Scientific Literacy for a Knowledge Society

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Scientific Literacy for a Knowledge Society

Glen Aikenhead, Graham Orpwood, and Peter Fensham

The role of science education in preparing students for the world of work was taken seriously by OECD (1996a,b) when it launched studies on how the world of work was changing, especially in science-related occupations. At about the same time, the Royal Society for the Arts, Industry, and Commerce initiated a similar study in Britain (Bayliss, 1998). Together these studies found that the nature of work in developed countries has changed in three ways: in kind, in the requirements for performance, and in the lack of permanence of one's engagement. These changes in the world of employment are driven by new forms of information technology, design requirements, and technology transfer. For example, oral and written literacies are no longer adequate; digital literacy is a new essential. The resulting new knowledge enables innovation of processes and products, locally and globally.

This new knowledge is increasingly becoming a primary source of economic growth in *knowledge-based economies*. Taken together, these changes characterize a *Knowledge Society* (Gilbert, 2005). A knowledge-based economy and a Knowledge Society create a need to re-examine SL in developed countries.

The chapter begins with an account of the features of a knowledge-based economy and a Knowledge Society, as these features affect the interpretation of SL. A policy position about SL-in-action is developed and analyzed in terms of considerations that would confront decision makers who determine school science curriculum policy. Special attention is paid to the choices that exist in types of school science content, and to the powerful influence of educational assessment practices.

A Knowledge-Based Economy

In a knowledge-based economy, knowledge takes three forms: codified, tooled, and personal (Chartrand, 2007). Codified knowledge is communicated in many different forms as *meaning*. Both sender and receiver must know the code if the message is to convey semiotic or symbolic meaning (Foray & Lundvall, 1996). *Newly* codified knowledge is often converted into legal property held by a company or institution: property that can be bought and sold through copyright.

Tooled knowledge is also communicated in many different ways but always as *function* (Chartrand, 2007). It is often protected by patents. Tooled knowledge takes two forms: hard and soft. Hard tooled knowledge is a physical implement or process that manipulates or responds to matter-energy. A scientific instrument is tooled knowledge that can extend human perception into domains referred to as electrons, quarks, galaxies, and the genomic blueprint of life, for instance. To accomplish this, scientific tools probe beyond human perception to produce numbers, which are often converted into graphics. Numbers and graphics are in turn treated by scientists and technologists as observations. Thus, many scientific observations today involve a cyborg-like relationship between a human and an instrument – "instrumental realism" (Ihde, 1991). Soft tooled knowledge, on the other hand, includes the standards embedded in an instrument (e.g., its designed voltage – 12, 110, or 220), as well as the instrument's programming, its operating instructions, and the techniques required to optimize its performance. Technology transfer, a key process in economic growth, involves tooled knowledge (soft and hard) being transferred from one company or institution to another.

Personal knowledge contrasts with both codified and tooled knowledge due to the fact that personal knowledge consists of bundles of memory and trained reflexes of nerve and muscle of a scientist, engineer, or technician (Chartrand, 2007; Foray & Lundvall, 1996). Importantly, some personal knowledge can be codified or tooled, but some inevitably remains tacit (Polanyi, 1958). Personal knowledge is legally protected as *know-how*.

Ultimately, however, all knowledge in a knowledge-based economy is personal knowledge because without a human to decode or push the right buttons, codified and tooled knowledge remain meaningless or functionless (Foray & Lundvall, 1996). This has implications for science education in a society propelled by a knowledge-based economy. It means that a country's knowledge-based economy relies, in part, on its people and their ability to code and decode semiotic or symbolic *meaning* and machine-instrument *function*. This know-how is one indicator of competitiveness in the global economy, and thus it is an important consideration for SL in a knowledge-based economy.

A country's scientific and technological know-how is characterized by a blend of knowledge and action. Codified knowledge is about *communicating*; tooled knowledge (soft and hard) is about *functioning*; and personal knowledge is about *participating* in some way in the economy. The purpose of 'knowing' and 'having knowledge and know-how' is thus linked to innovation in science-related occupations.

In the context of a knowledge-based economy, it is evident that the disciplines of science and technology are socially interrelated to such an extent that they form one heterogeneous domain – "technoscience" (Désautels, 2004; Fleming, 1989). For instance, R&D (research and development) is a conventional form of technoscience. Désautels, among others, has argued for this broader focus in school science. In this chapter, we adopt Désautels's technoscience formulation and draw on Hurd (1998) in designating technoscience as "science-technology" (ST).

Any perspective on SL that restricts its meaning to *codified scientific* knowledge will be inadequate for students' future participation in their country's knowledge-based economy. Such a perspective ignores tooled and personal knowledge, and it ignores technology.

A Knowledge Society

When the engine of a country's economy is knowledge-based, we have a Knowledge Society, in which the meaning of wealth creation has changed. "Where wealth was once related to resources and industrial processes, it is now a consequence of ever-renewing knowledges necessary to innovate, design, produce, and market products and service" (Carter, 2008, p. 621).

In an earlier work about the Knowledge Society, Gilbert (2005) explored the educational implications of these societal changes, based on a comparison to existing conditions in most educational systems:

1. knowledge is about acting and doing to produce new things, rather than being only an accumulation of established information; and
2. what one does with knowledge is paramount, not how much knowledge one possesses.

Consequently in a Knowledge Society, value is associated with:

1. knowing how to learn, knowing how to keep learning, and knowing when one needs to know more, rather than knowing many bits of content from a canonical science curriculum;
2. knowing how to learn with others, rather than only accumulating knowledge as an individual;
3. using knowledge as a resource for resolving problems rather than simply as a catalogue of 'right' answers; and
4. acquiring important competences (skills) in the use of knowledge, rather than only storing it.

Change is the norm in a Knowledge Society. It follows that learning in such a society should have a dynamic character that equips students to adapt to change, to generate new knowledge, and to continue to improve performance (Bybee & Fuchs, 2006; Fraser & Greenhalgh, 2001).

Implications for SL

A Knowledge Society relies on expertise in science-technology (ST) employment, and on the capacity of its citizens to deal with ST-related situations in their everyday lives. Participation in a Knowledge Society by employers, employees, and citizens calls for knowledge to be treated in conjunction with acting – 'knowing-in-action' – and not as stored facts, abstractions, and algorithms. Both expert knowledge and citizen knowledge are reconceptualized in this chapter in terms of *ST knowing-in-action*.

Some research programs in science education already support a Knowledge Society. These programs treat knowledge as contextualized social action – knowing-in-action. For example, Gaskell (2002) maps out partnerships between science education and industry, in which "knowledge is to be learned in the context of doing … 'working knowledge,' as opposed to abstract propositional knowledge" (p. 64). Further examples include research programs described by Roth and Calabrese Barton (2004) and by Roth and Lee (2004), and informed by activity theory associated especially with Lave and Wenger (1991).

Competence at ST knowing-in-action (i.e., competence at ST-related work skills or competence in resolving ST-related events and issues) is not simply a matter of 'applying' knowledge mastered in a conventional science classroom. A curriculum change, and thus a curriculum policy change, is required. Most science content in the typical curriculum is not directly useable in ST-related occupations and everyday situations. There are several reasons for this, established by research on situated cognition: "Thinking … depends on specific, context-bound skills and units of knowledge that have little application to other domains" (Furnham, 1992, p. 33).

The first reason is that a conventional science curriculum's content must be deconstructed and then reconstructed and integrated into the idiosyncratic demands of the specific everyday context (Jenkins, 1992; Layton, 1991; Ryder, 2001). "This reworking of scientific knowledge is demanding, but necessary as socio-scientific issues are complex. It typically involves science from different sub-disciplines, knowledge from other social domains, and of course value judgements and social elements" (Kolstø, 2000, p. 659).

Second, school knowledge tends to be compartmentalized in most students' minds, separate from their out-of-school (life-world) knowledge, and the two sources or knowledge systems simply do not interact (Hennessy, 1993; Solomon, 1984). The third reason is that science content used in ST-rich workplaces tends to be *procedural* scientific knowledge (knowing-in-action), which is simply different from the *propositional* knowledge of canonical school science (Gott, Duggan, & Johnson, 1999; Law, 2002). Because different science content is applicable in each setting, there is very little transfer of knowledge. Fourth, the *purpose* and *accountability* of the workplace and the science classroom differ dramatically. Consequently, workplace science is qualitatively different from school science (Chin et al., 2004).

These established research findings have significant implications for SL as a curriculum concept. SL in a Knowledge Society is necessarily literacy-in-action – oral, written, and digital literacy-in-action. Consequently SL as an educational outcome takes on an active, rather than a passive connotation. SL is not about 'How much do you know?' but instead, 'What can you learn when the need arises?' *and* 'How effectively can you use your learning to deal with ST-related events in the work world or the everyday world of citizens?' The shift in outcome – from 'knowing that' to 'knowing how to learn and to use this relevant content' – would represent a radical shift in school science curriculum policy. At the same time, it would resonate with the goals for a knowledge-based economy discussed by Gilbert (2005), and also by Guo (2007). In short, acquiring knowledge ('knowing that') would be replaced by *capacity building* ('knowing how to learn and knowing-in-action') as the primary mission for school science. For a Knowledge Society, the primary meaning for SL becomes *SL-in-action*.

In terms of Roberts's Visions I and II of SL (Chapter 1, this volume), our proposed school science policy position suggests a shift away from Vision I, given its concentration on theoretical reasoning and its inward-looking focus on the products and processes of science itself. Instead, ours is an intermediary position between Visions I and II, but favoring Vision II, given its concentration on a combination of theoretical, technological, and practical reasoning and its outward-looking focus on ST-related situations.

SL-in-action requires that students come to understand their ST knowledge as having a purpose beyond simply 'knowing that.' Examples of such purposes include: getting and keeping ST-related employment, informing daily activities, analyzing socio-scientific issues, and comprehending global concerns. As a curriculum concept, SL-in-action is highly promising as a way to increase the relevance of school science, and to engender habits of life-long learning.

Choosing School Science Content: A Theoretical Framework

Because we treat SL for a Knowledge Society as knowing-in-action associated with capacity building for life-long learning, we reposition ourselves in this chapter with respect to what counts as worthwhile knowledge to teach and assess in science education. To achieve SL-in-action for a Knowledge Society, we require an innovative way to determine the *content*, *processes*, and *contexts* for school science. Together this triad will be called "school science content." Content without context is ephemeral. Processes without content or context (i.e., generic skills) are powerless – a lesson learned from the failure of *Science: A Process Approach*, a 1960s elementary science program in the United States, and its counterpart in the United Kingdom, *Science 5-13* (Millar & Driver, 1987).

We emphasize a distinction between the *canonical* science content found in conventional science curricula, on one hand, and on the other hand, *relevant* science content – the type of science content actually used by employees in ST-related occupations and by the public coping with ST-related events and issues. In short, the distinction is between academic decontextualized knowledge (Roberts's Vision I to the extreme) and relevant contextualized knowing-in-action (Vision II), respectively.

We propose a theoretical framework for school science content based on two principles: *relevance* and *who decides* what is relevant for SL-in-action. The two principles are depicted in Table 2.1. Who decides what is relevant is represented in column 1; and column 2 represents, as a consequence, various types of school science content. Our framework recognizes seven groups of people who currently decide, or who could reasonably decide, what is to be included in school science content. The categories, based on the work of Fensham (2000) and Aikenhead (2006), are not discrete but overlap and interact in various ways. To work toward achieving SL-in-action for a Knowledge Society, curriculum developers can draw from several of these categories, and the resulting curricula will most likely consist of different combinations of categories.

[INSERT TABLE 2.1 HERE]

A conventional school science curriculum emerges from the first category, "wish-they-knew science" in Table 1. This category embraces the subject matter of scientific disciplines (the science curriculum). Wish-they-knew science predominates in Vision I versions of SL.

The other six categories in Table 1 reflect the work world of employers and employees, as well as the everyday world of citizens, in which ST content pertains to phenomena and events not normally of interest to most university science professors (scholarly academics), education officials, and currently many science teachers. The other six categories represent knowing-in-action, by and large, and are therefore supportive of SL-in-action for a Knowledge Society. They reflect an emphasis on Vision II SL.

Space does not allow us to review the research related to each category in Table 1 (see Aikenhead, 2006, Ch. 3), but two categories are summarized here, "functional science" and "have-cause-to-know science." They clarify suitable school science content for SL-in-action.

Functional Science

Functional science is the science content that has functional value to ST-rich employment and to ST-related everyday events. Systematic research has produced a wealth of general and specific results. For example, industry personnel placed 'understanding science ideas' at the lowest priority for judging a recruit to their industry. Why? The answer comes from the ethnographic research by Duggan and Gott (2002) in the United Kingdom, Rodrigues and colleagues (2007) in Australia, Law (2002) in China, Lottero-Perdue and Brickhouse (2002) in the United States, and Aikenhead (2005) in Canada. The researchers' *in situ* interviews with people in ST-related occupations indicated that the science content used by these science graduates in the workplace was so context specific it had to be learned on the job. High school and university science content was rarely drawn upon.

Thus, an important quality valued by both employers and employees in ST-related employment is the *capacity to learn* ST content on the job. Of course, school science content for the purpose of preparing students for ST-related occupations must include science concepts, but the choice of these concepts can be a functionally relevant choice, not a scholarly academic choice (i.e., opting for wish-they-knew science). The science content that underpins local contexts of interest works better for teaching students *how to learn and use* ST as needed (Aikenhead, 2006, Ch. 6).

Have-Cause-to-Know Science

This category represents science content identified by ST experts who consistently interact with the general public on real-life matters pertaining to ST, and who know the problems citizens encounter when interacting with these experts (Fensham, 2002). Out of the diverse research reported in the literature (see Aikenhead, 2006, Ch. 3), the research program undertaken by Law and her colleagues (2000) in China clarifies have-cause-to-know science the best. Their project determined the have-cause-to-know science for two different curricula: one aimed at citizens' capabilities at coping with everyday events and issues, and the other aimed at socio-scientific decision making (Law, 2002; Law et al., 2000). For the first curriculum, societal experts (e.g., people who work with home and workplace safety issues; and in medical, health, and hygiene areas) agreed that the public had cause to know basic scientific knowledge related to an event with which people were trying to cope, and to know specific applications of that knowledge (knowing-in-action). Most of all, they should be able to critically evaluate cultural practices, personal habits, media information, and multiple sources of conflicting information (Law, 2002). During their interviews, the experts noted public misconceptions, superstitions, and cultural habits detrimental to everyday coping.

For Law's second curriculum (citizens' participation in socio-scientific decision making), experts were selected from Hong Kong's democratic institutions (the legislature, a government planning department, and a civilian environmental advocacy group) and were interviewed. The researchers concluded that the public's have-cause-to-know science for decision making was very similar to that required for everyday coping, except socio-scientific decision making drew upon more complex skills to critically evaluate information and potential solutions (Law, 2002). The societal experts acknowledged the fact that socio-scientific decisions often rely more on applying values than on applying specific science content, a result duplicated in the United States with academic scientists at several universities (Bell & Lederman, 2003).

Overall, the Chinese ST experts placed emphasis on a citizen's capacity to undertake self-directed learning (life-long learning), but placed low value on a citizen's knowing particular content from a typical science curriculum. This result is similar to the research findings for functional science.

Summary: Pertinent Considerations for Making a Policy Decision

SL that nurtures economic growth requires science education to promote capacity building in which future workers and savvy citizens learn *how to learn* ST as the need arises. Life-long learning for a Knowledge Society ensues. The school science content essential to achieve this end is not solely "wish-they-knew science," but instead any combination of categories of school science content (Table 2.1) that leads to SL-in-action.

Curriculum policy makers are expected to consider what Deng identifies as the "institutional" domain of curriculum making (Chapter 3, this volume). Policy makers can be assisted by considering examples of the implications for the other two domains Deng identifies: "programmatic" and "classroom." For instance, SL-in-action in the *programmatic* domain is exemplified by:

1. a project that designs context-based school science materials for authentic ST social practices (Bulte, Chapter xx, this volume), which combined functional and personal-curiosity science content;
2. a Canadian grade 10 textbook, *Logical Reasoning in Science & Technology* (Aikenhead, 1991), which combined functional, have-cause-to-know, personal-curiosity, and wish-they-knew science content;
3. an AS-level textbook in the United Kingdom, *Science for Public Understanding* (Hunt & Millar, 2000), which combined enticed-to-know, have-cause-to-know, and wish-they-knew science content;

4. the "public understanding of science" curriculum (*Algeme Natuurwetenshappen*) in The Netherlands (De Vos & Reiding, 1999), which combined have-cause-to-know, need-to-know, and wish-they-knew science content; and
5. the *Science, Technology, Environment in Modern Society* project in Israel (Dori & Tal, 2000), which combined functional, have-cause-to-know, and wish-they-knew science.

Our SL-in-action policy in the *classroom* domain is illustrated by, for example:

1. Carlone's (2003) research program about physics teachers who offered *Active Physics* at their school, which combined wish-they-knew, functional, and personal-curiosity science content; and
2. Kortland's (2001) research program into students' learning how to make decisions in the context of a waste management module, which combined functional, have-cause-to-know, personal-curiosity, and wish-they-knew science.

Although concrete examples of program and classroom embodiments are useful to policy makers, assessment of students' learning is also a central consideration .We turn next to an exploration of the role of assessment in science education reform during the past several decades, and the potential implications for considering adoption of an SL-in-action policy for school science.

Potential Assessment Issues Surrounding SL-in-Action

Common sense dictates that there should be a strong, clear relationship between the substance of a curriculum and the assessment of students' learning based on it. The relationship can be complex, though, and the complexity becomes more apparent when the policy represents a considerable change from typical practice, as indeed SL-in-action would.

Orpwood (2001) recounts two well-known major shifts in science curriculum policy: the first was a shift to science processes and the structure of science in about 1960, and the second was a shift to STS/STSE, beginning early in the 1980s. In both cases development and acceptance of appropriate assessment procedures and strategies lagged by about 20 years behind adoption (on paper) of the new policy. In the former case, Orpwood notes that "The first significant 'performance assessments' ... were designed in England in the early 1980s by the Assessment of Performance Unit (APU, 1983) fully 20 years after the goal of instilling 'inquiry skills' in students had first been introduced into the curriculum" (p. 143). We also note the 20-year lag regarding the shift to STS/STSE. Only recently has the Assessment and Qualifications Alliance in England published its *General certificate of education: Science for public understanding 2004* (AQA, 2003). In about the same time frame, OECD's *Programme of International Student Achievement* (PISA) has made available some good examples of how to assess students on STS/STSE content.

The goal SL-in-action cannot wait 20 years for sufficient assessment procedures to be developed and implemented, as was the pattern for the previous two major shifts in science curriculum policy. Events in the world of work could well marginalize the canonical school science curriculum, making it more irrelevant than it is currently observed to be, as evidenced in the *Statement of Concern* at the beginning of this volume.

In the remainder of this section we offer an analysis of why educational assessment has such a powerful influence over the selection and implementation of science curriculum policy. The first part of the analysis examines four functions of educational assessment and some technical factors (notably validity and reliability) that are integral to understanding how different kinds of assessment serve different purposes. The second part is about power distribution in educational institutions. In the third part we apply these analytical insights to the case of SL-in-action, with particular reference to potential considerations for policy makers, educational researchers, and science educators.

Functions of Educational Assessment

Our first function of educational assessment concerns accountability. The public, media, and politicians in most Western democracies are increasingly demanding that education systems and individual schools provide evidence of their effectiveness, productivity, and 'value' for taxpayers' investment. In some countries, this has taken the form of 'league tables' of schools, based on the results of examinations designed for other purposes (e.g., GCSE and A levels in England & Wales). Elsewhere, international assessments such as *Trends in International Mathematics and Science Study* (TIMSS) and PISA are used as proxies for school and system effectiveness. Because of the authority that TIMSS and PISA command, their reports can have a profound impact on educational policy despite the very obvious limitations and inadequacies of their paper-and-pencil character and their objective to transcend local realities (Fensham, 2007). Finally, in some countries, special tests are designed with this accountability agenda explicitly in mind. In Canada, for example, the Pan-Canadian Assessment Program is a case in point.

A key expectation of assessments designed for accountability is the comparison among schools or school systems. The reliability of the assessment is therefore very important. For this reason, multiple choice tests are often used because these can be designed with high reliability for recall of factual information (i.e., superficial, codified, scientific knowledge, but not tooled knowledge, nor personal knowledge, nor technological knowledge). Recall is easier to assess with multiple-choice items than is the more complex knowing demanded by SL-in-action.

The PISA program was charged with assessing students' preparedness for 21st century life. Unlike TIMSS, the PISA program is not constrained to be a narrow test of school curriculum content. In its tests of reading, mathematics, and science in 2000, 2003, and 2006, PISA has demonstrated that compatibility between high reliability and the assessment of more complex knowing-in-action is possible with the use of a wider variety of item types.

Student certification and selection, a second function of assessment, is perhaps the most traditional role for assessment. Examinations are 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. This type of assessment can have the advantage of moving the certification role of education from the school level to an external (and supposedly impartial) agency level, thus ensuring an equality of standards countrywide. This advantage, however, becomes a disadvantage by inhibiting desired changes in curriculum policy and curriculum implementation when students can only be assessed by these externally designed assessment instruments, usually the paper-and-pencil type.

When the assessment of more complex goals is included, it has traditionally been engineered using open-ended or constructed-response items with the advantages and disadvantages that such items always have. They offer the student an opportunity to demonstrate their knowledge and skill in more diverse ways than with multiple-choice items. Thus, open-ended or constructed response items have greater validity. But reliable (consistent) marking remains a challenge. Moreover, the assessment is still confined to what can be written within a fixed (usually short) period of time.

In contrast, our vision of SL-in-action for a Knowledge Society emphasizes validity as being central to assessment. Students would be given time to solve a problem and the freedom to draw on a variety of resources, as is the case in ST-related employment in the everyday world. However, marking these types of responses requires one-on-one expert observation and evaluation of a student's performance. Although this is not impossible – music and dance have been evaluated this way for years – it is very rare in a science context, even though its validity is superior.

School improvement is a third function of educational assessment. Many people hold a view in which schools whose students achieve well in examinations are 'good schools' and that, correspondingly, schools with lower aggregate results are poor and are in need of improvement (a view we would argue is misguided). Assessment is therefore the basis for determining the quality of individual schools and for measuring whether they are improving.

In the Canadian province of Ontario, for instance, a whole new government bureaucracy has been developed with a view to improving school performance to meet government-set targets. On the face of it, this is a good plan. However, the use of assessment to label schools raises the stakes for schools, which can, in turn, have an undesirable impact on teaching and learning. In a recent study, for example, researchers found that some teachers try to avoid teaching a grade level in which provincial testing takes place; and that, in some schools, principals discourage teaching subjects that are not tested (Sinclair, Orpwood, & Byers, 2007).

In any agenda to improve school, assessments that mirror those designed for accountability can narrow the scope of the curriculum taught, as mentioned above. School improvement needs to be conceptualized more broadly. While assessment results can form a component, they should form only part of a broader description of the character and effectiveness of schools. For example, in the case of SL-in-action, analyzing the range of activities in which students are engaged can offer better evidence than statistics based on written tests narrow in scope.

A fourth function of assessment focuses on improving student learning. In recent years, science educators (e.g., Black & Wiliam, 1998; Bell & Cowie, 2001) have argued persuasively that the most important purpose for assessment, which they call 'assessment for learning' or 'formative assessment,' is also the most neglected. Assessment for learning aims squarely at the individual student's learning and is designed to have an immediate positive impact on that learning. It represents the antithesis of the other three approaches to assessment because: it is individual in its context; it is classroom-based; it is designed and practised exclusively by teachers; it lacks secrecy – indeed, the sharing of assessment criteria with students is a key to its success; and its results do not necessarily require documentation or reporting. It truly implements the view articulated by Wiggins (1993) that assessment is something we should do *with* students rather than *to* them.

In summary, all four functions of educational assessment are valid in their own terms. All offer potentially valuable contributions to education and, in an ideal system, all would have a place. However, political and professional pressures tend to flavor some over others, and the resulting imbalance can affect curriculum change. In particular, the choice of assessment function can threaten the implementation of SL-in-action. Imbalances also create a hierarchy among the four sets of purposes based in terms of the political and professional power of those controlling each level of assessment.

Power over Purpose

Senior levels of government typically have the power and resources to invest more in assessment than lower levels of government, 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 have greater power over those designed locally for promoting student learning. Importantly, the first three functions of educational assessment have greater power over the fourth function that supports student learning. The evidence for the existence of such a hierarchy is the financial resources devoted to each type of assessment.

For example, in Ontario the results of provincial mathematics and language assessments are used to make judgments about schools as a whole. Moreover, 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 functions of assessment 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 at the school and classroom levels.

The implications for assessment are clear. It is cheaper, simpler, easier, and more aggrandizing to measure students' memorization or accumulation of facts, abstractions, and algorithms than to assess the more complex competencies that make up a richer vision of SL for a Knowledge Society. Thus, in a competition for resources, political power wins out over education purpose every time, and SL-in-action is likely to suffer.

Assessing Knowing-in-Action

If SL-in-action is to become a reality, how should it be assessed when competence is judged as acting effectively, and assessment is seen as describing and monitoring that process? For a Knowledge Society, the focus is less on 'what you know' but more on 'what you can learn and what can you do with it in the context of the everyday world of work and responsible citizenship.' Science is understood in the context of technological and social challenges faced by individuals and societies.

We propose that assessment move correspondingly away from science knowledge in a static and de-contextualized sense (traditional assessment), and even beyond performance assessment with its focus on students' ability to perform science experiments. Assessment can move toward giving students real-world tasks where they learn relevant ST content and use this content to achieve a broader goal.

Real-world tasks can be of two kinds. First, more appropriate for elementary school, students can be given a simple task that requires the use of their knowledge, but its use is left to the student to determine. Examples of this kind of assessment can be found in the *Assessment of Science & Technology Achievement Project* (Orpwood & Barnett, 1997). A Grade 1 student who has been taught about the senses (seeing, hearing, touching, listening, and smelling) is asked to design a game for students who are blind. A Grade 6 student who has been taught about methods of heat transmission (conduction, convection, and radiation) is asked to design a cup that will keep a chocolate drink hot the longest.

Second, more appropriate at a senior level, real-world tasks can be broader and less concrete. Students can be asked for solutions to societal challenges to which there may be no right answers (Driver, Leach, Millar, & Scott, 1996). PISA does include a number of these types of challenges. Functional, have-cause-to-know, and need-to-know science content can be assessed through students' analysis of socio-scientific decision scenarios. This is illustrated by the *Science Education for Public Understanding Program* (SEPUP, 2003) in the United States (Thier & Davies, 2001), which explicitly connects its relevant science content (functional and have-cause-to-know science) to the wish-they-knew science of the country's *National Science Education Standards* (NRC, 1996). Assessing student decision making on ST-related events and issues has been a research program in a number of countries (Gaskell, 1994; Kolstø, 2001; Kortland, 1996; Ratcliffe & Grace, 2003; Sadler, 2009; Zeidler & Sadler, Chapter yy, this volume). For policy makers, all of these examples are rich sources for alternative procedures for assessing SL-in-action. These assessment methods go beyond marking answers as right or wrong, based on their matching a predetermined answer or based on a checklist of predetermined skills. Such simple methods are contradictory to preparing students for a knowledge-based economy.

Science students need to be exposed to situations where they can demonstrate their responses in a scientifically literate manner, and assessment specialists need to describe and monitor such responses. Because SL-in-action is 'knowing how to learn and knowing how to use that learning,' assessment of SL-in-action must describe and monitor those complex processes.

Conclusion

We succinctly reiterate two crucial concepts – 'SL-in-action' and 'school science content.' A Knowledge Society requires employers, employees, and citizens to develop the capacity to treat knowledge in terms of action – knowing-in-action. In science education this becomes *SL-in-action*.

We conceptualize *school science content* as a triad of scientific content, processes, and contexts, in which content and processes are invariably context-bound as they are in the world of employment (i.e., context-bound content and context-bound processes). This specified meaning for 'school science content' harmonizes science education with SL-in-action and ultimately with a Knowledge Society.

A major implication for policy concerning student assessment logically follows. Context-bound science instruction and learning are by and large incompatible with universal assessment ideologies found in many national and international testing institutions. In the agenda of a Knowledge Society, non-universal types of assessment for science-technology (ST) learning are given precedence over issues of accountability, student certification, student selection, and school improvement.

SL-in-action is about capacity building either for competence in ST-related occupations, or for resolving ST-related events and issues. If policies, curricula, teacher education programs, teacher professional development, and student assessment in science education do not support SL-in-action, they hinder a country's knowledge-based economy and thereby undermine its Knowledge Society (Munby, Hutchinson, Chin, Versnel, & Zanibbi, 2003).

We have offered policy makers a theoretical framework for choosing school science content in line with a Knowledge Society. In addition, we have clarified an ideology that would guide the development of student assessment policies that support a Knowledge Society. Current national and international assessment conventions and practices must give way to new ones so that all citizens develop a rich range of school science outcomes needed in a Knowledge Society.

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