. When epistemology of science is involved, the scholarly communities also legitimate the corresponding curricula. This is not contradictory to the fact that a part of scientists can consider that this type of knowledge about science is too difficult for students at secondary school. Similarly in vocational school, the professional communities legitimate a large part of curricula; society considers these communities are relevant for this legitimacy (Legardez 2006).
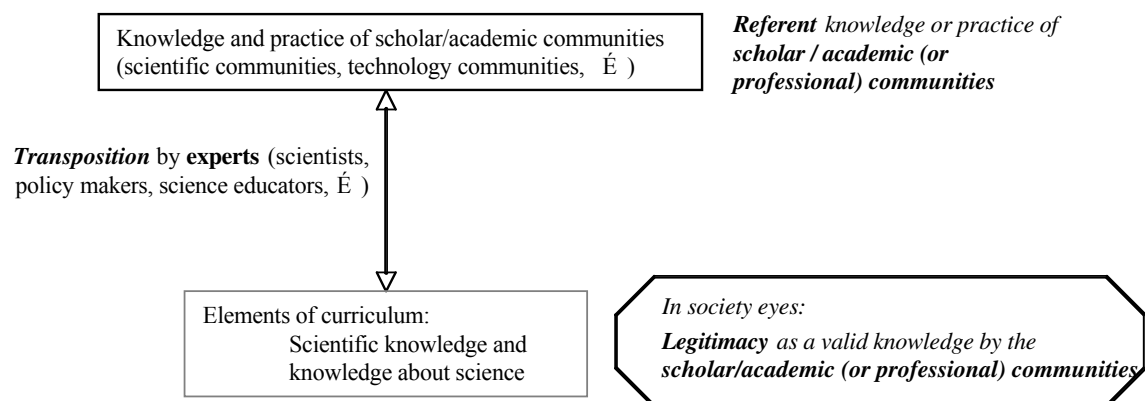
Figure 1: Case A, the elaboration processes of a curriculum (or a specific teaching content) when the school knowledge is transposed from scientific or professional knowledge (referent knowledge) of communities, these communities are also recognized by the society as legitimate

When curriculum requires that teaching situations involve personal, social, global contexts or have an objective of developing responsibility towards natural resources and the environments, the referent knowledge is not very well located in a given community, several communities are involved simultaneously. We differentiate this case (called case B) where legitimacy processes are much more complex from the first one (figure 1, case A). Case B will be first discussed from an example before being analysed in theoretical terms.

Example of case B: danger of cell phones (V. Albe)

Following Albe (2006), it appears that the introduction of socio-scientific issues in a curriculum necessitates several complex analyses. In the studied cases, like danger of cell phones and wind energy, controversies between experts arise, which is a rather usual situation

for socio-scientific issues. Then, in order to make teachable such issues, several analyses are necessary. First the different experts' studies on a particular issue have to be analysed from scientific and technological perspectives. In some cases, groups of citizens particularly concerned by the questions can become experts themselves, and of course their studies have also to be taken into consideration. Even at this step of the analyses, epistemological considerations relative to the inherent incertitude of scientific studies and the rhetoric used to reduce this incertitude are essential. Then sociological analyses of the "place" of the several expert groups in the society, of their proximity to social groups involved in the issues are also necessary. It is very interesting and informative to analyse the type of arguments used by each group of experts.

I consider that these analyses are required to make teachable socio-scientific issues. In this case, the chosen pedagogical approach was role-play, each small group of students playing a type of actors. The designers of the teaching session elaborated documents for teacher and students based on their previous analyses. Then, teachers were able to regulate the role-play in their classroom and to manage the conclusion (even if these regulation and management demand more than knowing the analyses). Let us note that the teacher should be able to distinguish between the elements which are rather well validated scientific results, the scientific incertitude which cannot be reduced and from which experts make decision, the social pressure of specific interests, etc. This previous work of analyses is a transposition work from knowledge and practices of several groups in the society to teaching materials; this transposition does not mean that all documents are transformed, few or many documents could be those produced by experts, but a framework can help students to situate them in a larger view with a possibility to understand roles of science and of technology and roles of social knowledge or practice in everyday life or professional contexts. In this case, researchers in science education with the help of scientists carried out the transposition work; an individual like a teacher, who has other duties, cannot do this work. If such a work is not done, a teacher who decides to introduce socio scientific issue in his/her classroom could be in a difficult situation where students bring their own opinions in the debate with partial elements of analysis and then the classroom group is transformed into public space of debate; the instructional role of school is lost. In this last case, a main risk is that parents and more largely the society will not legitimate such a teaching content/activity.

Legitimacy of curricula involving scientific, technological and other types of knowledge: case B

Figure 2 shows the transposition process in the case where the referent knowledge and practices are coming from socio-scientific issues. I emphasize two specificities of case B compared to case A. (1) Scholar or professional communities associated to referent knowledge cannot legitimate the whole teaching content. (2) Transposition process from referent knowledge and practice to teaching content is divided more explicitly than in case A, into two steps. A first one would consist of selecting sets of situations or issues relative to a variety of domains (health, natural resources, environment, hazard, …). I do not mean choosing specific situations but a more global choice. In comparison with case A, this choice is not in relation with a scientific/professional knowledge practices but with social life practices. In democratic country, my proposal is that a group of different representatives of the society makes this choice or at least gives advices. A second step consists of the effective transposition processes. Like in the example presented (cell phone), this process necessitates an important work leading in particular to teaching materials that currently are really missing even if some are available (Jorde, this document). This second step presents a challenge

because it needs expertise in different domains (scientific, epistemological, philosophic, ethic, professional, etc.) **and** in education.

The first specificity makes that case B differs drastically from case A. Case A may include situations where new approaches like introducing epistemology in a science teaching content are developed but still scholar associations can legitimate this new content.

The second specificity leads us to emphasize that, in case B, if the transposition process is mainly up to teachers, then they have a huge load to understand and analyse the socio-scientific issue and to prepare teaching materials; this is a generalisation of the comment done for the example of danger of cell phones issue; this type of work, which necessitates to distinguish different types of knowledge that are simultaneously involved and intricate, seems difficult for a teacher. As it was presented before, teachers could face a situation where their classroom becomes a public space debate, and then the risk that parents and the society do not legitimate such teaching practice is non negligible.
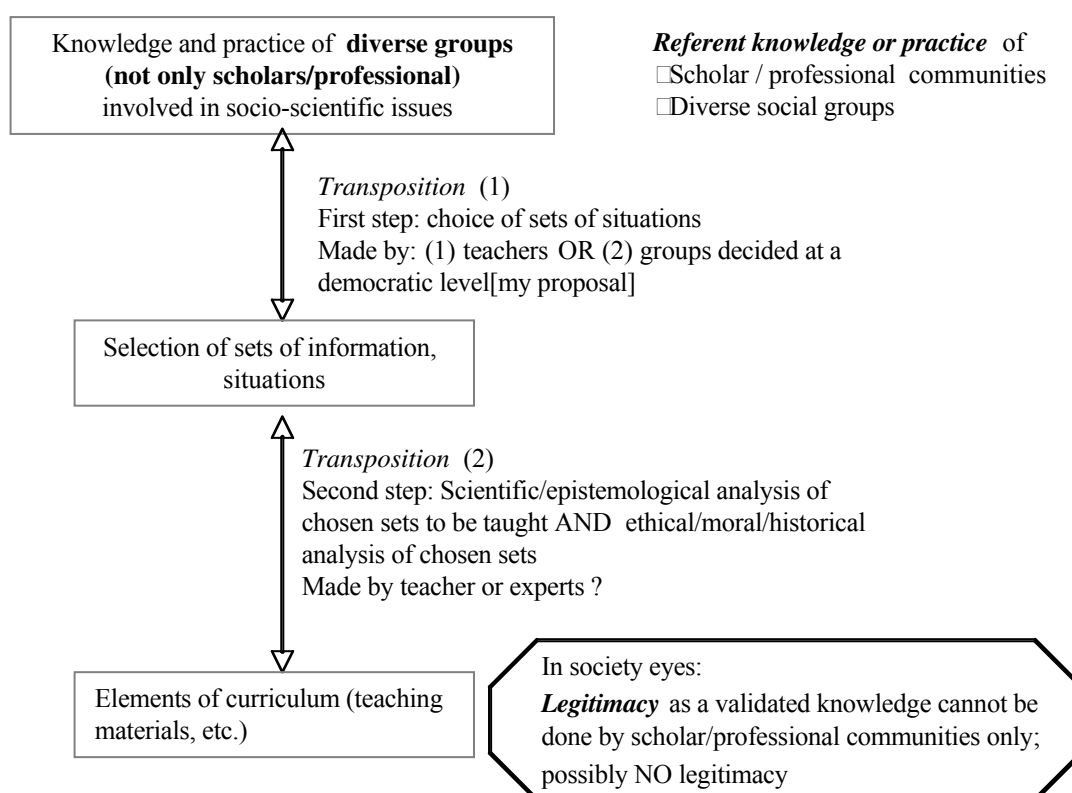

Figure 2: Case B, the elaboration processes of a curriculum when the school knowledge is transposed from socio-scientific situations (reference), the communities involved in these situations are not necessarily recognized by the society as legitimate

In conclusion scientific literacy education presents a challenge for science education community particularly in case B. What type of responsibility our community can take in this process of designing teaching materials, curriculum, and in teacher's professional development (Bulte, this document)?

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Scientific Literacy as an Issue of Curriculum Inquiry

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Scientific literacy has been widely accepted as a central goal of school science education in the 21st century. However, what should constitute the subject matter of school science for scientific literacy has not received sufficient attention in the literature. To explore this issue, this paper analyzes the meanings of scientific literacy from the perspective of curriculum making. It argues that the subject matter of school science is a cause of concern across the institutional, programmatic, and classroom curriculum, which demands serious investigation informed and enhanced by epistemologies and various curriculum theories and discourses. Subject matter thus is an important topic of curriculum inquiry, with three significant areas of research identified.

Addressing what constitutes the subject matter is important because fundamental educational reform requires a serious rethinking of the heart and core of teaching and learning—the subject matter. According to Schwab (1964), the curriculum field of inquiry is made up of four commonplaces—the learner, the teacher, the subject matter, and the milieu. Yet subject matter is the least attended topic in the academic community. With this analysis, we hope to draw attention to the need for addressing fundamental curriculum questions about subject matter through curriculum inquiry.

The meanings of scientific literacy in the literature

Scientific literacy has been deeply intertwined with social, economic, and political issues since its inception. Coined by Paul Hurd in the late 1950s, the notion was used to express concern about whether schooling was equipping students to cope with a society of increasing scientific and technological sophistication, and about public support for science in order to respond to the Soviet launch of Sputnik. In the early 1980s there was a reawakened interest in scientific literacy due to perceived threats to the economic competitiveness of the US and the crisis in science education. Eventually, this led to the development of national standards and benchmarks in science education in the late 1980s and early 1990s (DeBore, 1991).

Definitions abound in the literature, with no consensus about what scientific literacy is. Scientific literacy can be defined in terms of the attributes (knowledge, skills, and dispositions) of a scientifically literate person (e.g., AAAS, 1990, 1993; Hurd & Gallagher, 1966; Pella et al., 1966; Showalter, 1974). It can also be characterized in terms of broad categories and themes (e.g., Agin, 1974; O'Hearn, 1976; Pella, 1967). It can be construed in terms of the types of literacy involved (e.g., Branscomb, 1981; Shen, 1975; Shamos, 1995).

The above various definitions are useful for capturing the rich meanings of scientific literacy as an educational goal. However, they tell us very little about the meanings of scientific literacy when it is mandated as an educational goal, translated into curriculum and into classroom practice. In addition, a well-informed discussion of scientific literacy in relation to a broad social, political, and cultural context is largely lacking in the literature (Carter, 2005 a & b). What constitutes the subject matter of school science for scientific literacy remains a partially-explored issue.

Three basic domains of curriculum

The meanings of scientific literacy need to be analyzed from a broad perspective of curriculum making. According to Doyle (1992a & b), curriculum making operates across three basic domains, the <u>institutional</u>, the <u>programmatic</u>, and the <u>classroom</u>. The institutional curriculum, or the abstract or ideal curriculum, defines the connection between schooling and both culture and society. Institutional curriculum making invokes images, metaphors, or narratives to "typify" what could happen in a school or school system, and what is to be valued and sought after by members of a society or nation (Doyle, 1992b). It provides a normal, ideological basis for determining what should count as subject matter.

The programmatic curriculum—or the formal curriculum—results from a translation of the institutional curriculum for school and classroom use (Westbury, 2000). It consists of an array of school subjects, programs, or courses of study provided to a school or system of schools. For each school subject, the programmatic curriculum spells out content standards, instructional frameworks, assessment criteria, etc.. Programmatic curriculum making involves "framing a set of arguments that rationalize the selection and arrangement of content [knowledge, skills, and dispositions] and the transformation of that content into school subjects" (Doyle, 1992b, p. 71).

The classroom curriculum—also called curriculum-as-event—is characterized by a cluster of events jointly developed by a teacher and a group of students within a particular instructional context (Doyle, 1992a & b). Curriculum making at this level involves transforming the programmatic curriculum embodied in curriculum documents and materials into "educative" experiences for students. It entails further elaboration of the programmatic curriculum, making it connect with the experience, interests, and the capacities of students in a particular context (Westbury, 2000).

Scientific literacy taken on three different forms with respect to the above three basic domains of curriculum: 1) a curricular vision, 2) a school subject (i.e., school science), and 3) instructional events. Each of these forms, in a varying degree, determines what constitutes the subject matter of the school curriculum for scientific literacy.

Scientific literacy as a curricular vision

Scientific literacy takes the form of a curricular vision in the policy and institutional arena, with profound, all-encompassing meanings. Three metaphors—previously proposed by Scribner (1986)—can be used to capture the rich meanings of scientific literacy: literacy as adaptation (proficiencies necessary for effective performance in a variety of settings), literacy as power (enabling people to claim places in the world), and literacy as a state of grace (self-enhancing potential of literacy). Scientific literacy represents "a broad image that sets a high and desirable ideal standard for education" (Eisenhart, Frinkel & Marion, 1996, p. 282).

As a curricular vision, scientific literacy is used to convey the normative, ideological basis for determining the subject matter of school science. The meanings of scientific literacy need to be situated within a broad social, economic, and cultural context, and interpreted with attention to curriculum theories and discourses about the interplay between schooling, society and culture. Policymakers have invoked three types of arguments to promote scientific literacy, the <u>economic</u> (concerning the need for a scientifically literate workforce for economic growth), the <u>political</u> (concerning the need for a scientifically literate public in a democratic society), and the <u>cultural</u> (concerning the universal values of universalism, individualism and rationalism)

(McEneaney, 2003). Each type of arguments, in a varying degree, has the power to shape what counts as the subject matter of teaching and learning for scientific literacy.

However, while the notion of scientific literacy is broad and inclusive at the institutional level, it becomes narrow and problematic when translated into curriculum. The economic, political, and cultural forces that shape the meanings of scientific literacy tend to be obscured if not overlooked altogether.

Scientific literacy and school science

Scientific literacy is given programmatic forms when translated into curriculum documents and materials. The translation entails reinventing school science in a way that on the one hand, honors scientific literacy as a curricular vision, and on the other, takes into consideration of curriculum practice in school and classroom. School science for scientific literacy, Peter Fensham (1985) argues, needs to transcend the familiar discipline-based school science. It is for all students as future scientifically-literate citizens, requiring "a broader knowledge base from which to draw its knowledge of worth than single disciplinary sciences can provide" (Fensham, 2004, p. 158). At the heart of the translation are curriculum issues concerning the selection, organization and transformation of knowledge so as to become the subject matter of school science for scientific literacy.

However, translation has been construed narrowly and problematically. Two typical approaches are found in the literature, namely the "focus-on-sciences-and-scientists" and the "focus-on-situations" approaches (Roberts, 2007). The former is exemplified in a series of Project 2061 documents (AAAS, 1990,1993, 2000, 2001), in which the disciplines of science and the practices of scientists are employed as the central frame of reference for defining and delineating what should constitute scientific literacy. The subject matter of school science is then selected and arranged with a high emphasis on teaching important scientific concepts and principles and providing opportunities for students to engage in the practice of "real scientists." This approach overlooks alternative kinds of human knowledge and ways of knowing as the potential sources of subject matter. In addition, it does very little to address learners who are culturally and linguistically diverse. Furthermore, it does not account for "the fundamental relationships between individual and society, knowledge and power, or science, economics, and politics" (Roth & Barton, 2004, p. 3).

The focus-on-situations approach emphasizes starting with social situations which require the application of scientific knowledge, situations that students are likely to encounter as citizens. Subject matter is identified and arranged based upon an analysis of the situations, and can be derived from a wide range of sources. This approach, exemplified in Roth & Lee (2004) and Roth & Barton (2004), is claimed to be effective in enhancing "scientific literacy" for diverse learners, with the promise of addressing power relationships within a political context. However, this approach focuses primarily on the teaching and learning of small pieces of content, with little attention to the institutional and programmatic curriculum context in which the pieces fit. It tends to overlook the function of schooling as a public institution in providing the cultural content required for a variety of roles in the society—the function that necessarily goes beyond private interest and power (Reid, 1992).

Whether in the focus-on-sciences-and-scientists or in the focus-on-situations approach, the implications of a broad social, economic, and political context for what should count as scientific literacy—and/or what should constitute the subject matter of school science for scientific literacy—have not received sufficient attention from the

science education community (Canter, 2005a & b). Issues concerning the selection, organization, and transformation of knowledge for the subject matter of school science remain only partially-addressed.

Scientific literacy as instructional activities

At the school or classroom level scientific literacy takes the form of a sequence of instructional events jointly developed by a teacher and a group of students within a particular context (in school or out). The development of these activities is grounded in their understanding of the potential of the programmatic curriculum—represented by curriculum documents and materials. The programmatic curriculum embodies a "theory of content" (Doyle, 1992b)—a model or theoretical framework about the selection, organization, transformation, and elaboration of knowledge for the subject matter of school science. Understanding the subject matter of school science entails understanding what the scientific ideas to be taught are, what potential the ideas have for cultivating scientific literacy in students, and what it means to know the ideas, and what goal one is accomplishing when one is teaching the ideas.

However, what is involved in knowing the subject matter of school science for scientific literacy is an issue largely ignored in the literature.

Conclusion

What constitutes the subject matter of school science for scientific literacy is a cause of concern across all three basic domains of curriculum. Interrogation of subject matter demands that we be aware of and attentive to all three curriculum domains and their relationships, informed and enriched by epistemologies and various curriculum theories and discourses. Subject matter thus becomes an important topic of curriculum inquiry, with three areas of research identified.

The first area concerns the substantive meanings of subject matter at the institutional level. From an instititionalist perspective, subject matter is required for a variety of roles in a modern society. It is "necessary for society as it is and for society as it is to become future imagined community" (McEneaney & Meyer, 2000). What should account as scientific literacy? What should constitute the subject matter of school science for scientific literacy? Inquiry into these issues needs to be situated within the changing social, economic, and cultural context, with attention to various theories, models and discourses about the interplay between schooling, society and culture.

The second area concerns the formation of school science for scientific literacy, at the heart of which lie issues about the selection, organization, and transformation of knowledge for the school curriculum. What should count as knowledge? What are the various kinds of knowledge or ways of knowing that could be the potential sources of subject matter for scientific literacy? How should various kinds of knowledge be selected, arranged, and transformed into the subject matter of school science? Addressing these questions requires paying attention not only to epistemologies but also to different curriculum theories and models concerning the construction of school subjects or programs.

The third area concerns the meaning of the subject matter at the school or classroom level, the investigation of which requires examining the structures and process by which the subject matter of school science is interpreted and constructed by teachers and students. It also requires attending to theoretical frameworks, perspectives or models that are useful for analyzing the subject matter of school science—examples of which can be found in Deng (2007) and Klafki (2000).

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How to connect concepts of science and technology when designing context-based science education

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The development of a new chemistry curriculum as an example

> 'Can't we redesign some of these curriculum units? What I miss is the verb 'to synthesise' in the description of your contexts. Please let us shape a chemistry curriculum such that students have a notion that products such as pesticides don't grow on trees and aren't just available when it is convenient to us. Such products need to be *synthesised, produced by humans*, and we need the stuff to grow our food. Let us focus on that and not solely on the description how molecule such and such is structured and named.'
>
> *Quotation prof. Gerard van Koten, chair committee 'Nieuwe Scheikunde voor havo en vwo' [New Chemistry for secondary education in the Netherlands (Driessen & Meinema, 2003)], meeting with coaches April 25th 2007.*

This example refers to a genuine plea to have students experience the interrelation between societal issues and scientific knowledge. Instead of preparing students for a future education in science as a main curriculum emphasis, the quote gives emphasis to make students realise that they live their lives with a certain quality. And inevitably, that scientific and technological knowledge can have a desirable or undesirable impact on their lives. In fact, the quotation can be interpreted in terms of the transition from Science Literacy to Scientific Literacy (a shift from vision I $\rightarrow$ vision II) as is discussed by Roberts (Roberts, 2007).

On this morning on April the 25th, I was chairing a session with the seven coaches who are supervising Dutch working groups of teachers. In these groups, teachers and coaches together design new context – concept units for secondary school. Several new units are available and at the present time the coaches together plan to sequence the set of these units into a curriculum outline.

This innovation process develops according to a bottom-up approach. It should allow a long term dynamic development to avoid that a curriculum innovation leads to a new fixed curriculum for the next 25 years (or longer…). Scientific and societal issues develop fast, and therefore school curricula should take up recent developments when education aims to actively involve students in the meaningful learning of chemistry. Secondly, to allow the necessary professional development for teachers to take place, the active involvement of teachers in curriculum design is preferred over the 'traditional' in-service courses for the implementation of new curricula. This Dutch development consequently follows the innovation approach of Chemie im Kontext (ChiK) in Germany (Parchmann et al., 2006).

I had prepared this session by summarising the input of the coaches. I had asked them to characterise their units with a set of eight questions. Subsequently, I used their input to facilitate the sequencing of the units with a picture as is shown in Figure 1. As a group, we need to come to a curriculum outline in which students can conceptualise a set of core

concepts by involving them in inspiring and relevant contexts. As a second outcome, such a picture must help us to develop an explicit framework for the context-based units.

There is a sense of urgency. The Ministry of Education urges (as ministries of education tend to do…) the committee to come to a national examination experiment with a few selected schools. And new curriculum units should be communicated to the participating schools.
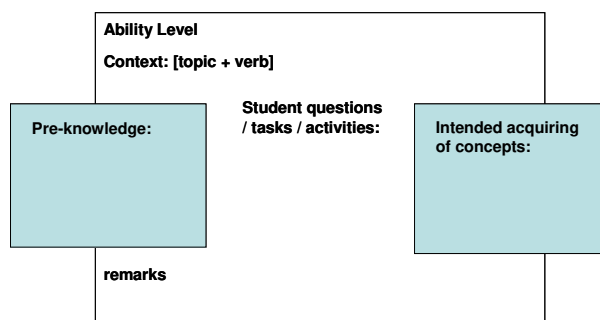

Figure 1 Format for summarising the set of developed context-based curriculum units

While discussing each unit during our session, the above remark was made. Furthermore, after the sequencing activity, two additional problems came up. First, one of the coaches remarked: 'what seems to me is that the described concepts do not fit with the described student activities for some units'. Second, a coach said that the argumentation for linking the units mostly came from the traditional chemistry contents. The new chemistry domains, 'Life & Chemistry', 'Material Innovation' and 'Sustainable Development', were not expressed in the sequence of the units. The contents of the traditional chemistry curriculum, also its predominant emphasis, 'Solid Foundation', implicitly guided the discussion. Again I like to refer to the quotation in the beginning of this text: a tendency to focus on *describing* substances in stead of focusing on activities such as *synthesising*.

Although in an previous meeting the entire group of coaches expressed their vision to mainly include the new Chemistry Domains in the examination experiment and to focus on meaningful student learning, the struggle here is to escape from the traditional body of knowledge, referred to as 'school chemistry' (De Vos, Bulte, & Pilot, 2002).

Two essential questions can be taken from this.
1. How to fit meaningful student activities in a context to facilitate the learning of relevant chemistry concepts?
2. How to make explicit a conceptual outline within new chemistry domains, e.g. Life & Chemistry, Material Innovation and Sustainable Development?

Such questions are essential when dealing with any science curriculum innovation when at least part of the curriculum should be shifted from the traditional emphases 'Solid Foundation' and 'Correct Explanation' (vision I?) to 'Science Technology and Decision' (vision II?) (Roberts, 1988). Therefore, in our science education community we must ask ourselves the question how the two questions above can be addressed by the input of *science education research*? In this paper I would like to present some strategies, research outcomes, and (speculative) outlines.

Contribution from science education research

In our curriculum research, we wished to take Roberts' message about curriculum emphasis seriously (Roberts, 1988). There should be no mixing of emphasis; no mixed, confusing messages to students about what why should to be learned.

The article 'A research approach to designing chemistry education using authentic practices as contexts' (Bulte, Westbroek, De Jong, & Pilot, 2006) illustrates how we have investigated a framework for context-based chemistry education, in which the characteristic principle is incorporated to sequence student activities and the learning of concepts on a need-to-know basis. In three research cycles, we have studied the extent to which students experienced the sequence of activities as meaningful for one particular curriculum unit about the quality of water. That is, they should experience the relevance of each activity when addressing the context question. The unit therefore should not include any confusing activity, with mixed messages about what is why to be learned.

In the next, I will discuss the development of a framework for context-based units, which we have investigated through a detailed study with one particular curriculum unit about the quality of water. This was taken as an exemplary context, because it is considered as a rich theme that can be discussed from a societal perspective (towards vision II?). We developed in this study three frameworks. The method we used can be described as design research (Lijnse, 1995) in which a unit was designed, explicitly based on a theoretical and empirical basis, related to expected learning processes and outcomes, evaluated with these expectations as criteria, and leading to conclusions about the theoretical basis.

The first framework: 1-2-3 model

The first framework consists of three parts. It resembles the model used for the development of a context-based physics curriculum in the Netherlands (Eijkelhof & Kortland, 1988); see Figure 2 left. Part 1 of the unit starts with a motivating context question: is this drinking water, swimming water, or water that can be used for the Zoo's aquarium good enough for its purpose? Is its quality good enough? In part 2, students need to acquire the theoretical knowledge to address the context-questions: about norms and parameters for determining the quality of the water. How much of what stuff is allowed in the water, and how can this be measured in a trustworthy way? In part 3, students deal with their context question and perform inquiry projects to find an answer to their questions using the theory of part 2.
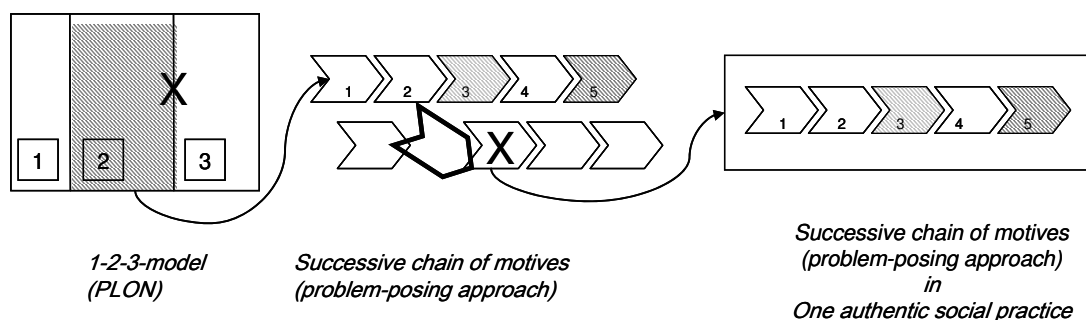

1-2-3-model
(PLON)

Successive chain of motives
(problem-posing approach)

Successive chain of motives
(problem-posing approach)
in
One authentic social practice

Figure 2 The three frameworks for context-based units in this study

The evaluation of the enactment of this unit in class revealed that students enthusiastically dealt with their context-question (part 1). They also studied the concepts of norms and parameters, and how to reliably measure quality. They also enthusiastically did their inquiry. However, they did not apply the concepts of part 2 during their inquiry project in part 3. In other words, the students did not experience their learning in part 2 as meaningful for the activities in part 3.

In the reflection on this framework, we concluded that the sequence of learning activities, especially in part 2, had not emerged from the *students' own experiences.* Its sequence and the general knowledge involved (part 2) is considered relevant from an *experts' point of view,* from the perspective and the context of those who already have acquired this knowledge. We as designers perhaps remained too close to the perspective of vision I, and did not reason from the perspective of the learner related to vision II?

Therefore, an adapted framework should adequately embody a 'need-to-know' principle from the perspective of the learner; the sequence of activities should be planned from the perspective of the students. S/he should see the relevance of each learning activity and the reason why to extend his or her knowledge in a certain direction.

The second framework: a problem posing approach

The adaptation resulted in a five phase problem-posing framework (Figure 2, middle). Part 1 of the unit now deals with a set of interrelated problems, e.g. about water quality, drinking water, swimming water, aquarium water. Part 2 focuses on one exemplary problem, drinking water, to allow students to focus collaboratively on the experimental determination of the quality using the norms and parameters of drinking water. The recurring question is: "Can you already decide whether the quality of the water is good enough to drink it?". This question results in a chain of motives of students to extent their knowledge. If the answer is no, then what do you need to know to decide this? This cycle continues until the students decide that they know enough to formulate an answer. Part 4 should refocus on the other context questions about e.g. swimming water, aquarium water. What do we need to know to be able to judge the water quality in other cases? Part 5 should lead to the explicit formulation of the concepts students have used in part 3. In this framework students explicitly formulate the whole set of concepts afterwards in a reflection activity, after they have performed a complete meaningful task (during their activities in part 3).

Within the second framework, students had a first orientation on a set of problems in part 1, after which they focused on the exemplary problem of drinking water (part 2). In this part, we planned a student activity in which students could bring their water samples from different sources, and purify this water sample. This led to the question: 'Will you drink this water?' This would make the unit motivating and exciting. Would they have sufficiently purified their water by means of the separation techniques they applied? Better to do some experiments first to test the quality of the water. This would induce a strong need-to-know how to do this, we expected.

In the evaluation of this framework, however, we identified a rather disturbing issue. The activity to *produce* drinking water from surface water disrupted the flow of activities. The students and the teacher were very much involved with the distillation and filtration processes. This activity shifted the emphasis from 'how to *determine* whether a water sample

is clean enough for drinking?' to 'how can we *produce* water that is clean enough to drink?' This shift in context involved a shift in concepts, a shift to other concepts, such as different production techniques and the influence of different water samples on the product. Consequently, this actually distracted the students from their original focus: to judge the quality of drinking water. As a result the activities in the second framework were not directed to the intended concepts.

The use of a leading context question did not serve as a sufficient heuristic guideline for implementing a coherent 'need-to-know' principle. The designer of a curriculum unit may select activities that generate the intended content-related motives in students for a chosen context. However, an inadvertent mixing of different contexts can easily occur. Therefore, according to this problem analysis, the relationship between the use and choice of context and the 'need-to-know' principle must be strengthened.

The third framework: involvement in social practices

We therefore redefined 'context' as '(social) practice', since this not only defines the specific situation, but also the type of actions together with the necessary knowledge and attitudes to be able and willing to perform these actions. This redefinition of context is inspired by activity theory (Van Aalsvoort, 2004; Van Oers, 1998; Vygotsky, 1978). An authentic (social) practice is defined as a homogeneous group of people working on real-world problems and societal issues in a 'community' connected by three characteristic features (Bulte et al., 2006): A. common motives and purposes, B. working according to a similar type of characteristic procedure leading to an outcome (e.g. solution for a problem, product), C. with apparent necessary concepts about the issue they work on.

Several 'authentic practices' can be found in society, and related to chemistry (or science in a broader perspective). To participate in a practice and to work towards a solution to practice-related problems, skills, attitudes and knowledge in and about science play an essential role. Van Aalsvoort (2004) proposed to use different roles of social (chemical) practices by simulating these roles in the school setting. By experimenting with different roles of different practices, students are expected to perceive which roles appeal to them, and experience their activities as meaningful. In this adaptation of the framework we designed student activities such that they experience these as relevant, combining the approach of involvement in social practices with a problem posing approach (Figure 2, right). This has led to the principle of establishing an instructional version of an authentic practice.

Towards the formulation of principles of the framework

An authentic practice can thus serve as a source of inspiration, and moreover as a heuristic guideline for the precise selection of activities within one curriculum unit. In this process the original authentic practice is transformed into an instructional version of the authentic practice. This strategy allows the designer of the unit to create one clear, meaningful flow of activities. This is actually an address to question 1 of this paper, to make student activities fit to the concepts to be learned.

We therefore can formulate the following heuristic guidelines.

- If the design of a curriculum unit is based on an authentic practice as context, then only use those concepts that are needed within that practice.
- When a set of concepts needs to be implemented in an educational programme, select only those social practices in which these concepts play an essential role.

This also implies that, for defining new curriculum goals, a set of motivating and societal relevant social practices thus can reveal that a set of new concepts is needed. This guideline is actually an address to question 2, to make explicit which concepts students need for activities within new chemistry domains.
In fact, our definition of context into social practice is an operationalisation of Roberts' message about curriculum emphasis. One curriculum unit, one emphasis; in our definition this means: one curriculum unit, one social practice. Inadvertent mixing of practices is inevitably inadvertent mixing of curriculum emphases.

In recent studies we explored this third framework by analysing how professionals in authentic practices and tasks deal with structure – property relations (Meijer, Bulte, & Pilot, 2005) and modelling activities (Prins, Bulte, Van Driel, & Pilot, 2005). The extent to which these authentic tasks and practices can be adapted for students to learn the concepts involved in a meaningful way, is now the focus of our research.

Further curriculum development; an illustration

How can these outcomes of the studies and the development of such principles of a framework for the development of context-based science curricula address the two questions posed above? I would like to illustrate this with an example for concepts and contexts related to catalysis in the domain of Sustainable Development. This example involves three curriculum units.

Type of activity ('verb')	Social practice (as context)	Outline of the sequence in which concepts are to be acquired
Optimizing formulation of a product	1. Development department of company that produces detergents with new (composition of) enzymes;	Qualitative aspects of catalysis -Selectivity & -Activity of a catalyst Quantitative: -optimal activity
Producing biofuels	2. Production company that aims to produce biofuels commercially	Qualitative aspects of catalysis - selecting appropriate catalyst; synthesis is influenced by specific 'active sites' of catalyst (structure – property relations) Quantitative: -optimizing production process
Investigating & developing 'green' production processes for pharmaceuticals	3. R&D department and academic research groups to shift 'traditional' synthesis to bio-catalyst based pathways	Qualitative & quantitative aspects -Investigating the influence of different active sites of catalysts

Increase in complexity of activity and conceptual understanding

Figure 3 Example how to sequence contexts and the connected learning of concepts of catalysis

Figure 3 shows a succession of three contexts (practices) (1 → 3) in which students can acquire concepts of catalysis with an increasingly complexity of the student activities. But also the complexity of the knowledge structure increases. This match between context related activities and conceptual understanding may be taken as a heuristic guideline for sequencing units within a curriculum. This example shows how concepts within new chemistry domains can be made explicit and can be used in the argumentation to sequence context-based units.

The developed framework of social practices also makes explicit that the choice of a context implies the choice of an activity, a 'verb'. This notion seems to be important when designing curricula that aim to implement scientific literacy. To avoid the predominant emphasis on describing substances and structures, a focus on activities like *production*, *synthesis* and *design* (e.g. of new synthetic pathways) should be used in order to meaningfully involve students in the contemporary socio-scientific and technological practices and to induce the learning of those concepts that are scientifically and technologically relevant.

In conclusion

I have speculated how a framework, based on involvement in social practices, can contribute to the implementation of scientific literacy (in stead of science literacy, vision I → vision II). It is however all but trivial to develop an adequate framework for designing such curricula. I therefore consider the further development of design research methodologies (beside descriptive research approaches) (Lijnse, 1995) as an essential aspect of our science education community. I look forward to share with you my experiences about the interplay between curriculum development and science education research.

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Promoting Science Inquiry – New possibilities using ICT

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I entered science education as a graduate student at UC Berkeley in 1979 – in the beginnings of the "constructivist" period as described by Erickson (2007 Symposium Proceedings). Early curriculum development projects took into account the need to illuminate pupil thinking so that we could uncover and eventually "correct" alternative conceptions in scientific concepts. The use of activities to explore new concepts, followed by new ideas related to these concepts was our recipe for creating new curriculum units. The evidence for learning was the ability of the child to use newly acquired concepts in new and old situations, using the correct scientific language in the process. As was mentioned in the review paper by Erickson, we have never really seen large-scale evidence that this type of science instruction is functional in school settings.

Our recent efforts to design science curriculum have been directed towards the use of information technology. Following the lead of the WISE[1] project developed at the University of California by Marcia Linn and colleagues, the Viten[2] project was developed in Norway. The curriculum units we are designing today represent a transition between Erickson's phase 2 (constructivism) and phase 3 (Phenomenological). At the same time they may be described as attempts to combine Robert's Vision 1 (product and process) and Vision 2 (knowing about science) into the same curriculum units. We recognize that science content is important and needs to be included in the curriculum, yet strongly mean that science is made relevant to students by placing it into contexts that have meaning to their lives as members of a society.

ICT and inquiry learning

WISE stands for Web-based Inquiry Science Education. As we know, there are many different ways to define and interpret the word Inquiry in science education. Both WISE and Viten use the following which includes ideas of argumentation:

> Inquiry is the intentional process of diagnosing problems, critiquing experiments, and distinguishing alternatives, planning investigations, researching conjectures, searching for information, constructing models, debating with peers, and forming coherent arguments (Linn, Davis, & Bell, 2004).

Typical Viten projects are embedded within socio-scientific issues (SSI) so that political, social, and economical decision-making processes are connected to modern issues in science. We embrace the ideas of Lemke, 2001 stating that, "students and

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[1] http://wise.berkeley.edu

[2] viten.no See also genetechnology.viten.no and northernlights.viten.no for English versions of newer programs.

teachers need to understand how science and science education are always a part of a larger communities and their cultures, including the sense in which they take sides in social and cultural conflicts that extend far beyond the classroom".

Both WISE and Viten are guided by the Scaffolded Knowledge Integration (SKI) framework for instruction (Linn and Hsi, 2000) with its 4 basic meta-principles: make science accessible; make thinking visible; help students learn from others; promote autonomy and lifelong learning. Each of these principles may be translated into design strategies for web-based curriculum. Using the Wolf controversy project developed in Norway (Jorde and Mork, 2007) we may exemplify the principles as follows:

Making science accessible – we design tools that allow students to consider their existing ideas and later to connect them to the new ideas found in the project. Students are placed within the authentic controversy about wolves in the landscape in Norway. Throughout the project they collect current data from the net and are encouraged to reflect on their personal opinions and values related to the data. At the end of the program students are placed into roles (sheep farmer, environmentalist, etc) for a classroom debate. Projects combine live web-sites (URL's) for current information, together with traditional science information (created using interactive text, simulations, animations, etc)

Make thinking visible – The Viten environment allows students to make reflective notes as they work through the project. The notes are often prompted by questions to be answered, forcing students to respond to new information. This action also sends students back into the program if there are interactive texts, pictures or animations that need to be re-visited. Teachers are able to look at student notebooks on-line or as they engage with students in the classroom. The debate at the end of the program clearly illuminates the way students are able to use scientific concepts in their argumentation and allows teachers to follow-up on student understanding of concepts.

Help students learn from each other – Viten and WISE projects embrace the social nature of learning (Linn, Davies, et al, 2004). Students work in pairs throughout the project, sharing one computer. Talking about multiple ways of viewing a socio-scientific issue in a public forum allows students to hear what others are thinking and meaning.

Promoting autonomy and lifelong learning – Critical reflection on the use of information found on the Internet is one of the greatest challenges we have in using modern teaching environments. As curriculum designers we believe our role is to guide students in understanding how available information may be evaluated, used and misused.

In the Wolf controversy project the overall goals for students are that they:
- Learn about fundamental ecological ideas including food chains and webs, predator-pray relations and ecological management, especially as related to wolves in the environment
- Learn about different viewpoints in a socio-scientific controversy in the Norwegian society
- Engage in the construction of arguments and the practice of debate

- Engage in the use of ICT as a took for gather and evaluating information

Our curriculum projects combine goals of scientific literacy together with those of basic literacy. In addition, we include computer literacy since this is an important basic skill in the Norwegian national curriculum and is easily taught through the use of web-based curriculum projects.

In our assessments of student argumentation in the Wolf project, we have looked critically at the use and construction of argumentation in the final debate. Our analysis included arguments based on biological, economic, social and political arguments – all of which are present in the project materials (Jorde and Mork, 2007).

Challenges to Modern Curriculum Development

ICT based science curriculum is opening up many new possibilities in science teaching that never existed before. I truly believe that most of these changes are advantageous, especially in modern cultures that have integrated the use of computers into the daily lives of our youth. If we ignore the use of ICT in science teaching we will be creating a wide gap between the artifacts used in a modern society (and by the youth culture) and those used to teach science.

There are and will continue to be challenges for using new methodologies in teaching science and I wish to list some of them to contribute to our discussions on the role of science curriculum and scientific literacy.

Web-based curriculum changes the role of the teacher and student by placing the knowledge base and reflective questioning closer and more accessible to the student. How much ICT based instruction is beneficial compared to other ways of teaching science? How far do we want to press this way of teaching science?

It is clear that animations enacting the processes of DNA replication are easier to understand for most students than still pictures. How do we then integrate visualizations with the proper amount of text? What do we know about reading text on the screen? How is scientific literacy connected to reading literacy?

Viten has been a success in Norway if we look at numbers of classrooms using the projects (of which there are over 20). What are the factors that contribute to its success? How do we assess student progression and learning in ICT based environments? We are experimenting with argumentation as an indicator for conceptual development. But what about the other criteria of scientific literacy connected to citizenship? How do we assess a student ability to find and critique information found on the web?

Viten projects are most often used to enhance science teaching and are seen an additional resource for teaching rather than a replacement for existing methods. Is this a good strategy? Are we ready to replace textbooks with web-based materials?

How do we determine what is relevant science content? Do we follow the lead of curriculum frameworks or do we follow the important debates found in society? Or do

we listen to what students think is relevant? What should the balance be between science content (its products and processes) and knowledge about science?

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