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--DRAFT- NOT FINAL VERSION--

White Paper 4: New assessments and environments for knowledge building

This paper proposes a framework for integrating two different approaches to 21st century skills: "working backward from goals" and "emergence of new competencies." Working backward from goals has been the mainstay of educational assessment and objectives-based instruction. The other approach is based on the premise that breakthroughs in education to address 21st century needs require not only targeting recognized objectives but also enabling the discovery of new objectives—particularly capabilities and challenges that emerge from efforts to engage students in authentic knowledge creation. Accordingly, the focus of this paper is on what are called "knowledge building environments." These are environments in which the core work is the production of new knowledge, artifacts, and ideas of value to the community—the same as in mature knowledge-creating organizations. They bring out things students are able to do that are obscured by current learning environments and assessments.

At the heart of this white paper is a set of developmental sequences leading from entry-level capabilities to the abilities that characterize members of high-performing knowledge-creating teams. These are based on findings from organization science and the learning sciences, including competencies that have already been demonstrated by students in knowledge-building environments. The same sources have been mined for principles of learning and development relevant to these progressions.

The inclusive model of 21st century knowledge building we envision operates across formal educational and out-of-school contexts so as to ensure continuity. We accordingly distinguish educational approaches that emphasize preparation for future work from approaches that engage students directly and throughout their school lives in authentic creative work appropriate to their circumstances. In modern knowledge-creating organizations technologies are integral to the day-to-day work of the organization; we note the advantages of a parallel situation in education. Most significantly, assessment can become concurrent, embedded, and transformative; that is, it is just-in-time, available on demand, and comprehensive enough to support higher-order achievements across the full range of 21st century skills, from elementary through to tertiary education. As such it enables continual improvement, with feedback to work as it proceeds, rather than at the end of a unit or term when it is too late to make adjustments.

Our end-in-view from integrating different approaches to 21st century skills is enabling a broader systems perspective. Once knowledge-building environments are integral to the day-to-day work, student discourse can be used to predict results on large-scale summative assessments, with feedback immediately available to increase chances of better results on these and other achievement tests. The knowledge building environments that support the local community can also support globally networked communities of students, teachers, designers, parents, and policy makers, providing a greatly enriched research base for decision-making and accountability, with means to disseminate practices associated with most significant achievements. New semantic web technologies additionally provide ways to support the full spectrum of 21st century skills while making it possible to monitor and facilitate progressively deeper inquiries. Accordingly, traditional and new goals of education support each other and counteract one of the greatest concerns expressed regarding new 21st century curricula: that the current mile-wide-inch-deep curriculum will be made wider and shallower by adding a new 21st century skills curriculum to an already crowded traditional curriculum. We end with suggestions for new initiatives to help advance education for a knowledge-building society.

4. NEW ASSESSMENTS AND ENVIRONMENTS FOR KNOWLEDGE BUILDING

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Knowledge societies and the need for educational reform

There is general agreement that the much-heralded 'knowledge society' (Drucker, 1994, 1968; Bell, 1973; Toffler, 1990) will have profound effects on our health, educational, cultural, and financial institutions, and create an ever-increasing need for robust lifelong learning, innovation, and the knowledge and skills to solve problems of the future. This need for innovation is emphasized by the shift from manufacturing-based to knowledge-based economies, with the health and wealth of nations tied to the innovative capacity of its citizens and organizations. Furthermore, Thomas Homer-Dixon (2000) points out that problems such as global climate change, terrorism, information glut, antibiotic-resistant diseases, and the global financial crisis, create an *ingenuity gap*: a critical gap between our need for ideas to solve complex problems and the actual supply of those ideas. More and more, prosperity—if not survival—will depend on innovation and the creation of new knowledge.

Citizens with little or poor education are particularly vulnerable. As David and Foray (2003) emphasize, disparities in productivity and growth of various countries have far less to do with their natural resources than with their capacity for creating new knowledge and ideas: "The 'need to innovate' is growing stronger as innovation comes closer to being the sole means to survive and prosper in highly competitive and globalised economies." (p. 22)

The call to action that launched this project, entitled *Transforming Education*: *Assessing and Teaching 21st Century Skills,* stresses the need for systemic education reform to address the new challenges that confront us:

The structure of global economy today looks very different than it did at the beginning of the 20th century, due in large part to advances in information and communications technologies (ICT). The economy of leading countries is now based more on the manufacture and delivery of information products and services than on the manufacture of material goods. Even many aspects of the manufacturing of material goods are strongly dependent on innovative uses of technologies. The start of the 21st century also has witnessed significant social trends in which people access, use, and create information and knowledge very differently than they did in previous decades, again due in many ways to the ubiquitous availability of ICT. These trends have significant implications for education. Yet most educational systems operate much as they did at the beginning of the 20th century and ICT use is far from ubiquitous. Significant reform is needed in education, world-wide, to respond to and shape global trends in support of both economic and social development.

According to one popular scenario, the introduction of technological advances into education will democratize knowledge and the opportunities associated with it. This may be too "romantic" a view, however, The current project is based on the assumption, shared by many (Laferrière, 2001; Raizen, 1997; Law, 2006), that there is little reason to believe that technology combined with good intentions will be enough to make the kinds of changes that need to happen. To address these challenges, education reform must be systemic, not just technological. Systemic reform requires close ties between research-based innovation, deliberate practice (e.g. Ericsson et. al, 2010; Bransford and Schwartz, 2009) and assessment of progress, in order to create the know-how for knowledge-age education and workplace productivity. It also requires the alignment of organizational learning, policy and the other components of the system (Bransford, Copeland, Honig, Nelson, Mosborg, Gawel, Phillips, & Vye, in press; Darling-Hammond, 1997, 2000). As the call to action indicates:

Systemic education reform is needed that includes curriculum, pedagogy, teacher training, and school organization. Reform is particularly needed in education assessment. … Existing models of assessment typically fail to measure the skills, knowledge, attitudes and characteristics of self-directed and collaborative learning that are increasingly important for our global economy and the fast-changing world.

Trilling and Fadel (2009) in their book "21st Century Skills: Learning for Life in our Times" talk of "shifting-systems-in-sync." In order to judge different approaches to assessment it is necessary to view them within the larger context of system dynamics in education. Traditionally, testing has played a part in a system that tends to stabilize at a level of mediocre performance and to be difficult to change. The system itself is well recognized and gives us such phenomena as the "mile wide, inch deep" curriculum, which no one advocates and yet which shows amazing persistence. Inputs to the system include standards, arrived at by consensus of educators and experts, tests geared to the standards, textbooks and other educational material geared to the standards and the tests, responses of learners to the curriculum (often manifested as failure to meet standards), responses of teachers, and pressures from parents (often focused on desire for their children to perform well on tests). These various elements interact until a state is reached that minimizes tensions between them. The typical result is standards that represent what tests are able to measure, teachers are comfortably able to teach, and students are comfortably able to learn. Efforts to introduce change may come from various sources, including new tests, but the system as a whole tends to nullify such efforts. This change-nullifying system has been well recognized by education leaders and has led to calls for "systemic reform." On balance, then, a traditional objectives- and test-driven approach is not a promising way to go about revolutionizing education or bringing it into the 21st century.

What are the alternatives? *How People Learn* (2000) and related publications from the National Academies Press have attempted to frame alternatives grounded in knowledge about brain, cognitive, and social development and embodying breakthrough results from experiments in the learning sciences. A rough summary of what sets these approaches apart from the one described above is elaborated below, including several examples that highlight the emergence of new competencies. In essence, instead of starting only with standards arrived at by consensus of stakeholders, these examples suggest the power of starting with what young learners are able to do under *optimal conditions (*Fischer & Bidell, 1997; Vygotsky, 1986). The challenge then is to instantiate those conditions more widely, observe what new capabilities emerge, and work toward establishing conditions and environments that support "deep dives" into the curriculum (Fadel, 2008). As the work proceeds, the goal is to create increasingly powerful environments to democratize student accomplishments and to keep the door open to further extensions of "the limits of the possible." This open-ended approach accordingly calls for assessments that are concurrent, embedded, and transformative, as we elaborate below. These assessments must be maximally useful to teachers and students so that they are empowered to achieve new heights. Formative assessment thus takes on a new meaning. It is integral to the learning process and connects communities (Earl, 2003; Earl & Katz, 2006). Instead of using it to narrow the gap between present performance and some targeted outcome, it is used to increase the distance between present performance and what has gone before, opening the door for exceeding targeted outcomes. It is additionally used to create increasingly effective knowledge building environments that sustain such work and produce greater change over time.

In 21st century schools and other educational settings, knowledge and technological innovation will be inextricably related, as is currently the case in many knowledge-creating organizations, which provide models for high-level 21st century skills in action and the knowledge-building environments that support them. Once information and communication technology (ICT) becomes integral to the day-to-day, moment-to-moment workings of schools, organizations, and communities, a broad range of possibilities for extending and improving designs for knowledge-building environments and assessments follow. Accordingly, the goals for this paper are to:

- generate an analytic framework for analyzing environments and assessments that characterize and support knowledge-creating organizations and the knowledge building environments that sustain them;
- apply this framework to a set of environments and assessments in order to highlight models, possibilities, and variations in the extent to which they engage students in or prepare them for work in knowledge-creating organizations;
- derive technological and methodological implications of assessment reform;
- propose an approach to research that extends our understanding of knowledge-building environments and the needs and opportunities for promoting 21st century skills.

We start by discussing two concepts that underlie our whole treatment of assessment and teaching of 21st century skills: *knowledge-creating organizations* and *knowledge-building environments*.

Knowledge-creating organizations

A popular saying is that the future is here now; it's simply unevenly distributed. *Knowledge-creating organizations* are examples; they are companies, organizations, associations, and communities that have the creation, evaluation, and application of knowledge either as their main function or as an essential enabler of their main functions. Examples include research institutes, highly innovative companies, professional communities (medicine, architecture, law, etc.), design studios, and media production houses.

Creating new knowledge entails expectation and the means to go beyond current practice. Its goals are *emergent*, which means that they are formed and modified in the course of pursuing them. If computer design had not been characterized by emergent goals, computers would still be merely very fast calculating machines. Emergent outcomes cannot be traced back to subskills or subgoals, because they come about through self-organization—structure that arises from interactions among simpler elements that do not themselves foreshadow the structure. Colour is a classic example of emergence; individual molecules do not have any colour, but through self-organizing processes molecular structures arise that do have color. System concepts are similarly applied to explaining the evolution of complex anatomical structures (Dawkins, 1996) and to accounting for creativity (Simonton, 1999)—one of the widely recognized 21st century skills. Creative work and adaptive expertise (Hatano & Inagaki, 1986) alike are characterized by emergent goals. This makes them especially relevant to 21st century skills. The message here is not that "anything goes" and standards and visions should be abandoned. Instead, the message is that high standards and policies that support them must continually be "on the table" as something to be evaluated and exceeded , and that processes for innovation need to be supported, celebrated, assessed and shared.

In a study by Barth (2009), "Over two-thirds of employers said that high school graduates were 'deficient' in problem solving and critical thinking." The importance of this point is highlighted by a survey in which about 3000 graduates of the University of Washington, 5 to 10 years after graduation, rated the importance of various abilities they actually used in their work (Gillmore, 1998). The top-ranked abilities were (1) *defining and solving problems, (2) locating information needed to help make decisions or solve problems, (3) working and/or learning independently, (4) speaking effectively,* and (5) *working effectively with modern technology, especially computers.* These were the abilities rated highest by graduates from all the major fields. Regardless of the students' field of study, these skills outranked knowledge and abilities specific to their field. They correspond fairly closely to items that appear on 21st century skill lists generated by business people and educators. Accordingly, it seems evident that they represent something important in contemporary work life, although precisely what they do represent is a question yet to be addressed.

The fact that so much of the pressure for teaching 21st century skills is coming from business people has naturally provoked some resistance among educators. Their main objections are to the effect that education should not be reduced to job training and that the private sector should not be dictating educational priorities. These are legitimate concerns, but they can be answered in straightforward ways:

- Teaching 21st century skills is a far cry from job training. It amounts to developing abilities believed to be of very broad application, not shaped to any particular kind of job. Indeed, as The North American Council for Online Learning and the Partnership for 21st Century Skills state (2006): "All citizens and workers in the 21st century must be able to think analytically and solve problems if they are to be successful—whether they are entry-level employees or high-level professionals." (p.7)

- Employability is an important consideration for today's students. Contrasting the changes taking place today with those of the Industrial Revolution, Peter Drucker (2003) has pointed out that very little relearning was required for a farm worker to become a factory worker, but that extensive learning and relearning is required for a factory worker to become a knowledge worker—learning that is best started in childhood.

- Crawford (2006) has questioned the emphasis on skills in the processing of abstract information. It is not expected that everyone will become what Reich (1991) called “symbolic analysts,” but symbolic analysis and the use of technology for carrying it out are becoming increasingly essential for otherwise “manual” occupations (Leonard-Barton, 1995).

- Well-accepted educational values require that whatever is done to promote 21st century skills should not be confined to the élite. It must be inclusive, foster equal participation, address issues of citizenship and multiculturalism, and provide for deliberative governance (Hearn & Rooney, 2008; Robinson & Stern, 1997; Treviranus, 1994, 2002).

- Increasing the level of knowledge-related skills is not only important for the managers and developers in an organization but also for empowering workers at all levels “to assume more responsibilities and solve problems themselves.” (U.S. Department of Commerce, U.S. Department of Education, U.S. Department of Labour, National Institute of Literacy, and the Small Business Administration, 1999, p.1).

- It is not assumed that modern corporations, research laboratories, design studios, and the like represent ideal models for education to emulate. There is probably as much to be learned from studying their shortcomings as from studying their successes. What they do represent, which is valuable for education systems, are social organizations that function to produce knowledge rather than merely to transfer and apply it. Thus they offer insight into a level of constructivism deeper than that characteristic of even the more active kinds of school learning (Scardamalia & Bereiter, 2003).

The previous bullet point returns us to the theme of knowledge building and emergence. Instead of taking at face value the 21st century skills identified by committees of educators and business people, we might start by considering what constitutes knowledge creation at its best and what traits, abilities, and environments enable it. It is characteristic of “soft” skills of all kinds (of which 21st century skills are a subset) that everyone already possesses them to some degree (unlike “hard” skills, such as solving simultaneous equations and tooth filling, which may be totally lacking in the untrained). Thus for each skill identified as relevant to knowledge creation, we may establish a continuum running from the skill level almost everyone may be assumed to have, up to a level sufficient for engaging in creative knowledge work. The skills and competencies required for productive work in innovative organizations and professions provide a foundation for designing environments, practices, and formative assessments to help schools and education systems meet 21st century expectations (Treviranus, 1994, 2002; Wiggins & McTighe, 2006; Anderson, 2006).

Knowledge-building environments

Although the term “knowledge building” now appears in approximately half a million web documents, this is less frequently than the term “knowledge creation,” and it is almost never defined. In documents with a business orientation the term is used as a synonym for “knowledge creation,” roughly equivalent to concepts such as collective intelligence, intellectual capital, knowledge work, and innovation. In education documents it is generally used more as a synonym for “constructivist learning” (Wilson, 1996), with rough equivalence to concepts such as active learning, discovery learning, and inquiry- and project-based learning.

Our literature review indicates that the term “knowledge building,” was originally introduced into the educational literature in 1989 (Bereiter & Scardamalia, 1989, p.388), and had its basis in studies of expertise and innovation, summarized in the book *Surpassing Ourselves: An Inquiry Into the Nature and Implications of Expertise* (Bereiter & Scardamalia, 1993). The phrase “progressive problem solving” was used to denote the process by which experts become experts and continue to develop their expertise (in contrast to becoming experienced non-experts)—through investing their surplus cognitive resources in tackling problems at higher levels. The same basic idea, applied to knowledge building, took the form of a contrast between shallow and deep constructivism. If we imagine a line with shallow constructivism at one end and deep constructivism at the other, much of what is called “constructivist learning” in schools would be located toward the shallow end. Take for example the ubiquitous school “project” in which different project members assemble information that is then compiled in a multimedia presentation, One long-time observer of the school scene described this as using a computer to make a scrapbook. Knowledge building, with its focus on knowledge *creation*, would be located at the opposite end, aiming for the deepest levels of work with ideas, leading to emergence of new ideas and continued efforts to improve them (Scardamalia & Bereiter, 2003).

Over the history of thought, the idea of knowledge as a human construction is relatively new. Designing environments to support knowledge creation is newer yet. Schools were not built for that purpose, and to this day many would claim they should not or could not. Yet universal access to the process whereby new knowledge is created arguably depends on bringing knowledge building environments into schools.

In brief, w**e** use the term “knowledge-building environments” to refer to contexts supportive of the emergence and further development of new ideas—knowledge creation in organizations of all kinds. Conceptually, economically and technologically, it may be necessary to connect currently distinct environments for creative work with ideas (e.g., knowledgeware) to those for learning (e.g., courseware, tutorials, simulations), so as to encourage their integration and easy movement between these different and essential aspects of mature knowledge work. What would a more integrative approach look like? We say more about that below. For now, we elaborate the concept of knowledge building environments by focussing on features that favour the emergence of new skills.

Knowledge-building environments provide special support for creative work with ideas, so that ideas may grow from nascent form to something of greater consequence than could have been imagined before. Improved ideas emerge as they are generated in multiple and varied contexts and are entered into communal spaces. Within these more public spaces, collaborators as well as competitors can elaborate, critique, reframe, link, re-position, create higher-order structures, explore and devise uses for ideas, and in other ways work creatively with them. It is through such sustained and varied engagement that ideas, like colourless molecules, acquire new properties through structural organization. In line with this *emergence* perspective, a knowledge-building approach considers the “promisingness” of an idea, recognizing that through new combinations and sustained work something brilliant might emerge. In creative knowledge work it is important both to avoid wasting resources on unpromising ideas and to guard against killing off ideas that have promise. As the designer of a program for forest conservation remarked in response to criticisms of the plan, “an imperfect program which can be improved is better than none at all” (“Saving the rainforest: REDD or dead?” 2009).

In summary, a knowledge building environment, virtual or otherwise, is one that enhances collaborative efforts to create and continually improve ideas. It exploits the potential of collaborative knowledge work by situating ideas in a communal workspace where others can criticize or contribute to their improvement. In these collaborative open contexts, discourse that is democratic and directed toward idea advancement compounds the value of ideas, so that collective achievement exceeds individual contributions. A local knowledge-building community gains strength as it connects to a broader one. The local community not only draws upon, but also affords participation in, the larger one, with possibilities for symmetrical advances of knowledge. A successful knowledge-building environment will bring innovation closer to the central work of an organization. It is an environment in which members are continually contributing to and enhancing the shared intellectual resources of the organization. Each advance precipitates another, so that at both the individual and group level there is continual movement beyond current understanding and capacity. Emergence becomes a way of life, different from but both more productive and more personally satisfying than a life restricted to following known paths to known goals. Innovation, as Peter Drucker (1985, p.151) put it, becomes “part and parcel of the ordinary, the norm, if not routine.”

New goals and methods to support the emergence of new skills

Advocates for the adoption of 21st century skills generally look for this to have an overall transformative effect on the schools. However, the nature and extent of this envisaged transformation can range from conservative to fundamental, as suggested by the following three levels:

1. *Additive change*. Change is expected to result from the addition of new skill objectives, new curriculum content (nanotechnology, environmental studies, cross-cultural studies, systems theory, technology studies, etc.), and new technology. Changes to existing curricula will be needed to make room for additions.

2. *Assimilative change*. Instead of treating work on 21st century skills as an add-on, existing curricula and teaching methods are modified to place greater emphasis on critical thinking, problem solving, collaboration, and so forth. This is the most widely recommended approach and reflects lessons learned from the disappointing results of a previous wave of "higher-order thinking skills" instruction that took the additive approach (Bereiter, 1984).

3. *Systemic change*. Instead of incorporating new elements into a system that retains its 19th century structure, schools are transformed into 21st century organizations. Toward this end we present a case for schools to operate as knowledge-creating organizations. The envisaged educational change is not limited to schools, however. Knowledge creation by young people can and often does take place in out-of-school contexts.

The present authors clearly favour systemic change but recognize that the realities of public education often mean that assimilative change and, in many cases, additive change is as far as a school system will go in adapting to 21st century opportunities and needs. Accordingly, approaches to teaching and assessing 21st century skills need to be applicable and potentially transformative at any of the three levels. That said, however, we suggest that countries whose schools are transformed into knowledge-creating organizations may gain a tremendous advantage over those that struggle to incorporate knowledge-age education into industrial-age curricula and structures.

Two general strategies are applicable to pursuing the practical goals of advancing 21st century skills, and we argue that both are important and need to be used in a complementary fashion. One is the approach of *working backward from goals*. The other is one that, for reasons that will become evident, we call an *emergence* approach.

"Working backward from goals" to construct a system of subgoals and a path leading from an initial state to the goal is one of the main strategies identified in Newell and Simon's classic study of problem solving (1972). It will be recognized as the most frequently recommended way of designing instruction. As applied to educational assessment, it comprises a variety of techniques, all of which depend on a clearly formulated goal, the antecedents of which can be identified and separately tested. Although working backward is a strategy of demonstrable value in cases where goals are clear, it has two drawbacks in the case of 21st century skills. Most 21st century skills are "soft" skills, which means among other things that there is an inevitable vagueness and subjectivity in regard to goals, which therefore makes "working backward" not nearly so well structured as in the case of "hard" skills (such as the ability to execute particular algebraic operations). A more serious difficulty, however, is that working backward from goals provides no basis for discovering or inventing new goals—and if 21st century education is to be more than a tiresome replication of the 1970s "higher-order skills" movement, it has to be responsive to potential expansions of the range of what's possible.

As noted earlier, in the context of teaching and testing 21st century skills, "working backwards from goals" needs to be complemented by a working-forward approach growing out of what has been called the "systems revolution" (Ackoff, 1974). Self-organization and emergence are key ideas in a systems approach to a vast range of problems. An "emergence" approach, when closely tied to educational experimentation, allows for the identification of new goals based on the discovered capabilities of learners. The observation that, in advance of any instruction in rational numbers, children possess an intuitive grasp of proportionality in some contexts, led to formulation of a new goal (rational number sense) and development of a new teaching approach that reversed the traditional sequence of topics (Moss, 2006). Results suggest that both the traditional goals (mastering appropriate algorithms) and the path to achieving them (starting by introducing rational numbers through models that connect children's whole number arithmetic) were misconceived, even though they were almost universally accepted. If that can happen even on such a well-travelled road as the teaching of arithmetic, we must consider how much riskier exclusive reliance on a working backwards approach might be to the largely untried teaching of 21st century skills. But the drawback of the emergence approach, of course, is that there is no guarantee that a path can be found to the emergent goal. Invention is required at every step, with all its attendant uncertainties.

Two concrete examples may help clarify the nature of an "emergence" approach and its benefits. The first example expands on the previously cited work of Moss (2006). The second example, drawn from work on scientific literacy, points to a potentially major 21st century skill that has gone unrecognized in the top-down and "working backward" approaches that have dominated mainstream thinking about 21st century skills.

1. *Beyond rational number skills to proportional thinking*. Failure to master rational numbers is endemic and has been the subject of much research. Much of the difficulty, it appeared, is that students *transferred* their well-learned whole number arithmetic to fractions and thus failed to grasp the essential idea of proportionality, or the idea that fractions are numbers in their own right. The standard way of introducing fractions, via countable parts of a whole, was seen as reinforcing this tendency. Joan Moss and Robbie Case observed, however, that children already possessed an idea of proportionality, which they could demonstrate when asked to pour liquid into two different-sized beakers so that one was as full as the other. Once proportional reasoning was recognized as a realistic goal for mathematics teaching, "working backwards" could then be applied to devising ways of moving toward that goal. Moss (2005) developed a whole environment of artifacts and activities the purpose of which was to engage students in thinking proportionally. Instead of introducing fractions as the starting point for work on rational numbers, Moss and Case started with percentages, as being more closely related to spontaneous understanding (consider the bars on computer screens that register what percent of a task has been completed). In final assessments, students in grades 5 and 6 out-performed educated adults. Another name for proportional thinking is rational number sense. Greeno (1991) characterized number sense as knowing one's way around in a numerical domain, analogous to knowing one's way around in a geographical area. It is not something that is directly taught, but rather something that emerges from experience in crossing and re-crossing a domain in different directions and with different purposes. It is assessable, but it is not specifiable in the way that hard skills are. And, quite obviously, proportional thinking or rational number sense is a more fundamental and more skill-enhancing outcome than mastering (or not quite mastering) a number of rational number algorithms.

2. *Beyond "scientific method" to theory building.* The second example of an emergence approach, more directly related to 21st century skills, comes from work on theory building. Broadly conceived, creative *knowledge* work of all kinds—planning, inventing, and so forth—is theory building. Even the Wright Brothers, known to the world as exceptionally clever tinkerers, were explicitly engaged in theory building at the same time they were engaged in building an airplane (Bereiter, 2009). Ability to construct, test, and improve theory-like knowledge structures could therefore rate as a top-level 21st century skill. It does not appear on 21st century skill lists, however, possibly because it is not readily described in skill terms and because little is known about what students are capable of in this respect. Expert opinion has suggested that work on theory building should wait until high school (Smith & Wenk, 2006) and that the learning progression should start with hypothesis testing and control of variables (Kuhn, Schauble & Garcia-Mila, 1992; Schauble, Glaser, Duschl, Shulze & John, 1995). Instructional results from this approach have not been encouraging with respect to scientific literacy, and there have been many efforts to find new approaches (Carey et al. 1989; Carey & Smith, 1993; Honda, 1994, Smith et al., 2000), with further confirmation of the conventional expert wisdom that theory building is beyond the capacity of young students. When free to pursue problems of understanding on their own initiative, however, students were observed to engage spontaneously in a good deal of theorizing (Scardamalia & Bereiter, 2006). A small experiment was carried out in which grade 4 students in a class where such knowledge building was the norm were compared with similar students who had followed a more traditional inquiry approach (Bereiter & Scardamalia, 2009). In the knowledge-building class there was no explicit teaching of "scientific method" and no carrying out of pre-specified experiments. Instead, the students were supported in creating, exploring, and considering theories from multiple perspectives. Results showed significantly higher levels of theoretical work and scientific literacy and superior scientific writing for the emergent goals approach (Bereiter & Scardamalia, 2009; Chuy, et al., 2009). Theory building, it turns out, is not only possible in 10 to 12-year-olds but also at even earlier ages. A kindergarten teacher in the same school learned of the findings and thought her students might have relevant, untapped capacities. She asked them to generate theories about why some trees in their schoolyard had no new leaves in the early spring while other trees did. The children not only generated a number of reasonable explanations but also connected these with supportive facts. It would seem, therefore, that

theory building could justifiably gain a place among the 21st century skills to be developed and tested from early childhood onward. Work by Shutt, Phillips, Van Horne, Vye, & Bransford (2010) also supports this point of view.

In a later section, on technology for supporting the emergence of new competencies (pp. 237 ff.) we discuss the specific forms of support that have enabled the achievement of exceptional levels of proportional reasoning and theory development. As the preceding examples suggest, discovering new goals is not simply a matter of turning students loose in an environment and waiting to see what happens. Discovering new goals is an aspect of scientific discovery, and rarely is such discovery accidental. People know in a general way what they are looking for, and particular moves may be carefully calculated, but this process as a whole has to be structured so as to allow room for unexpected insights. When Darwin set sail on the Beagle he did not know he was about to explain the origin of species, but he was not merely a collector of curious specimens, either.

Most current school reform efforts, whether involving new management structures or the introduction of new standards and curricula, are additive as far as their treatment of 21st century skills is concerned. Changes are based on conservative practices and templates drawn from instruction in traditional subjects. More transformative change requires goals and methods to be considered anew. Education for 21st century skills may in fact have no "tried and true" methods to draw on, so riskier approaches are needed. It would be difficult to get excited about 21st century education reform were it nothing more than extending existing goals to more demanding performance levels. It should, of course, include such goals—performance demands are indeed likely to rise, and there will no doubt continue to be students who need help in meeting even today's modest standards. But anything that deserves the name of education for the 21st century needs new kinds of objectives, not simply higher standards for existing ones.

In the following sections we examine 21st century skills as they are being enacted in knowledge-creating organizations. We focus on what is involved in the knowledge creation being carried out by experts actually working in these organizations, providing a sharpened focus for "working backward" to identify methods and goals that might apply to schools, while allowing us to go beyond the identification of the desirable traits and skills that are viewed by employers wishing to hire people for knowledge work. We then consider the knowledge-building environments that support work in knowledge-creating organizations, followed by examining learning and assessment theory. In the section on specific investigations (pp.38 ff) we propose specific investigations within an emergence framework, using findings from the working backward approach to test transfer and generalization effects so as to achieve a best-of-both-worlds, working-backwards and emergence of new competencies, synthesis

Characteristics of knowledge-creating organizations

How do businesses succeed in a knowledge economy? How are knowledge-intensive firms organized and how do they function? How are jobs different in a knowledge economy? And what kinds of skills are needed?

Industry- or firm-level studies in the U.S. (Stiroh, 2003), the U.K. (Borghans & ter Weel, 2001; Dickerson & Green, 2004; Crespi & Pianta, 2008), Canada (Gera & Gu, 2004; Zoghi, Mohr, & Meyer, 2007), France (Askenazy, Caroli, & Marcus, 2001; Maurin & Thesmar, 2004), Finland (Leiponen, 2005), Japan (Nonaka & Takeuchi, 1995), and Switzerland (Arvanitis, 2005), have found many similar results—a major factor in the success of highly productive, innovative firms is the use of ICT (UNESCO, 2005). Of course, productivity and innovation increases did not come merely with the introduction of new technologies. Rather, technology use must be associated with a pattern of mutually reinforcing organizational structures, business practices, and employee skills that work together as a coherent system. Also, organizational structures have become flatter, decision-making has become decentralized, information is widely shared, workers form project teams within and across organizations, and work arrangements are flexible. These changes in organizational structures and practices have been enabled by the application of ICT for communication, information sharing, and simulation of business processes. For example, a U.S. Census Bureau study (Black & Lynch, 2003) found significant firm-level productivity increases associated with changes in business practices that included reengineering, regular employee meetings, the use of self-managed teams, up-skilling of employees and the use of computers by front-line workers. In Canada, Zohgi, Mohr and Meyer (2007) found a strong positive relationship between both information sharing and decentralized decision-making and a company's innovativeness. Recent studies of firms (Pilat, 2004; Gera & Gu, 2004) found significant productivity gains when ICT investments were accompanied by other organizational changes, such as new strategies, new business processes and practices, and new organizational structures. Murphy (2002) found productivity gains when the use of ICT was accompanied by changes in production processes (quality management, lean production, business re-engineering), management approaches (teamwork, training, flexible work and compensation) and external relations (outsourcing, customer relations, networking).

These changes in organizational structure and business practices have resulted in corresponding changes in the hiring practices of companies and the skills needed by workers. A study of labour tasks in workplaces found that, commencing in the 1970's, routine cognitive and manual tasks in the U.S. economy declined and non-routine analytic and interactive tasks grew (Autor, Levy, & Murnane, 2003). This finding was particularly pronounced for rapidly computerizing industries. The study found that, as ICT is taken up by a firm, computers *substitute* for workers who perform routine physical and cognitive tasks but they *complement* workers who perform non-routine problem solving tasks. Similar results were found in the U.K. and the Netherlands (Borghans & ter Weel, 2001; Dickerson & Green, 2004), France (Maurin & Thesmar, 2004) and Canada (Gera & Gu, 2004).

Because repetitive, predictable tasks are readily automated, computerization of the workplace has raised the demand for problem-solving and communications tasks, such as responding to discrepancies, improving production processes and coordinating and managing the activities of others. In a survey of U.K. firms, Dickerson and Green (2004) found an increased demand for technical know-how, and for skills in high-level communication, planning, client communication, horizontal communication, problem-solving and checking. Meanwhile, there was a decreased demand for physical skills. The net effect of these changes is that companies in the U.S., the U.K. and other advanced economies (Lisbon Council, 2007) are hiring workers with a higher skill set. It is also interesting that many of these skills (e.g. communication, collaboration, flexibility) are often referred to as "soft skills" yet are some of the most important for success and some of the most difficult to help people develop to high levels of refinement.

The creation of knowledge as a social product (Scardamalia & Bereiter, 2003; 2006) is a major part of that higher skill set. It requires collective responsibility for accomplishments and it is something that scientists, scholars and employees of highly innovative companies do for a living (Nonaka & Takeuchi, 1995). An interesting example is the design of Boeing 787 aircraft, built by nearly 5,000 engineers (not counting production workers) from around the world. The design and engineering work takes place simultaneously at multiple sites, over a long period of time, and yet all the parts ultimately fit nicely together (Gates, 2005). In collaborative, creative endeavours of this nature, team members need to understand the top-level goal and share responsibility for the interrelated network of ideas, sub-goals, and designs, with success dependent on all members rather than concentrated in the leader. They share responsibility for establishing effective procedures, for assigning and completing practical tasks, for understanding and facilitating team dynamics (Gloor, 2006), for remaining cognitively on top of activities and ideas as they unfold (Leonard-Barton, 1995), and for the process as a whole. As issues emerge, they collectively shape the next steps, build on each other's strengths, and improve their ideas and designs. Members create the cultural capital of their organization as they refine the "knowledge space" and products that represent their collective work.

Of course this work includes timelines, specified goals, and deadlines. The idea of collective responsibility is not to ignore such aspects, but to engage participants in setting deadlines, taking responsibility for achieving them, and redefining goals and schedules as necessary. It also requires a commitment to working in public spaces, making one's thinking and processes explicit and available, and entering artifacts into the shared knowledge space to advance the state of knowledge of the community. If everyone is doing the same thing (as is often the case in schools) the redundant, repetitive work interferes with productivity. The shared problem space needs to grow, based on shared goals and helpful, diverse contributions from all members.

This cluster of changes—organizational structure, business practices, and more-complex employee tasks and skills—is particularly pronounced for knowledge-intensive, knowledge-creating organizations. Probably the most intensive knowledge-creating organizations are research laboratories. Current research in the sociology and anthropology of science has focused on two aspects of the work of scientists: the distributed nature of scientific work over time, resources, and place and the moment-by-moment coordination of instruments, representations, and discourse as scientists construct meaning from the results of their research.

In contemporary science, creating new knowledge requires the coordination of activities through time and across space to assemble methods, tools, and theories, building on previous findings to conduct new research and generate new knowledge (Fujimura, 1992). To achieve this spatial and temporal coordination, scientists develop technological and social systems that support the movement of specialized scientific objects, like ideas, data, sketches, and diagrams, across this distributed network. This coordination within and across organizations and across time, place, and objects was apparent in Kozma's study (Kozma, Chin, Russell, & Marx, 2000; Kozma, 2003) of chemists in a pharmaceutical company. Here the synthetic products of one group were frequently the starting materials of another group, as activities related to the creation of a new drug were distributed across laboratories, chemists with different specializations, and equipment with different purposes. This coordination was maintained, in part by standardized procedures and in part by attaching labels with diagrams of chemical structures to the vials as they moved from lab to lab.

The laboratory is where the moment-by-moment work of science is done, much of it centred on instruments and representations. In their collaborative activities, scientists talk and represent visually their ideas to one another in supportive physical spaces (Ochs, Gonzales, & Jacoby, 1996). The indexical properties of these physical spaces and representations are essential for the ways that scientists collaborate and establish shared meaning (Goodwin & Goodwin, 1996; Hall & Stevens, 1995; Suchman & Trigg, 1993). In their discourse, scientists make references to the specific features of diagrams and data visualizations as they coordinate these representations to understand the products of their work (Kozma et al., 2000, Kozma, 2003). The features of these representations are often used as warrants for competing claims about their finding, as scientists try to adjudicate their different interpretations.

These research findings on the practices, organizational structures and needs of innovative, knowledge creating organizations have significant implications for the practices and organizational structures of environments needed to support the acquisition of 21st century skills and for finding productive connections between in- and out-of-school learning environments. Knowledge-creating organizations rank high on all of the 21st century skills listed in various documents and articles (for example, The Partnership for 21st century skills, 2009; Binkley, et al., 2009; Johnson, 2009). Consequently, an analysis of knowledge-creating organizations additionally provides high-end benchmarks and models to guide the design and implementation of modern assessment. For example, the literature on how distributed teams have managed to successfully produce more and better outputs helps to operationalize concepts such as collaboration, group problem solving, use of ICT, and so on. Also relevant are the social, material and technological practices and organizational structures in which members of knowledge-creating organizations operate.

Table 1 maps in condensed form the characteristics of knowledge-creating organizations onto the 21st century skills presented in White Paper 1. Our goal is to align these different perspectives and, as elaborated below, provide an analytic framework for educational environments and assessments to identify those most in keeping with characteristics of knowledge-creating organizations.

There are major differences between 21st century skills as they figure in school curricula and the skills manifested in knowledge-creating organizations. In schools the skills are frequently treated separately, each having its own learning progression, curriculum, and assessment. In knowledge-creating organizations different facets of work related to these skills represent a complex system, with the skills so intertwined that any effort to separate them in contexts of use would undercut the dynamic that gives them meaning.

Table 1: 21st century skills as experienced in knowledge-creating organizations

21st century skills	Experience in knowledge-creating organizations
Creativity and Innovation	Work on unsolved problems; generate theories and models, take risks, etc; pursue promising ideas and plans

Communication	Knowledge building/progressive discourse aimed at advancing the state of the field; discourse to achieve a more inclusive, higher order analysis; open community knowledge spaces encourage peer-to-peer and extended interactions
Collaboration/teamwork	Collective or shared intelligence emerges from collaboration and competition of many individuals and aims to enhance the social pool of existing knowledge. Team members aim to achieve a focus and threshold for productive interaction and work with networked ICT. Advances in community knowledge are prized, over-and-above individual success, while enabling each participant to contribute to that success
Information literacy / research	Going beyond given information; constructive use of and contribution to knowledge resources to identify and expand the social pool of improvable ideas, with research integral to efforts to advance knowledge resources and information
Critical thinking, problem solving and decision-making	High-level thinking skills exercised in the course of authentic knowledge work; the bar for accomplishments is continually raised through self initiated problem finding and attunement to promising ideas; participants are engaged in complex problems and systems thinking
Citizenship—local and global	Citizens feel part of a knowledge-creating civilization and aim to contribute to a global enterprise; team members value diverse perspectives, build shared, interconnected knowledge spanning formal and informal settings, exercise leadership, and support inclusive rights
ICT literacy	ICT integrated into the daily workings of the organization; shared community spaces built and continually improved by participants, with connection to organizations and resources worldwide
Life and career skills	Engagement in continuous, “lifelong” and “life-wide” learning opportunities; self-identification as a knowledge creator, regardless of life circumstance or context
Learning to learn / meta-cognition	Students and workers are able to take charge at the highest, executive levels; assessment is integral to the operation of the organization, requiring social as well as individual metacognition
Personal and social responsibility—incl. cultural competence	Team members build on and improve the knowledge assets of the community as a whole, with appreciation of cultural dynamics that will allow the ideas to be used and improved to serve and benefit a multicultural, multilingual, changing society

Characteristics of knowledge-building environments

Knowledge-building environments represent *complex systems* that support *emergent outcomes*. They are places that, like knowledge-creating organizations, produce public knowledge—knowledge that does not just reside in the minds of individuals but that is available to others to build on and improve. Public knowledge develops through discourse, in which declarative statements play a necessary role, as do models, theories, and artifacts that are available to the community as a whole. Having students become active agents in knowledge construction is an important theme in the literature on school reform and knowledge building processes (Engle & Conant, 2002; Herrenkohl & Guerra, 1998; Lamon, Secules, Petrosino, Hackett, Bransford, & Goldman, 1996; Lehrer, Carpenter, Schauble, & Putz, 2000; Paavola & Hakkarainen, 2005; Tabak & Baumgartner, 2004). Of particular interest in this regard is *collective cognitive responsibility,* the requirement to take responsibility for the state of public knowledge (Scardamalia, 2002).

As the Boeing example suggests, networked, communal knowledge spaces are at the heart of work in knowledge creating organizations. Accordingly, the work of participants has an “out-in-the-world” existence. The intellectual life of the community—objectified as theories, inventions, models, plans, and the like—is accessible, in tangible form. In the business world, this is referred to as the organization’s corporate knowledge; in the knowledge building literature, it is referred to as “community knowledge” (Scardamalia, 2002). This community knowledge space is typically absent from classrooms, making it hard for students’ ideas to be objectified, shared, examined, improved, synthesized, and used as “thinking devices” (Wertsch, 1998) so as to enable further advances. It also makes assessment difficult because students’ ideas are neither explicit nor in tangible form. In contrast, the commitment to work in open, shared spaces not only renders ideas as objects of discussion and improvement but opens the door for concurrent, embedded, and transformative assessment, as we elaborate below. In turn, these communities can sustain work at the high end of 21st century skills, as identified in Table 1.

Group learning

Group learning and group cognition may well become the dominant themes of technology in the next quarter-century, just as collaborative learning was in the previous one (Stahl, 2006). Group learning is learning *by* groups, which is not the same as learning *in* groups or individual learning through social processes. The term *learning organization* (Senge, 1990) reflects this emphasis on the organization itself operating as a knowledge-advancing entity and reflects the larger societal interest in knowledge creation. Knowledge building is a group phenomenon, even when contributions come from identifiable individuals. Members are responsible for the production of public knowledge that is of value to a community. Again, this maps directly onto the Boeing example presented above. The community may be a research or design group or the world at large or it may be a group of learners—in which case it is important to distinguish individual learning from the group’s knowledge-building accomplishments. Neither one can be reliably inferred from the other, although the interaction between the two is vital and deserving of study in its own right. We return to this issue in the final sections of this paper.

In a knowledge-building group, the crucial assessment questions are about the group’s achievements in advancing the state of knowledge—comparable to the “state of the art” reviews common in the disciplines and professions. Self-assessment by a knowledge-building group can be valuable both for helping the group progress and for individual learning (Lee, Chan, & van Aalst, 2006). External assessment can serve the purposes of troubleshooting and management. Evidence available suggests that such an approach increases individual learning, not just group learning, because the group needs each individual’s contribution; thus there is social pressure to perform (e.g., Barron, 2003). However, this is a finding much in need of replication and extended study.

Knowledge building developmental trajectory

Building on the characteristics of knowledge-creating organizations and what it is we know about learning, we can begin to specify the characteristics of knowledge-building environments and the implications they have for educational practices. Table 2 is an elaboration of Table 1 and provides a developmental framework for analyzing learning environments. For each 21st century skill, the table suggests a continuum running from the entry-level characteristics that may be expected of students who have had no prior engagement in knowledge building to a level characteristic of able participants in a knowledge-creating enterprise. The continuum is an “emergence” continuum—a developmental trajectory from active or constructivist learning as the entry point, to complex systems of interactivity and knowledge work that enable the generation of new knowledge, the capacity to exceed standards, and the drive to go beyond best practice at the high end.

Table 2: Developmental trajectory for knowledge-creating environments

21st century skills	Characteristics of knowledge-creating organizations	
	Entry Level	High
Creativity and innovation	Internalize given information; beliefs/actions based on the assumption that someone else has the answer or knows the truth	Work on unsolved problems; generate theories and models, take risks, etc; pursue promising ideas and plans
Communication	Social chit chat; discourse that aims to get everyone to some predetermined point; limited context for peer-to-peer or extended interactions	Discourse aimed at advancing the state of the field; to achieve a more inclusive, higher order analysis; open spaces encourage peer-to-peer and extended interactions

21st century skills	Characteristics of knowledge-creating organizations	
Collaboration/ teamwork	Small group work: divided responsibility to create a finished product; the whole is the sum of its parts, not greater than that sum	Shared intelligence from collaboration and competition enhances existing knowledge. Individuals interact productively and work with networked ICT. Advances in community knowledge are prized over individual success, while enabling each contribute to it
Information literacy/ research	Inquiry: question-answer, through finding and compiling information; variable testing research	Collaborative expansion of social pool of improvable ideas, with research integral to efforts to advance knowledge
Critical thinking, problem solving and decision-making	Meaningful activities are designed by the director, teacher or curriculum designer; learners work on predetermined tasks set by others	High-level thinking skills exercised in authentic knowledge work; the bar for accomplishments is continually raised by participants as they engage in complex problems and systems thinking
Citizenship—local and global	Support of organization and community behavioural norms; "doing one's best"; personal rights	Citizens feel part of a knowledge-creating civilization and aim to contribute to a global enterprise; they value diverse perspectives, build shared knowledge in formal and informal settings, exercise leadership, and support inclusive rights
ICT literacy	Familiarity with and ability to use common applications and web resources and facilities	ICT integrated into organization's daily work; shared community spaces built and continually improved by participants, with connection worldwide
Life and career skills	Personal career goals consistent with individual characteristics; realistic assessment of requirements and probabilities of achieving career goals	Engagement in continuous, "lifelong" and "life-wide" learning opportunities; self-identification as a knowledge creator, regardless of life circumstance or context
Learning to learn / meta-cognition	Students and workers provide input to the organization, but the high-level processes are under the control of someone else	Students and workers are able to take charge at the highest, executive levels; assessment is integral to the operation of the organization, requiring social as well as individual metacognition
Personal and social responsibility—incl. cultural competence	Individual responsibility; local context	Team members build on and improve the knowledge assets of the community, with appreciating cultural dynamics that allow the ideas to be used and improved for benefit of multicultural, multilingual, changing society

In the section on needed research (pp.36ff) we propose experiments to develop this scheme, including additional points along the continuum, to indicate how designing environments with sights set on the high-end of the scale can facilitate the advancement of any school, any teacher along these lines.

Advancing domain knowledge and 21st century skills in parallel

21st century skills—often labelled "soft" or "generic" skills--have been widely recognised as central to innovative capacity and hence as vital for success in a 21st Century global economy. Although 21st century skills are recognized in recent curriculum standards, the main emphasis in standards and assessments is on "hard" skills in language and mathematics as well as "hard" factual knowledge. There is a concern that attention given to "soft" skills will detract from efforts to improve the skills and subject-matter knowledge for which the schools are held accountable. The consensus among researchers in the learning sciences is that these two are not in conflict (Bransford, Brown, & Cocking, 1999; Darling-Hammond, et al., 2008); their interdependence is suggested in Figure 1. In formal education beyond the most basic "3 Rs" level, hard skills are generally treated as a part of domain knowledge. Ability to solve quadratic equations, for instance, is part of algebraic domain knowledge.

Hence, as modelled in Figure 29, domain knowledge and hard skills are combined to constitute the focus of formal education, while a common set of soft skills surrounds expertise in all domains.

Figure 1: Centrality of deep disciplinary knowledge to all knowledge work

Making 21st century skills universally accessible, rather than the province of knowledge élites, requires that the environments that support knowledge creation be made accessible to all. From the *emergence* perspective, the challenge is to shift to environments that take advantage of what comes naturally to students across the full range of 21st century skills (idea production, questioning, communication, problem solving, and so forth) and engage them in the kinds of environments for sustained idea development that are now the province of knowledge élites. These knowledge building environments that score at the high end of all the developmental continua identified in Table 2 increase innovative capacity through engagement in a knowledge building process—the production of public knowledge of value to others so that processes of collective responsibility for knowledge advancement can take hold (Scardamalia & Bereiter, 2003). That is how idea improvement, leading to deep disciplinary knowledge, gets to the centre of the enterprise, with 21st century skills inseparable and serving as enablers.

Comparative research and design experimentation are needed to add substantially to the knowledge base on relations between inquiry and knowledge building activities and the meeting of traditional achievement objectives. The research and design experiments proposed in the final section should help address these issues through use of formative assessment, combined with other assessments, selected to evaluate advances in both "hard" and "soft" skills, and the changes over time that are supported through work in information-rich knowledge-building environments. The proposition to be tested is: *Collective responsibility for idea improvement in environments that engage all students in knowledge-advancement should result in advances in domain knowledge in parallel with advances in 21st century skills*. This argument is in line with that set forth by Willingham (2008): "Deep understanding requires knowing the facts AND knowing how they fit together, seeing the whole."

This notion that deep understanding or domain expertise and 21st century skills are inextricably related has led many to argue that there is not much new in 21st century skills—deep understanding has always required domain understanding and collaboration, information literacy, research, innovation, metacognition, and so forth. In other words, 21st century skills have been "components of human progress throughout history, from the development of early tools, to agricultural advancements, to the invention of vaccines, to land and sea exploration" (Rotherham & Willingham, 2009).

But is it then also true that there are no new skills and abilities required to address the needs of today's knowledge economy? One defensible answer is that the skills are not new but that their place among educational priorities is new. According to Rotherham and Willingham, "What's actually new is the extent to which changes in our economy and the world mean that collective and individual success depends on having such skills. … If we are to have a more equitable and effective public education system, skills that have been the province of the few must become universal." "What's new today is the degree to which economic competitiveness and educational equity mean these skills can no longer be the province of the few" (Rotherham, 2008). Bereiter and Scardamalia (2006) have argued, however, that, “there is in fact one previously unrecognized ability requirement that lies at the very heart of the knowledge economy. It is the ability to work creatively with knowledge per se.” Creative work with knowledge—with conceptual artifacts (Bereiter, 2002)—must advance along with work with material artifacts. Knowledge work binds hard and soft skills together.

The deep interconnectedness of hard and soft skills has important implications for assessment, as does the commitment to individual contributions to collective works. As Csapó et al. (2009) state, “how a domain is practiced, taught, and learned impacts how it should be assessed… the real promise of technology in education lies in its potential to facilitate fundamental, qualitative changes in the nature of teaching and learning” (Panel on Educational Technology of the President’s Committee of Advisors on Science and Technology, 1997, p.33). Domains in which it is most important to include technology in the assessment of 21st century skills include, according to Csapó and colleagues, those in which technology is so central to the definition of the skill that removing it would render the definition meaningless (e.g., the domain of computer programming), those in which higher levels of performance depend on technology tools, and those that support collaboration, knowledge building, and the social interactions critical for knowledge creation. We would argue that to make knowledge building and knowledge creation broadly accessible, technological support for knowledge building also needs to be broadly accessible (e.g. see also Svihla, V., Vye, N. J., Brown, M., Philips, R., Gawel, D., & Bransford, J. D. (2009). .).

Assessment of “soft” skills is inherently more difficult than assessing the “hard” skills that figure prominently in educational standards. Assessing knowledge creation processes may be even harder. Nonetheless, this core capability should be further enhanced and clarified through programs of research and design that aim to demonstrate that the processes that underlie knowledge creation also underlie deep understanding; knowledge-building environments promote both. We return to these ideas below.

Advancing literacy and closing gaps

Among the skills needed for life in the knowledge age, literacy is perhaps the most crucial. Without the ability to extract and contribute useful information from complex texts, graphics, and other knowledge representations, one is in effect barred from knowledge work. Print literacy (as with other literacies) has both hard skill and soft skill components; e.g., in reading, fluent word recognition is a testable hard skill, whereas reading comprehension and critical reading are important soft skills. Soft-skill components of reading are mandated and tested but traditional schooling typically deals with them through often ineffectual “practice makes perfect” approaches.

Although there are diverse approaches to literacy education, most of them treat it as an objective to be pursued through learning activities that have literacy as their main purpose. For the most part, with school-based reading, motivation comes from the level of interest in the reading material itself. Consequently, the unmotivated reader, who is frequently one for whom the decoding of print is not fluent, is a persistent problem (Gaskin, 2005). During the past decade, however, new approaches have developed in which the focus is not on literacy as such but on collaborative inquiry, where the primary motivation for reading is solving shared problems of understanding. Effects on literacy have been as great as or greater than those of programs that emphasize literacy for its own sake (Brown & Campione, 1996; Sun, Zhang, & Scardamalia, 2008). Work in Knowledge Forum technology, specially developed to support knowledge building, has provided evidence of significant literacy gains through ICT (Scardamalia, et al., 1992; Sun, Zhang, & Scardamalia, 2008; in press). Whereas literacy-focussed programs typically engage students with reading material at or below their grade level, students pursuing self- and group-directed inquiry frequently seek out material that is above their grade level in difficulty, thus stretching their comprehension skills and vocabularies beyond those normally developed. Rather than treating literacy as a prerequisite for knowledge work, it becomes possible to treat knowledge work as the preferred medium for developing the literacies that support it, with student engagement involving a full range of media objects, so as to support multi-literacies. This approach raises major research issues, which we return to in the final section of this paper.

Knowledge building analytic framework

We have developed a *Knowledge Building Analytic Framework* to advance the two goals presented in the introduction to this paper, to:

- derive an analytic framework for analyzing environments and assessments that characterize and support knowledge-creating organizations and the knowledge-building environments that sustain them
- apply this framework to a set of environments and assessments to better understand models, possibilities, and variations in the extent for which they engage students in knowledge-creating organizations or prepare them for work in them.

In the Paper 4 Annex, we have included a template that can serve as a scoring scheme to apply to a broad range of environments and assessments, making it possible to characterize strengths and weaknesses of knowledge building environments and assessments. The scheme is the same as presented above, in Table 2. It is simply set up in the Annex as a scoring scheme to encourage users to assess specific environments and compare scores by different assessors of the same environment. Users have reported that it is a helpful instrument for reflection on key aspects of the environment analysed, and becomes increasingly beneficial once they have a chance to view and discuss ratings of the same environment by different raters. The discussion of rationales for different ratings facilitates understanding of the dimensions and functions associated with knowledge-creating organizations. Graduate students studying in the field of knowledge creation tended to rate environments lower than the proponents of those environments (see the second section of the Annex, p.44), but not much can be made of this, as the sample is very small. We offer the template to foster the sort of conversation that may be engendered through analysis of a developmental framework related to characteristics of a knowledge-creating organization.

Knowledge Building and Learning Theories

An important question is how environments that help students prepare for the knowledge society and to participate in, contribute to, and benefit from, knowledge-creating organizations relate to modern theories of learning. For example, how does an emphasis on knowledge building fit the "How People Learn" framework, shown in Figure 2, which has been used by a National Academy of Science Committee to organize what is known about learning and teaching (NRC, 2000). The framework highlights a set of four lenses that can be used to analyze learning environments, ranging across homes, community centers classrooms, schools and higher levels of educational organization. The components of the framework involve a focus on four areas that need to be flexibly balanced, depending on current goals and needs. Each area of the framework is accompanied by a set of questions that are useful for exploring the design of learning opportunities, particularly those that support knowledge building.

Figure 2: The 'How people learn' framework

1. *Knowledge-centred*: What needs to be taught to meet the changing needs of people and societies? (Answering this question is fundamental to this entire project.)
2. *Learner-centred*: How can new information be connected with learners' existing beliefs, values, interests, skills and knowledge so that they learn with understanding and can flexibly use what they know?
3. *Community-centred*: How can we develop communities of learners that value excellence as people work together to build new knowledge for the common good? And how can we broaden our sense of community and explore opportunities for learning that connect activities in and outside schools?

4. *Assessment-centred*: How can we develop frequent and useful opportunities for students, teachers, school systems and nations to assess the progress they are making toward 21st century skills?

Knowledge Centred

As discussed above, the world has changed and different kinds of skills and knowledge are required for successful and productive lives in the twenty-first century. Many of the skills identified above are not associated with traditional subject domains, such as the sciences, mathematics, or history—although these, of course, will continue to be important in the 21st century. But work by contributiors to this series of white papers suggests that constant questions about what people need to learn is one of the most important activities for our future, and this will undoubtedly continue to change as well.

Expertise and knowledge organization

More than ever before experts' knowledge must be more than a list of disconnected facts and must be organized around the important ideas of current and expanding disciplines. This organization of knowledge must help experts know when, why and how aspects of their vast repertoire of knowledge and skills are relevant to any particular situation (see Bransford, Brown, & Cocking, 1999). Knowledge organization especially affects the ways that information is retrieved and used. For example, we know that experts notice features of problems and situations that may escape the attention of novices (e.g. see Chase & Simon, 1973; Chi, Feltovich, & Glaser, 1981; de Groot, 1965). They therefore "start problem solving at a higher place" than novices (de Groot, 1965). Knowledge Buildng suggests that learning must include the desire and ability to notice new connections and anomalies, and to actively seek ways to resolve disconnects by restructuring what they know and generating new, domain-bridging ideas.

Generative knowledge building must also be structured to transcend the problem that current courses and curriculum guidelines are often organized in ways that fail to develop the kinds of connected knowledge structures that support activities such as effective reasoning and problem solving. For example, texts that present lists of topics and facts in a manner that has been described as "a mile wide and an inch deep" (e.g. see Bransford, Brown, and Cocking, 1999) are very different from those that focus on the "enduring ideas of a discipline" (Wiske, 1998; Wilson, 1999). However a focus on knowledge building goes beyond attempts to simply improve learning materials and seeks to help learners develop the vision and habits of mind to develop their own abilities to refine, synthesize and integrate.

Adaptive expertise

An especially important focus on knowledge building separates "routine experts' from "adaptive experts" (e.g. Hatano & Inagaki, 1986; Hatano & Osuro, 2003). Both routine experts and adaptive experts continue to learn throughout their lifetimes. Routine experts develop a core set of skills that they apply throughout their lives with greater and greater efficiency. In contrast, adaptive experts are much more likely to change their core skills and continually expand the breadth and depth of their expertise. This restructuring of core ideas, beliefs and skills may reduce their efficiency in the short run but make them more flexible in the long run. These processes of restructuring often have emotional consequences that accompany realizations that cherished beliefs and practices need to be changed. Research by Anders Ericsson and colleagues (2009) show that a major factor in developing expertise is to resist plateaus—in part by continually moving out of one's comfort and engaging in "deliberate practice." This analysis of expertise highlights the need for unlearning as well as learning, and for the kinds of social collaboration that are often invisible when we see write-ups of "experts" in the research literature or the media (e.g. see Bransford & Schwartz, 1999)

This research has implications for the design of environments to support knowledge building. First, an emphasis on building a deep understanding of key ideas is important. This serves as the basis for organizing facts that would otherwise depend on sheer memorization. Second, understanding with respect to the adaptability of knowledge structures highlights the need to support processes of review and reflection.

Learner Centred

The Learner Centred lens of the How People Learn Framework overlaps with the Knowledge Centred lens, but specifically reminds us to think about learners rather than only about subject matter. Many educators deal with issues of understanding learners in ways that allow them to engage in culturally responsive teaching (e.g., Banks, et al., 2007). This includes learning to build on peoples' strengths rather than simply seeing weaknesses (e.g. Moll, 1986), and helping people learn to "find their strengths" when confronted with new knowledge building challenges. Several important aspects of being learner centred are discussed below.

Understanding the constructive nature of knowing

The constructive nature of knowing grew out of the work of Swiss psychologist Jean Piaget. Piaget used two key terms to characterize this constructive nature: *assimilation* and *accommodation*. In Piaget's terms, learners assimilate when they incorporate new knowledge into existing knowledge structures. In contrast, they accommodate if they change a core belief or concept when confronted with evidence that prompts such as change.

Studies by Vosniadou and Brewer illustrate assimilation in the context of young children's thinking about the earth. They worked with children who believed that the earth is flat (because this fit their experiences) and attempted to help them understand that, in fact, it is spherical. When told it is round, children often pictured the earth as a pancake rather than as a sphere (Vosniadou & Brewer, 1989). If they were then told that it is round like a sphere, they interpreted the new information about a spherical earth within their flat-earth view by picturing a pancake-like flat surface inside or on top of a sphere, with humans standing on top of the pancake. The model of the earth that they had developed—and that helped them explain how they could stand or walk upon its surface—did not fit the model of a spherical earth. Everything the children heard was incorporated into their pre-existing views.

The problem of assimilation is relevant not only for young children, but also for learners of all ages. For example, college students have often developed beliefs about physical and biological phenomena that fit their experiences but do not fit scientific accounts of these phenomena. These preconceptions must be addressed in order for them to change their beliefs (e.g. Confrey, 1990; Mestre, 1994; Minstrell, 1989; Redish, 1996). Creating situations that support accommodation is a significant challenge for teachers and designers of learning environments-––especially when knowledge building is involved.

Connecting to students' previous experiences

Ideally, what is taught in school builds upon and connects with students' previous experiences, but this is not always the case. A number of researchers have explored the benefits of increasing the learner centredness of teaching by actively searching for "funds of knowledge" in students' homes and communities that can act as bridges for helping them learn in school (e.g., Lee, 1992; Moll, 1986; Moses, 1994). Examples include helping students see how the carpentry skills of their parents relate to geometry; how activities like riding the subway can provide a context for understanding algebra; how everyday language patterns used outside of school often represent highly sophisticated forms of language use that may be taught in literature classes as an academic subject but have not been linked to students' out-of-school activities. Work by Bell and colleagues specifically link activities in homes and communities with work in schools (e.g. Bell, Lewenstein, Shouse, & Feder, 2009; Tzou & Bell, 2010).

Learner centredness, metacognition and basic cognitive processes

Being learner centred also involves an awareness of some basic cognitive processes that influence learning for everybody. "Metacognition" is the field of psychology that can be used to help people learn about the cognitive processes that underlie their own abilities to learn and solve problems. Several cognitive processes are particularly important.

Attention & fluency

Learning about attention is an important part of becoming a metacognitive learner. For example, here are important constraints on how much we can pay attention to at any particular point in time. The amount of attention that we need to devote to a task depends on how experienced and efficient we are at doing it. When learning to read, for example, the effortful allocation of attention to pronouncing words can make it difficult to also attend to the meaning of what one is reading. The attentional demands that accompany attempts to learn anything new mean that all learners must go through a period of "klutziness" as they attempt to acquire new skills and knowledge. Whether people persist or bail out during these "klutz" phases depends in part on their assumptions about their own abilities. Some people may decide "I'm not good at this" and give up trying before they have a chance to learn effectively (e.g. Dweck, 1986). Wertime (1979) notes that an important part of being learner centred is to help students learn to persist in the face of difficulty by increasing their "courage spans."

Technology presents challenges of "multitasking", and many students feel that this does hot hurt their performance. They can be helped to test this idea for themselves by listening to a lesson with full attention versus listening to one while also multitasking. This is an effective way to help students discover their own abilities and limits rather than simply be forced to comply with "no computers can be on in this class."

Transfer

Learning about ourselves as learners also involves thinking about issues of transfer—of learning in ways that allow us to solve novel problems that we may encounter later. The mere memorization of information is usually not sufficient to support transfer. Learning with understanding typically enhances the experience (e.g. NRC 2000). An important goal for transfer is cognitive flexibility (e.g., Spiro, Feltovich, Jackson, & Coulson, 1991). Experts possess cognitive flexibility when they can evaluate problems and other types of cases in their fields of expertise from many conceptual points of view, seeing multiple possible interpretations and perspectives. Wiggins and McTighe (1997) argue that understanding complex issue involves being able to explain them in more than one way. Spiro et al. (1991) argue that the inability to construct multiple interpretations in analyzing real-world cases can result from instruction that oversimplifies complicated subject matter.

Motivation

Helping students learn to identify what motivates them is also an important part of being learner centred that contributes strongly to knowledge building. Researchers have explored differences between extrinsic motivators (grades, money, candy, etc.) and intrinsic motivators (wanting to learn something because it is relevant to what truly interests you). Both kinds of motivation can be combined; for example, we can be intrinsically interested in learning about some topics *and* interested in receiving extrinsic rewards as well (e.g. praise for doing well, a consultants fee). However, some people argue that too much of an emphasis on extrinsic rewards can undermine intrinsic motivation because people get too used to the external rewards and stop working when they are removed (e.g., Robinson & Stern, 1997).

There appear to be important differences between factors that are initially motivating (the assumption that learning to skate-board seems interesting), and factors that *sustain* our motivation in the face of difficulty ("hmm, this skate-boarding is harder to learn than it looked"). The social motivation support of peers, parents and others is an especially important feature that helps people persist in the face of difficulties. It is also important to be provided with challenges that are just the right level of difficulty—not so easy that they are boring and not so difficult that they are frustrating. Creating the right kinds of "just manageable difficulties" for each student in a classroom constitutes one of the major challenges and requires expert juggling acts. Explorations of the literature on motivation can be found in Deci and Ryan (1985), Dweck (1986) and Stipek (2002).

Agency

An emphasis on knowledge building especially highlights an important aspect of meta-cognition and motivation that involves the need for people to develop socially responsive agency. That is, students must learn to make their own choices, experience the social consequences that arise from them, and revise their strategies when necessary. This is a progressive process of moving from the situation in which the teacher makes decisions about student learning to one where students are increasingly responsible for their own learning activities.

An example involves a recent set of studies on Science Kits for middle school students (Shutt, Phillips, Van Horne, Vye, & Bransford, 2009). They involve hands-on activities such as working with and studying (without harming them) fish, isopods and a variety of other creatures. Throughout the course of the year, the goal is to develop a sense of key variables (e.g. range of temperatures, ranges of acidity, etc) that affect the life of all species. As originally developed, the science work is extremely teacher-directed; the hypotheses to be tested and the methods to be used, such as determining whether isopods desire moist or dry soil, are specified by the teacher. Redesigning these teaching situations has been found to give much more agency to the students. They are given a terrarium and told that their task (working in groups) is to keep their organisms (e.g. isopods) alive. To be successful, they have to choose what questions to ask, how to run the studies, how to do the kind of background research (via technology when needed), and so forth. The initial findings (more precise data will be available soon) show that the sense of agency is very important to students and they take their work very seriously. This kind of activity can hopefully strengthen other skills such as global sensitivity since the students all do their work with the well being of others (even though they are non-humans) foremost in their minds.

Community Centred

The preceding discussion explored a number of issues relevant to being knowledge centred and learner centred. The community centred aspect of the How People Learn framework is also related to being knowledge and learner centred, but it focuses special attention on the social, material, and temporal nature of learning.

The social aspects of learning

The social aspects of learning often include the norms and modes of operation of any community that we belong to or are joining. For example, some classrooms represent communities where it is safe to ask questions and say, “I don’t understand this, can you explain it in a different way?” Others follow the norm of, “Don’t get caught not knowing something.” A number of studies suggest that—in order to be successful—learning communities should provide people with a feeling that members matter to each other and to the group, and a shared belief that members’ needs will be met through their commitment to be together (Alexopoulou & Driver, 1996; Bateman, Goldman, Newbrough & Bransford, 1998). Many schools are very impersonal places, and this can affect the degree to which people feel part of, or alienated from, important communities of professionals and peers.

Concerns that many schools are impersonal and need to be smaller in order to be more learner and community centred can also be misinterpreted as simply being an argument for helping students feel good about themselves. This is very important, of course, but more is involved as well. More includes searching for “funds of knowledge” in students’ lives and communities that can be built upon to enhance their motivation and learning. The more we know about people the better we can communicate with them and hence help them (and us) learn. And more they know about one another, the better they can communicate as a community.

The importance of creating and sustaining learning communities can be traced to Vygotsky’s theory in which culture and human interaction plays a central role in developmental processes. Vygotsky focussed on the intersection between individuals and society through his concept of the zone of proximal development (ZPD)—the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance, or in collaboration with more capable peers (Vygotsky, 1976:86). What a child can perform today with assistance she will be able to perform tomorrow independently, thus preparing her for entry into a new and more demanding collaboration. The emphasis here is on the ways learners draw on each other for ideas and resources that support or scaffold their own learning.

The material aspects of learning

Vygotsky also emphasized the ways in which material resources, such as tools and technologies, change the nature of tasks and the cognitive skills that are required to perform them. This is particularly important in the 21st century, not only because of the ways in which technologies have changed the nature of task and work in the world outside of schools but because students increasingly use a wide range of technologies in their everyday lives and bring these technologies with them into schools. Often teachers do not take advantage of these technologies or use the skills and experiences that students bring with them as a way to increase students' knowledge of school subjects or further develop their 21st century skills. Learning and assessment are far different if students have access to a range of technological tools, digital resources, and social support than if they learn or are assessed without access to these resources; while the real world of work and students' social environments are filled with these tools and resources and they can be effectively built into the learning environment (Erstad, 2008).

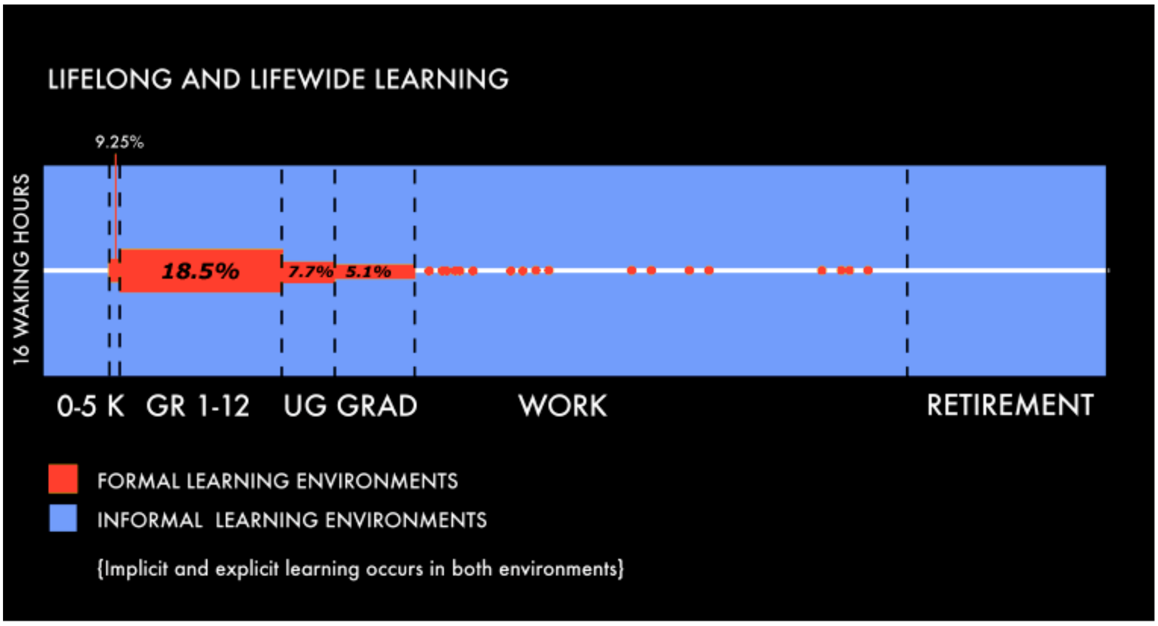


Figure 3: Time spent in formal and informal learning across a typical lifespan

The temporal aspects of learning

At a broader level, being community centred also means reaching beyond the walls of the schools in order to connect with students' out-of-school experiences, including experiences in their homes.

Figure 3, from the LIFE Center, illustrates the approximate time spent in formal (school) and informal (out of school) environments. A great deal of learning goes on outside of school (Banks et al., 2007), but often teachers do not know how to connect these kinds of experiences to school learning. Earlier we discussed the idea of searching for "funds of knowledge" that exist in communities and can be built upon so as to help students succeed. The challenge is to help students build strong social networks within a classroom, within a school, and between classrooms and in- and out-of-school contexts.

Assessment Centred

We've discussed learning centred on knowledge, learner and community; now we turn to assessment centred learning. It is easy to assume that assessment simply involves giving tests to students and grading them. Theories of learning suggest roles for assessment that involve much more than simply making up tests and giving grades.

First, teachers need to ask what they are assessing. This requires aligning their assessment criteria with the goals for their students (part of being knowledge centred) and the “readiness” of students in their classroom (learner and community centred). Assessing memorization (e.g. of properties of veins and arteries) is different from assessing whether students are understanding why veins and arteries have various properties. Similarly, assessing whether students can answer questions about life cycles (of frogs for example) is different from assessing whether they will spontaneously retrieve this information when attempting to solve problems.

At the most general level, issues of what to assess relate to the issue of what students need to know and be able to do in order to have fulfilling lives once they graduate. Because of rapid changes in society, this is an issue that constantly needs to be reconsidered. Debates about standardized tests include concerns that they may “tip” teaching in a direction that is counter-productive for students, because some teachers spend most of their time teaching to the tests while the tests do not assess the range of skills, knowledge and attitudes needed for successful and productive lives in the twenty first century.

Different kinds and purposes of assessment

An especially important aspect of the assessment centred lens in the How People Learn framework is its emphasis on different kinds of assessments for different purposes. When most people think about assessments they think about <u>*summative assessments*</u>. These include unit exams at the end of a unit, standardized tests at the end of the year, and final exams at the end of a course. Summative assessments come in all forms: multiple choice tests, essays, presentations by students, and so forth. These assessments are very important as an accountability mechanism for schools, teachers, and students. Often they reveal important information that the teachers wish they had seen earlier. This is why <u>*formative assessments*</u> are important. These are used for the purpose of improving teaching and learning. They involve making students’ thinking visible as they progress through the course, giving them feedback about their thinking, and providing opportunities to revise.

Assessment and theories of transfer

It is also important for teachers to understand ways in which assessment practices relate to theories of transfer. Consider summative assessments, for example. We all want to make sure that these provide an indication of students’ ability to do something other than simply “take tests.” Ideally, our assessments are predictive of students’ performance in everyday settings once they leave the classroom.

One way to look at this issue is to view tests as attempts to predict students’ abilities to <u>*transfer*</u> from classroom to everyday settings. Different ways of thinking about transfer have important implications for thinking about assessment. Central to traditional approaches to transfer is a “direct application” theory and a dominant methodology that Bransford and Schwartz (1999) call “sequestered problem solving” (SPS). Just as juries are often sequestered in order to protect them from possible exposure to “contaminating” information, subjects in experiments are sequestered during tests of transfer. There are no opportunities for them to demonstrate their abilities to learn to solve new problems by seeking help from other resources, such as texts or colleagues, or by trying things out, receiving feedback and getting opportunities to revise. Accompanying the SPS paradigm is a theory that characterizes transfer as the ability to directly apply one’s previous learning to a new setting or problem. We call this the Direct Application (DA) theory of transfer. Some argue that the SPS methodology and the accompanying DA theory of transfer are responsible for much of the pessimism about evidence for transfer (Bransford & Schwartz, 1999).

An alternative view that acknowledges the validity of these perspectives also broadens the conception of transfer by including an emphasis on people’s “preparation for future learning” (PFL). Here, the focus shifts to assessments of people’s abilities to learn in knowledge-rich environments. When organizations hire new employees they don’t expect them to have learned everything they need for successful adaptation. They want people who can learn, and they expect them to make use of resources (e.g., texts, computer programs, and colleagues) to facilitate this learning. The better prepared they are for future learning, the greater the transfer (in terms of speed and/or quality of new learning). Examples of ways to “prepare students for future learning” are explored in Schwartz and

Bransford (1998), Bransford and Schwartz (1999) and Spiro, Vispoel, Schmithz, Samarapungavan, and Boeger (1987).

The sole use of static assessments may mask the learning gains of many students, as well as masking the learning advantages that various kinds of educational experiences provide (Bransford & Schwartz, 1999). Linking work on summative assessment to theories of transfer may help us overcome the limitations of many existing tests. Examples of SPS versus PFL assessments of learning and transfer are discussed in Bransford and Schwartz (1999).

Implications for assessment reform

Two distinct approaches to the design of environments and assessment have been described. One involves working backward from goals to construct a system of subgoals and learning progressions from an initial state to the goal. The second approach involves e*mergent goals* that are not fixed in advance but take shape as learning and thinking proceed. We have indicated the trade-offs associated with both the *working-backward* and *emergence* approaches, and below, after reviewing assessment challenges related to 21st century skills, we specify the research needed, depending on what one sets out to pursue. In the additive model the "21st century skills" curriculum is added to the traditional curriculum, although often the goal is more in line with assimilative efforts to merge skill and content elements or to piggy-back one upon the other. The problem, exacerbated if each 21st century skill is treated separately, is that the current "mile wide, inch deep" curriculum will grow miles wider and shallower, with the 21st century skills curriculum taking valuable time away from traditional skills. The goal of the transformational model is to effect a deeper integration of domain understanding with 21st century skills. The rationale, elaborated in the section on the parallel advance of domain knowledge and 21st century skills (pp.13ff), is that if a deep understanding of domain knowledge is achieved through exercising 21st century skills, the result will be enhanced understanding in the domain, as well as advances in a broad range of 21st century skills. That is the guiding principle underlying the knowledge building approach. The Knowledge Building Analytic Framework, described in the Annex (p.41), helps those wishing to engage in this transformation to consider progress along its multiple dimensions. Since these dimensions represent a complex interactive system, treating them separately may prove more frustrating than helpful. Fortunately, this also means that tackling one dimension is likely to lead to advances along several of them. The implication for assessment is that we must anticipate and measure generalization effects. We elaborate possibilities for design experiments to integrate working backward and emergence models in the section on specific investigations (pp.38ff). But first we discuss a broader set of issues regarding assessment challenges and 21st century skills.

Assessment challenges and 21st century skills

The quest for evidence-based assessment of 21st century skills is hindered by many factors. First, there are huge variations in formal and informal learning environments and the kinds of assessment that are possible in them. Second, the knowledge and skills that deal with the media and technologies used within a domain need to be distinguished from domain-specific knowledge and skills (Bennett, Persky, Weiss, & Jenkins, 2007; Quellmalz & Kozma, 2003). Third, methods for designing 21st century assessments and for documenting their technical quality have not been widely used (Quellmalz & Haertel, 2008). Fourth, assessments need to be coherent across levels of educational systems (Quellmalz & Pellegrino, 2009; Pellegrino, Chudowsky, & Glaser, 2001). Coherence must start with agreement on the definition of 21st century skills and their component knowledge and techniques. Moreover, the design of international, national, state and classroom level tests must be clarified and aligned, otherwise assessments at different levels will not be balanced and inferences about student performance will be compromised.

Evidence-centred design (Messick, 1994; Mislevy & Haertel, 2006) links 21st century skills to the task features and reports of evidence that characterize student performance and progress. In the sections immediately following we describe how evidence-centred design can be used to develop formative assessments that are embedded in learning environments and that link these formative assessments to large-scale, summative assessments.

Cognitively-principled, evidence-centred assessment design

As described above, research on the development of expertise in many domains has indicated that individuals proficient in a domain have large, organized, interconnected knowledge structures and well-honed domain-specific problem-solving strategies (Bransford, Brown & Cocking, 2000). The design of assessments, therefore, should aim to measure both the extent and connectivity of students' growing knowledge structures and problem-solving strategies (Pellegrino et al., 2001; Glaser, 1991). For example, in the domain of science, core knowledge structures are represented in models of the world built by scientists (Hestenes, Wells, & Swackhamer, 1992; Stewart & Golubitsky, 1992). Technologies are seen as tools that support model-based reasoning by automating and augmenting performance on cognitively complex tasks (Norman, 1993; Raizen, 1997; Raizen, Sellwood, Todd & Vickers, 1995).

The NRC report, *Knowing What Students Know,* presents advances in measurement science that support the integration of cognitive research findings into systematic test design frameworks. As a brief overview, evidence-centred assessment design involves relating the learning to be assessed, as specified in a *student model*, to a *task model* that specifies features of the task and questions that would elicit observations of learning, and to an *evidence model* that specifies the student responses and scores that serve as evidence of proficiency (Messick, 1994; Mislevy et al., 2003; Pellegrino et al., 2001). These components provide a structure for designing assessments of valued 21st century skills and also for evaluating the state of current assessment practices. Evidence-centred design (Messick, 1994; Mislevy & Haertel, 2006) can be used to design formative assessments and link these to large-scale, summative assessments.

The role of domain knowledge

An issue for large-scale 21st century assessments is the role of knowledge about topics and contexts in a discipline or specialization that is required to accomplish tasks and technology-based items. Large-scale assessments of 21st century skills cannot assume that all students will have learned a particular academic content. Fortunately, assessments of 21st century skills within learning environments *can* identify the content knowledge within which they will be situated. In academic subjects, current assessments of problem solving and critical thinking skills, if they are directly assessed and reported at all, are typically reported as components of subject matter achievement (i.e., math problem solving, science inquiry), not as distinct 21st century skills. In addition, in core school subjects as well as informal settings, students may use common or advanced technologies, but their technology proficiencies tend not to be tested or reported. Therefore, to assess and report progress on 21st century skills, the design of assessments of students' performance relevant to them must specify the knowledge and skills to be tested and reported for each skill (see White Paper 1); either cross-cutting processes such as problem solving or communication, or their ability to use technologies in a range of academic and practical problems. An important feature of knowledge-building environments and the assessments of ICT skills within them will be to test not only the use of ICT tools, simple and advanced, but also the learners' skill in using a range of ICT tools to extend and build their knowledge and strategies for increasingly more complex tasks. In addition, learners' adaptive expertise, their ability to transfer their existing knowledge and strategies to novel problems, will need to include direct assessment of their ability to learn and apply new technologies.

Assessments embedded in technology-rich environments

The design of assessments must begin by specifying their purposes and intended uses (AERA/APA/NCME, 1999). These specifications then lead to validity questions such as "Does the assessment support the inferences and actions based on it?" The two conventional distinctions are between summative and formative purposes. As indicated earlier, summative assessments are administered at the end of an intervention, or a unit within it, so as to judge whether goals have been met. Formative assessments are administered during interventions to inform learners and instructors, giving time for midcourse corrections. A recent definition proposed in the U.S. by the Formative Assessment for Students and Teachers (FAST) state collaborative, supported by the Council of Chief State School Officers, is that "Formative assessment is a process used by teachers and students during instruction that provides feedback to adjust ongoing teaching and learning to improve students' achievement of intended instructional outcomes." According to the FAST definition, formative assessment is not an instrument, but the process of using information about progress toward a goal to improve learning. Important attributes of formative assessments are that the outcomes are *intended* and clearly *specified* in advance, the methods are deliberately planned, the *evidence of learning* is used by teachers and students, and *adjustments occur during instruction*. Attributes of effective FAST formative assessment include: clearly articulated learning progressions; learning goals and criteria for success that are clearly identified and communicated to students; evidence-based descriptive feedback; self and peer assessment; and collaboration of students and teachers in working toward learning goals. Formative assessments of 21st century skills, therefore, would specify the 21st century outcomes and systematic methods for monitoring progress and providing feedback, as well as clear criteria for success. Formative assessments for 21st century skills could be employed for all the 21st century skills in all kinds of learning environments.

This FAST prescription of formative function of 21st century assessments is quite different from the use of embedded assessments to validate large-scale assessment results, or to augment the evidence that could be collected in a one-time, on-demand test. A third function of embedded assessments can be to collect detailed information about processes and progress for research purposes, and to begin to create a more coherent integration of formative and summative assessment.

What evidence will be sought?

Within an evidence-centred design assessment framework, broad 21st century skills, such as problem solving or communication, need to be further dissected into component targets for assessment. Problem-solving targets in mathematics might involve planning solution strategies or evaluating solutions. In science, problem solving might involve targets such as planning investigations or interpreting data in visualizations (Quellmalz & Kozma, 2003). In literature, problem solving may involve analyses of Shakespeare plays, looking for recurring symbolism related to the plot. Problem-solving targets to assess in a practical situation might involve selecting a green technology, such a wind turbine, and analyzing its potential environmental impacts. The assessment targets for 21st century problem-solving skills will be at a more general level for applications across domains and situations and in more specific terms than problem-solving applications in specific domains. Problem-solving assessment tasks will need to represent highly structured problems with known solutions and also problems with several appropriate solutions. In domain-centred learning environments, assessment tasks will go beyond the repetition of previously-performed experiments to open-ended tasks permitting numbers of appropriate methods for eliciting evidence of how well learners plan, conduct, and interpret evidence in solving a problem or achieving a goal.

Evidence-centred assessment design requires that embedded assessments articulate the qualitative or quantitative information that would document achievement of each 21st century skill and its component targets. For formative assessments, a crucial feature is that the evidence and criteria be understandable and useable by teachers and students. For example, self and peer assessment are key features of effective formative assessment. Such activities are already familiar in classes that use peer review of drafts of compositions or peer critiques of presentations. In the workplace, peer review is a hallmark of professional publications.

While common Internet and productivity tools are often integrated across contexts and disciplines, the “tools of the trade” differ between humanities, sciences, and social sciences, and so on, as well as between post-secondary learning environments, the workplace, and the professions. In primary and secondary formal schooling, common Internet and productivity tools are often integrated across contexts and disciplines. Once again, the knowledge and skills will need to be specified and further decomposed as they apply to different learning environments. Evidence of achievement will also need to be specified in ways that are shareable with learners and teachers. Thus embedded assessments of use of specific technologies will vary according to the context and domains emphasized. Nonetheless, new assessment possibilities are opening up through efforts to create tools that are useable across domains and that link domain-specific environments with more general environments.

An important value of 21st century skills that are difficult to assess in a timed, on-demand large-scale test, is that they can be monitored over time within learning environments. For example, creativity and innovation can be assessed in relation to how learners have gone beyond what was specified in learning activities. Collaboration with present and virtual peers and experts can be monitored throughout formation of teams, integration of contributions and feedback, to reflect on the effectiveness of the team processes and the achievement of goals.

Design of assessments to elicit evidence of 21st century skills

Systematic, direct assessment of 21st century skills in classrooms is rare. Although students may be taught to use common and advanced tools, teachers tend not to have specific standards for 21st century skills for students to meet nor testing methods to gather evidence of student skill in using the technologies. In either formal or informal learning environments, teachers are typically left on their own to figure out how to integrate technology into their curricula or into informal learning activities. The state of integration of the assessment of 21st century skills into learning activities remains in its infancy.

Assessment must be designed to elicit evidence of learning related to each assessment target. Research on effective formative assessment describes types of formal and informal observations of learning, from questions to and from learners, to examinations of work in progress, and evaluations of work products. However, these observations should be planned for in advance with the criteria for success laid out and shared with learners. For example, systematic observations of groups during collaboration activities can be structured so as to record the types and quality of interactions. These observations can be summarized and reviewed with groups and individuals.

The 21st century skills integrate learners' use of a range of technologies over the variety of contexts and domains in the learning environments. Central to the 21st century skills is the learner's ability to select and use appropriate technologies during processes such as innovation, communication, collaboration, problem solving, and citizenship. Technologies offer many possibilities for designing richer, deeper, wider-ranging learning activities and assessments. Possibilities for technology-supported reform of learning environments and assessments include:

- provision of authentic, rich, dynamic environments
- access to collections of information sources and expertise
- use of formal and informal forms of collaboration and social networking
- presentation of phenomena difficult or impossible to observe and manipulate in classrooms
- examples of temporal, causal, dynamic relationships "in action"
- allowing multiple representations of stimuli and their simultaneous interactions (e.g., data generated during a process)
- the use of overlays of representations, symbols
- student manipulations/investigations, multiple trials
- student control of pacing, replay, revision
- making student thinking and reasoning processes visible
- capturing student responses during activities (e.g., research, design, problem solving)
- allowing the use of simulations of a range of tools (internet, productivity, domain-based).

Below, in the section on assessment and the knowledge building developmental trajectory (pp.33ff), we extend this list. But first we introduce the notion of an assessment profile and elaborate on the potential for new environments and assessments to inform and be informed by large-scale assessments.

Assessment profile

The purpose of the Knowledge Building Analytic Framework, (see Annex, p.41), is to determine the extent to which an educational environment is moving toward a knowledge-creating enterprise, in line with the developmental trajectories defined in Table 2. The assumption underlying this Framework is that educational environments, not only students, should be evaluated. But of course the work of students must also be analysed, and for this purpose these dimensions need to be translated into measures of individual and group performance. We propose such work as part of a necessary program of research (see pp.36ff). But for now we offer six dimensions of assessment to support use and coverage of all manner of assessments to measure 21st century skills, across all classrooms, so as to ensure quality assessments and to guide instructional practices.

Alignment between assessments and 21st century skills. Some assessment instruments may not assess or support one or more of the 21st century skills, so it is helpful, for each target 21st century skill, to determine if there is (1) full, (2) partial, or (3) no alignment.

Purpose and intended use of assessments. Assessment data, tasks and items may serve as (1) formative assessments, so students and instructors can monitor learning and adjust instruction as it proceeds, (2) summative evidence of end-of-instruction achievements, or (3) project evaluation or research, not shared with learners and instructors. For each 21st century skill it is worth tracking its purpose on each of these purposes.

Construct Representation. Assessment tasks and items can sometimes produce evidence about only portions of the targeted constructs, desired knowledge or skills. For example, if the target is systems knowledge, components or simple interactions may be tested rather than dynamic, emergent behaviours. Or basic facts or steps may be tested rather than higher level, integrated knowledge and skills. When constructs are only partially tested, important components may not be fully represented. For each 21st century skill it should be determined whether available evidence represents (1) the construct; (2) part of the construct; or (3) none of the construct.

Integration into learning activities. Assessments in learning environments may be integrated into ongoing activities to a greater or lesser extent. Integrated, ongoing assessments can gather evidence of learning throughout their activities. Interim assessments less directly linked to ongoing activities may be periodically administered as checks. Or, de-contextualized, external assessments can be dropped in. Thus it is helpful, for each 21st century skill, to determine the extent to which tasks and item responses (1) are fully integrated into learning activities; (2) are assessed afterwards, separately from learning activities; or (3) are not assessed.

Feasibility. Assessments in learning environments may also differ in the feasibility of their use. They may be easily completed and interpreted by learners and instructors or need access to technologies that may be permanently available, or only periodically. Thus it needs to be determined whether the assessment is (1) easily used, with minimal or no support; (2) possible to use, but requiring ongoing support; or (3) complex, requiring specialized methods and support.

Technical quality. The assessments may require levels of expertise to administer and score that are beyond the training of many instructors. Technical quality evidence would include not only confirmation that the assessments provide credible information for their intended uses in the environments (e.g., formative or summative), but also that the interpretations of observations and evidence are reliable across instructors and environments. Thus it is important to clarify if technical quality is (1) fully, or (2) only partially established.

Connecting learning environments and formative assessments to large-scale tests

Currently, there are different, often competing, approaches to assessing 21st century skills. One approach focuses on assessment *of* technology, such as the International Computer Driving License and technology proficiency tests in some states in the U.S. These tests measure the facts and procedures needed to operate common Internet and productivity tools, while the content or the academic or applied problem and context are deliberately chosen to be familiar background knowledge (Venezky & Davis, 2002; Crawford & Toyama, 2002). The cognitive processes addressed in 21st century skills, such as problem solving, communication, collaboration, innovation, and digital citizenship are not targeted by such tests *of* technology operations.

In a second approach, 21st century skills emphasize learning *with* technology by presenting test problems and items that *integrate* measurement of technology operations in terms of strategic use of technology tools to solve problems with subject matter knowledge and processes, by way of carefully designed sets of tasks and items related to complex academic and real world problems.

In a third approach, the testing is implemented *by* technology. Assessments *by* technology simply use technical infrastructures to deliver and score tests that are designed to measure other content and skills, in subjects such as mathematics and reading. These test designs aim to reduce or eliminate the demands of the technology, treating it as a construct of no relevance. Equivalence of paper-based and technology-based forms is the goal here. Technology-based tests are increasing rapidly in large-scale state, national, and international testing, where technology is being embraced as a way of reducing the costs and logistics of assessment functions, such as test delivery, scoring, and reporting. Technology-based tests typically assume that supporting technology tools such as calculators or word processors are irrelevant to the content constructs being tested and therefore, are not to be measured separately. Since these types of testing programs seek comparability of paper and online tests, the tests tend to present static stimuli and use traditional constructed-response and selected-response item formats. For the most part, these conventional, online tests remain limited to measuring knowledge and skills that can be easily assessed on paper. Consequently, they do not take advantage of technologies that can measure more complex knowledge structures and the extended inquiry and problem solving included in the 21st century ICT skills described in the *Assessment and Teaching of 21st Century Skills* project and reported in White Paper 1 (Csapó, 2007; Quellmalz & Pellegrino, 2009). In short, a technology-delivered and scored test of traditional subjects is not an assessment of 21st century ICT skills and should not be taken as one. 21st century skills assessments will not use technology just to support assessment functions such as delivery and scoring, but will also focus on measuring the application of 21st century skills while using technology.

Large-scale assessments of 21st century skills could provide models of assessments to embed in learning environments, but current large-scale tests do not address the range of 21st century skills in ways that would advance knowledge-building environments. In the U.S., the new 2012 Framework for Technological Literacy for the National Assessment of Educational Progress sets out three major assessment areas: Technology and Society, Design and Systems, and Information Communication Technologies (see naeptech2012.org). Technological literacy in the framework blends understanding of the effects of technology on society, 21st century skills, and technology design. The 2012 assessment will present a range of long and short scenario-based tasks designed to assess knowledge and skills in the three areas. In the U.S., assessments of 21st century skills and technological literacy are required for all students by grade 8. However, state tests or school reports are considered sufficient to meet this requirement, and school reports may be based on teacher reports that, in turn, can be based on questionnaires or rubrics that students use in ICT-supported projects. Most teachers do not have access to classroom assessments of 21st century skills, or professional development opportunities to construct their own tests. Moreover, the lack of technical quality of teacher-made and commercially developed classroom assessments is well documented (Wilson & Sloane, 2000). Even more of a problem is the lack of clarity for teachers on how to monitor student progress on the development of 21st century skills, not only the use of the tools, but ways to think and reason with them. Teachers need formative assessment tools for these purposes.

Concurrent, embedded and transformative assessment of knowledge building

In line with the emergence approach as well as the knowledge-creation imperative to continually go beyond what is currently viewed as best practice, we describe new forms of data from classroom environments that make it possible to provide richer, more comprehensive, and more readily available accounts of student performance than are possible through traditional testing. They require new, powerful knowledge building environments of the sort discussed above.

In the preceding sections we have discussed embedded, formative, and summative assessment, now we add the concepts of concurrent and transformative assessment. Concurrent assessment means that the assessment is available instantaneously The challenge is effective design of feedback that informs high-level processes as well as more straightforward procedures. Transformative means that the evaluation is not simply an account of past performance, pointing to the next immediate steps, but also provides indication of ways individuals and teams can tackle broader problems and situate their work in relation to that of other team members and teams, within and outside the school walls.

When student discourse is central to the operation of the community, with members contributing to shared, public knowledge spaces, and building on each other's ideas, vast new possibilities for assessment become possible, for enriching the community's work and enabling concurrent and transformative assessment. The discourse to be analysed may include online as well as face-to-face interactions, recorded through video or conferencing software and transcribed. Examples of the profiles of student work that can be generated easily from such data are presented below. Even at this early stage, there is a great deal of excitement among the researchers, teachers and students who have pilot-tested these tools in their classrooms. Teachers and students alike readily see their advantage and generate ideas for improving them.

For the examples presented, the data was generated automatically from student discourse and artifacts, and as suggested below, the tools can be used to identify patterns and support continual improvement in practice and student achievement. A substantial part of the challenge in advancing concurrent, embedded, and transformative assessment will be avoiding pitfalls while taking advantage of substantial new opportunities.

Contributions. A contribution tool can provide measures of the number of notes created, the nature of entries (based on keywords, media type, etc.), an overview of the content areas participants worked in, and so forth. Contributions related to a specific problem can be traced, thus making it possible to start investigating individual and group problem solving. The teacher can use the tool during each session or immediately afterwards, to determine how productive each student has been (e.g., how many notes were read, created or modified). Such information helps the teacher to direct attention to students who may need more support or instruction, and helps them identify barriers that are preventing students from participating fully in the knowledge building community. Students can use the tools, if the teacher enables their access, to see where they are in the class distribution (no names are shown).

"Thinking types" or scaffolds to support 21st century skills. Scaffolds can be built on the basis of theory-driven accounts of advanced knowledge processes (see the section on technology to support emergence of new skills, pp.34ff)**.** Computer-mediated and customizable scaffold supports allow teachers and students to use scaffolds and rubrics flexibly and for students to tag their notes according to thinking type (Andrade, 2000; Chuy, et al., 2009; Law & Wong, 2003; Lai & Law, 2006). By identifying the 21st century skill they are engaged in (problem solving, theory development, research, decision making etc.) students become more cognizant of these skills. And once text is tagged, searching by scaffolds make it easy for students and teachers to find, discuss, and evaluate examples. Formative assessment tools can be used to provide feedback on patterns of use and to help extend students' repertoires.

Use of new media and multiliteracies. Students can contribute notes representing different modalities and media, such as text, images, data tables, graphs, models, video, audio, and so forth. Results suggest that growth in textual and graphical literacy are important by-products of work in media-rich knowledge-building environments (Sun, Zhang & Scardamalia, 2008; Gan, Scardamalia, Hong & Zhang, 2007).

Vocabulary. A vocabulary tool can provide profiles for individuals and groups, including the rate of new word use, use of selected words from curriculum guidelines (or from any set of words), and so on. It is also easy to look at the growth of vocabulary in comparison to external measures or benchmarks, such as a grade-level lists. Thus teachers can determine if important concepts are entering the students' productive vocabularies, the extent of their use of words at or above grade level, their growth in vocabulary based on terms at different levels in the curriculum guidelines, and so on. Information about the complexity and quality of notes can also give the teacher direction as to the type of instruction the class may need. Early, informal use of these vocabulary tools suggests that students enjoy seeing the growth in their vocabulary, and begin to experiment with new words that have been used by others in the class.

*Writing***.** Measures of writing start with basic indicators (e.g. total and unique words, mean sentence length). There are many sophisticated tools already developed and open source arrangements will make it increasingly easy to link discourse and writing environments.

Meta-perspectives. A brainstorming tool (Nunes, Nunes, & Davis, 2003) can be used to foster students' metacognitive thinking about specific skills and support students in the exercise of creativity, leadership and collaboration. Tools can also be built to allow students to tag notes containing questions asked but not answered, claims made with no evidence, etc. Once tagged, visualization tools can bring to the forefront of the knowledge space ideas needing extra work.

Semantic Analysis. This tool makes it possible to work in many and flexible ways with the meaning of the discourse. A semantic-overlap facility extracts key words or phrases from user-selected subsets of the discourse and shows overlaps. For example, one application of this tool is to examine the overlap between a participant's discourse and discourse generated by experts in a discipline or in curriculum guidelines. Other applications include the examination of overlap between two or more participants or student writing and assigned readings. A semantic field visualization provides graphical displays of the overlap of the semantic fields of subsets of the discourse by employing techniques from latent semantic analysis (Teplovs, 2008). For example, a benchmark can be identified, representing a specific domain. The tool can show the growing overlap of semantic fields between the students' discourse and the benchmark representing any complex knowledge domain of interest, as the following visualizations suggest. The benchmark, at the top of each graph, might be the semantic space for curriculum guidelines, for test items, for authoritative sources or for any selected text or set of texts.

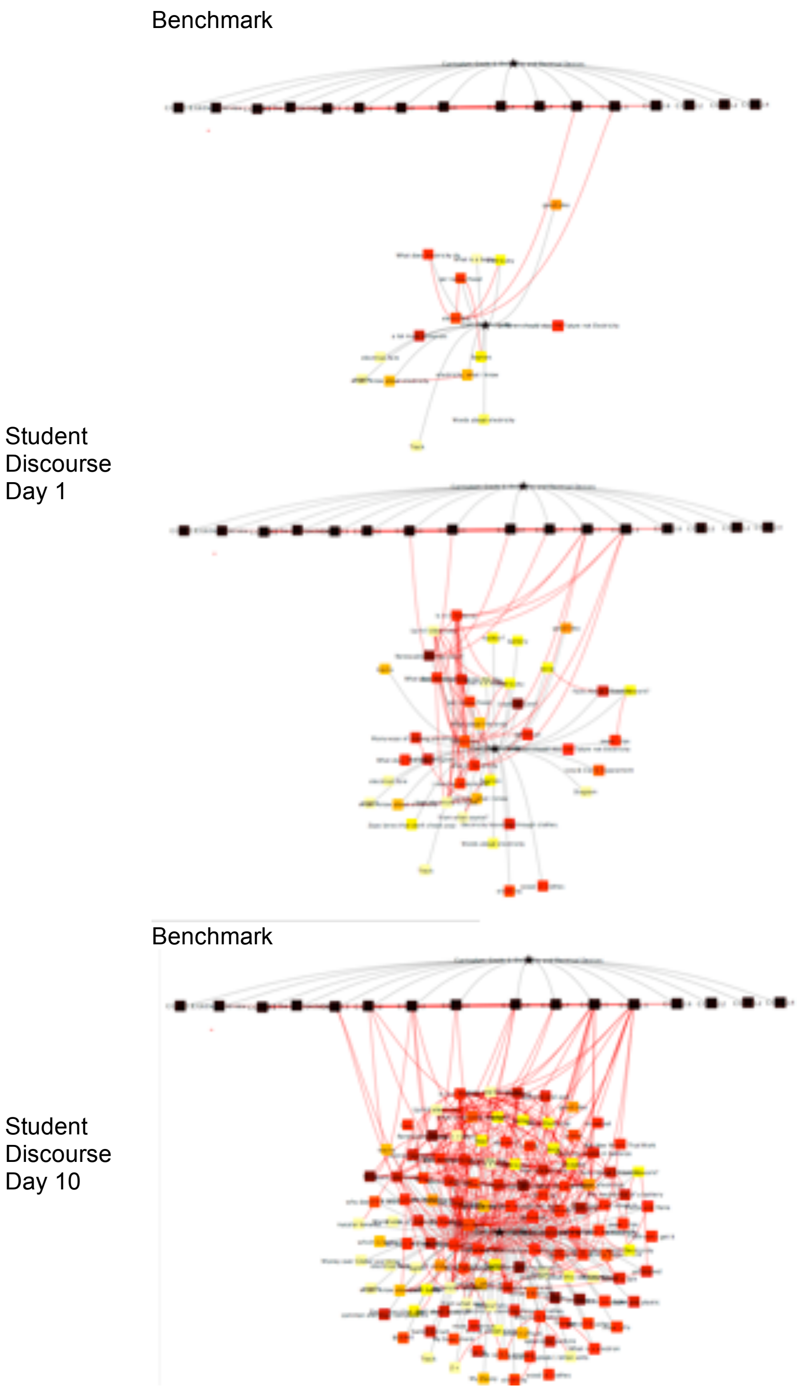


Figure 4: Semantic field visualization of a classroom over ten days

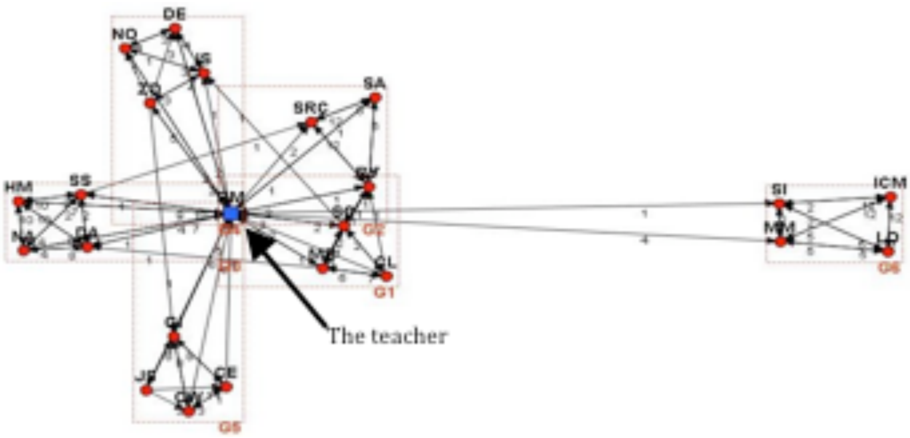
Social Network Analysis. Social Network Analysis tools display the social relationships among participants based on patterns of behaviour (e.g., who read/referenced/built on whose note). A Social Network Analysis Tool can help teachers to better understand who the central participants are in the knowledge building discourse and to see whether existing social relationships are limiting the community's work or influencing it positively. The tool draws the teacher's attention to children who are on the periphery and makes it more likely that these children will receive the direct support they may need to be more integral to the work of the class.

Increasing levels of responsibility for advancing collective knowledge is facilitated when student contributions to classroom work are represented in a communal knowledge space. Below are graphics generated from the social network analysis tool to give some sense of how it is possible to uncover classroom practices associated with advances in student performance—practices that would be impossible to uncover without use of communal discourse spaces. The work reported in Figure 5 (Zhang, Scardamalia, Lamon, Messina, & Reeve, 2007; Zhang, Scardamalia, Reeve, & Messina, 2009) is from a Grade 4 classroom studying optics. The teacher and students worked together to create classroom practices conducive to sustained knowledge building. Social network analysis and independently generated qualitative analyses were used to assess online participatory patterns and knowledge advances, focusing on indicators of collective cognitive responsibility.

The social network graphs generated by the *Social Network Analysis tool* indicate increasingly effective procedures for advancing student knowledge corresponding to the following social organizations: (a) Year 1—fixed, small-groups; (b) Year 2—interactive small groups working together throughout their knowledge work; and (c) Year 3—opportunistic-collaboration, with small teams forming and disbanding under the volition of community members, based on emergent goals that arose as they addressed their shared, top-level goal of refining their knowledge of optics. The third-year model maps most directly onto the organic and distributed social structure in real-world knowledge-creating organizations. Among the three designs, the opportunistic-collaboration model resulted in the highest level of collective cognitive responsibility, knowledge advances, and dynamic diffusion of information. This 3-year account, as shown from the perspective of the social network analysis tool, is shown in the following figure (see Zhang et al. 2009 for details)..

I

Year 1



Year 2

Year 3

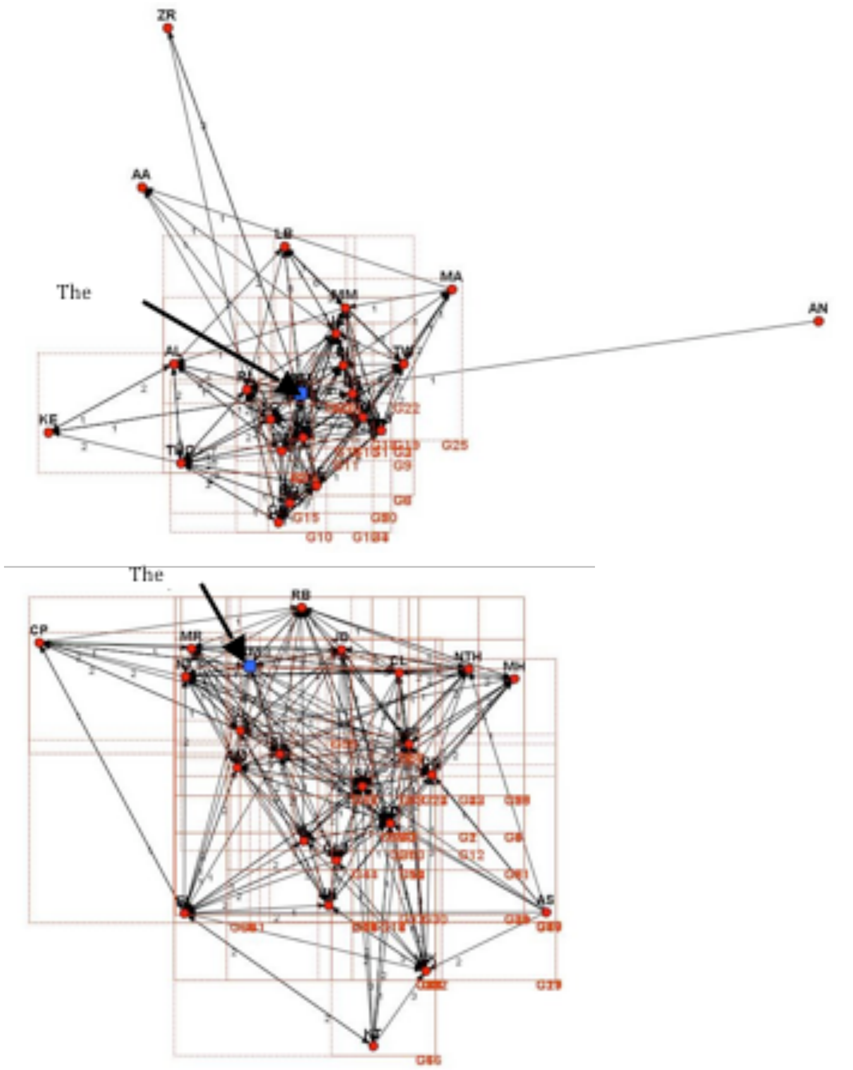


Figure 5: The emergent process of knowledge building over three years

In these graphs a node represents a group member. A line between two nodes denotes a note linking relation between two members, indicating that one member has built on or referred to a note by the other. The direction and frequency of such connections are represented by the arrow and value on the line. The more information flow a member carries, the more centrally he/she is displayed in a network. Tools such as those presented above allow teachers and students to visualize their work in new ways. They can be applied to discourse on any topic, at the group as well as individual level. There are endless possibilities for reconstructing knowledge spaces to bring different issues and concerns into perspective and to show change over time. This work is in its infancy and Web 2.0/3.0 developments will greatly enhance it.

Assessment, open knowledge resources and development of knowledge building

The need for developmental frameworks, definitions, and models runs through the *Assessment and Teaching of 21st Century Skills project*. This is evident in this report in the discussion of frameworks (ch.2), the argument for the need to identify learning progressions to describe pathways that learners are likely to follow towards the mastery of a domain (ch.3) and in the discussion of item development (ch.4). We hope to contribute to these efforts through identifying developmental progressions grounded in the theory and practices of knowledge creating organizations. We argue that all citizens should have the opportunity to participate in knowledge building environments that fully integrate 21st century skills and move them along the developmental trajectories set out earlier in Table 2. The tools we describe above can help accomplish this by charting progress and addressing design principles in new ways.

Design principles for knowledge-building environments include: (a) empowering users and transfering greater levels of agency and collective responsibility to them; (b) viewing assessment as integral to efforts to advance knowledge and identify problems as work proceeds; (c) enabling users to demand changes and customization of tools so the environments are powerful enough to be embedded in the day-to-day workings of the organization; (d) supporting the community in self-directed rigorous assessment, so there is opportunity for the community's work to exceed, rather than simply meeting the expectations of external assessors; (e) incorporating standards and benchmarks into the process, so they are entered in digitized form and become objects of discourse, and so can be annotated, built on, linked to ongoing work and lifted above; (f) supporting inclusive design, so there is a way in for all participants; this challenge brings with it special technological challenges (Treviranus, 1994, 2002); (g) providing a public design space to support discourse around all media (graphics, video, audio, text, etc.) with links to all knowledge rich and domain specific learning environments; (g) encouraging openness in knowledge work. Once these requirements are met, participants are engaged with ICT in meaningful, interactive contexts, with reading and writing part of their expressive work across all areas of the school curriculum. They can then make extensive use of the forms of support that prove so helpful in knowledge-creating organizations—connections with other committed knowledge workers and world-class knowledge resources.

Combining ICT-enabled discourse environments and open resources sets the stage for breakthroughs in charting and enhancing development in knowledge building environments. For example, student discourse environments can be linked to powerful simulation, tutorial, intelligent tutoring, and other domain-specific tools (Quellmalz & Haertel, 2008; *http://www.ascd.org/publications/educational_leadership/nov09/vol67/num03/The_Next_Generation_of_Testing.aspx*; *http://oli.web.cmu.edu/openlearning/initiative*. It is then possible to combine the benefits of these different tools and promote interactions surrounding their use. As explained in The Open Learning Initiative, Carnegie Mellon University, it is possible to build assessment "into every instructional activity and use the data from those embedded assessments to drive powerful feedback loops for continuous evaluation and improvement." Assessments from these tutorials, simulations, games, etc. can complement those described in the section on open-source software and programming interfaces (pp.29ff), and, combined with interoperability of applications, allow us to further break down the barriers between various environments and assessments that have traditionally been separate and disconnected, so as to search and compile information across them. Open resources make it possible to assemble information on learning progressions, benchmarks, and learning modules. Curriki is an example of a web site where the community shares and collaborates on free and open source curricula (*http://www.curriki.org/*). Creative Commons licences further expand access to information to be shared and built upon, bringing an expanded concept of intellectual property.

These open resources, combined with data from discourse environments, make it possible to build student portfolios, based on classroom work and all the web-accessible information created from in- or out-of-school uses of simulations, games, etc, across topics and applications (dealing with ethical issues presents a different, significant challenge). Extended student portfolios will allow us to chart student progress in relation to various and changing developmental benchmarks, as well as to foster development through formative feedback. For example, "nearest neighbour" searches, based on student semantic spaces, can identify other people, in the same class or globally, as well as local or global resources, working with similar content. Connections can then be made, just in time, any time, to meet both teacher and student needs. This support can help the class as a whole to operate as a 21st century organization, as well as supporting individual student achievement.

We envision worldwide teams of users (Katz, Earl & Jaafar, 2009) and developers taking advantage of new data-mining possibilities, intelligent web applications, semantic analysis, machine learning, natural language processing, and other new developments to advance the state of the art in education.

Technology to support emergence of new competencies

Two recent books discuss in depth the effects that new technologies can have in shifting education on to a new basis for the 21st century. One is *Rethinking Education in the Age of Technology: The Digital Revolution and Schooling in America* (Collins & Halverson, 2009). Collins and Halverson argue that new technologies create learning opportunities that challenge traditional schools. They envision a future in which technology enables people of all ages to pursue learning on their own terms. Figure 31 above indicates that more time by far is spent in out-of-school contexts, across the entire lifespan. If these become primary contexts for learning, tasks designed especially for school will pale by comparison in their impact on education. The second book is *The World Is Open: How Web Technology Is Revolutionizing Education* (Bonk, 2009). Bonk explains ways in which technologies have opened up the education world to anyone, anywhere. He discusses trends such as web searching, open courseware, real-time mobility, portals, and so forth that will impact learning in the 21st century. These technologies are not envisaged as a cafeteria line for students to proceed along and pick and choose (which, unfortunately, seems to have been the formative concept in many instructional support systems); instead, they are envisaged as constituting an environment supportive of a more fully engaged community of learners, more open to the world's cognitive and emotional riches.

These ideas are in line with our earlier discussions of the emergence of new competencies and open resources. Rather than simply extrapolating from existing goals or expert-identified objectives, new goals can emerge from the capacities that students demonstrate in supportive environments—such as the capacities for proportional reasoning and theory building revealed in the examples cited. Both these experimental approaches have, in fact, made use of computer-supported knowledge-building environments that provide support for the creation of public knowledge (Moss & Beatty, 2006; Messina & Reeve, 2007). Among the technical affordances serving this purpose are "thinking types" or scaffolds, described above, "rise-above" notes that serve the purposes of synthesis and the creation of higher-order representations of ideas, and graphical backgrounds for creating multiple representations and organizing ideas (Scardamalia & Bereiter, 2006).

In the theory-building work elaborated above (pp.6ff) scaffolds supported theory building. The "theory supports" included the following phrases: "My theory," "I need to understand," "Evidence for my theory," "Putting our knowledge together," "A better theory." To use these scaffolds students simply need to click on one of these phrases, arrayed on a panel to the left of their writing space, and a text field containing the phrase is copied into their text at the appropriate point. Text that the student inserts into the text field to complete the phrase is automatically tagged according to the scaffold name. This simple support has increased the use of these phrases in student writing, and, results suggest, has enhanced the high-level knowledge processes they represent. In the Knowledge Forum environment, used in the theory-building example, scaffolds are customizable, so these discourse supports can easily be changed to fit any 21st century goal. (They can also be used after the fact, to mark up text already written.) These scaffolds foster metacognitive awareness, as students use them to characterize their discourse. The scaffold supports also serve as search parameters, further encouraging their use and allowing students and teachers easily to search their communal knowledge space so as to determine what different theories there are in the database, what evidence is used to defend them, the nature of theories that are considered to be improvements on earlier theories, and so forth. And it is quite easy with these tagged "thinking types" to build formative assessments to enhance student development. For example, it is possible to create profiles of student or group activity, to find whether students and the class are generating lots of theories but providing no evidence—or perhaps they are providing evidence but cannot put their ideas together to generate an improved theory. Patterns of use make it possible to detect underrepresented knowledge processes and to inform and advance such work.

An important role for technology is to support individuals in constructive contributions to the group. The scaffolds help. At the group level the essential question is: has the public knowledge shared by a group progressed—to what extent has this knowledge emerged from a group process as opposed to being merely an aggregation of individual products? New Web developments under the banner of Web 3.0 are known as the "semantic web," in that the units of primary interest are ideas or meanings rather than words. Some educational evaluation tools have already made this leap (Teplovs, 2008); we can look forward to further developments in this sphere, which align the powerful machinery of Web technology with the educational interests of a knowledge-creating culture. We elaborate on these ideas in the section on technological and methodological advances to support the development of 21st century skills (pp.39ff).

Although findings from the emergence approach are very limited, they suggest that students who are so engaged demonstrate advances across a broad range of 21st century skills (Chuy, et al, 2009; Gan et al, 2007; Sun et al. 2008, in press), and that an emergence approach may contribute genuinely new discoveries to inform large-scale assessment. Positive results of an emergence approach also suggest that defining and operationalizing 21st century skills one-by-one, while important for measurement purposes, may not be the best basis for designing educational activity.

As technology blurs the line between in- and out-of-school contexts, and knowledge becomes a social product situated in open worlds, the need for environments and formative assessment that span educational contexts and support “community knowledge” and group or “collective intelligence” will become increasingly important.

Necessary Research

This section identifies important areas of research and development related to the overall goal of developing new assessments and environments for 21st century knowledge building. We start with research and development to improve formative assessments in current learning environments and then move on to studies and advances in formative assessment likely to transform schools into the image of knowledge creating organizations.

Analysis of 21st century skills in current learning environments

A research program on reforming the assessment of 21st skills would benefit from greater understanding of 21st century skills as found in current learning environments. Projects could be selected to represent various learning environments, and assessments would focus on 21st century skills frameworks and developmental trajectories, such as those proposed by ATC21S. We anticipate that all of the learning environments will show limits to the extent to which they address 21st century skills, and this analysis could provide important information for evidence-centred initiatives to promote these skills.

The second phase of the study would analyze the technical quality of the projects’ assessments and their utility for providing formative evidence during instruction. Using the evidence-centred design framework, we anticipate that there will be weak links between assessments of 21st century skills, learning tasks used to elicit those skills, and the evidence that teachers and students can use to understand development of the skills.

A third phase of the study would involve the creation of evidence-centred classroom assessment systems with representative projects to address all or many of the 21st century skills. Technical quality data would be collected about their reliability and validity for classroom formative purposes. In addition, the designs of the formative 21st century assessments would be linked to the more compressed, constrained designs of the large scale, summative 21st century assessment tasks being designed by all ATC21S working groups. Classroom formative assessments would be embedded in the learning activities, provide evidence of ongoing learning processes related to 21st century skills, such as problem solving, collaboration and communication, and would provide rich, deep, frequent streams of evidence to be used by learners and instructors during their learning activities, to monitor and support their progress. For example, in domain-centred learning environments, such rich, embedded formative assessment would be made possible by digital capture of student processes during domain-specific learning activities such as information research, use of simulations, and network analyses. The study would examine the formative utility and technical quality of the assessments and the value they had added to interim benchmark summative assessments and to even more distal large-scale state, national, and international assessments. The research on the design of quality formative assessments for the full range of 21st century skills that could be embedded in projects in each of the different learning environments would serve as models for reforming and transforming 21st century formative assessments in learning environments.

Social and technological innovations for inclusive knowledge-building society

The goals currently being promoted for 21st century skill development are, as previously noted, based mainly on expert and stakeholder analysis of goals. In this section we propose design experiments that complement this top-down approach to goal identification with a bottom-up approach based on the capacities, limitations, and problems that learners reveal when they are actually engaged in knowledge-creating work. The first step in mounting such research is to identify or establish schools able to operate as knowledge-creating organizations—given, as Laferrière and Gervais (2008) suggest—that at this point it may be difficult to locate schools able to take on such work. The proposed research has the dual purpose of (a) discovering previously unrecognized skill goals and (b) developing ways of assessing these emergent skills through minimally intrusive instruments.

Sites thus engaged, willing to take on an ambitious new research agenda, and equipped with appropriate technology, could then support a broad-based research and development effort aimed at addressing questions related to knowledge practices and outcomes. At a policy level we would begin to collect data and evidence to address issues that are dividing educators. For example, many educators favour those curriculum procedures and processes that are well-defined and have a step-by-step character—but knowledge creation is not an orderly step-by-step process. Knowledge-creators go where their ideas take them. How can the challenge of engaging students in more self-directed and creative work with ideas be reconciled with the classroom routines and activity structures that many educators feel to be essential for teachers, students, and curriculum coverage? How does self-organization, an important component of knowledge creation, actually combine with intentional development of ideas at the process level? How are promising ideas worthy of further development sorted out from the large pool of ideas students often generate? How can "pooling of ignorance" be avoided?

"Pooling of ignorance" is a problem that looms large in discussions about open discourse environments for naïve learners. Although "making thinking visible" is one of the advantages claimed for constructivist computer environments, it can increase the chances of "pooling ignorance" and spreading "wrong" ideas. Teachers, accordingly, are tempted to exert editorial control over what ideas get made public in student inquiry; and students, for their part, may learn that it's better to put forward authoritative ideas, rather than their own. Research is needed, first to determine whether "pooling ignorance" is a real or only an imagined problem, and second—if it does prove to be real—to carry out design research to find a constructive way to deal with this dilemma.

Concurrent, embedded, and transformative assessments (pp.29ff) need to be geared to demonstrations of new ways around old problems. We can then collectively test the notion that formative assessments, built into the dynamics of the community, will allow for a level of self-correction and a focus on high-level goals unparalleled in most educational contexts.

Challenges related to complex interventions

Brown (1992); Collins, Joseph and Bielaczyc (2004); and Frederiksen and Collins (1989) discuss theoretical and methodological challenges in creating complex interventions and the problems of narrow measures. They stress the need for design experiments as a way to carry out formative research for testing and refining educational designs based on theoretical principles derived from prior research. It is an approach of "progressive refinement." As Collins, Joseph and Bielaczyc (2004) explain, design experimentation:

involves putting a first version of a design into the world to see how it works. Then, the design is constantly revised based on experience… Because design experiments are set in learning environments, there are many variables that cannot be controlled. Instead, design researchers try to optimize as much of the design as possible and to observe carefully how the different elements are working out. (p.18)

White Paper 2 raises a number of methodological issues regarding assessment of 21st century skills. The proposed research could contribute to progress on each of the issues raised there: (a) *distinguishing the role of context from that of the underlying cognitive construct*—the experiment would allow us to find examples of the construct across different national and domain contexts; (b) *new types of items that are enabled by computers and networks*—the network we propose would implement new designs and explore uses of new item types; (c) *new technologies and new ways of thinking to gain more information from the classroom without overwhelming the classroom with more assessments*—we propose to engage a network of international, multilingual, cross-domain centres to explore issues and determine how concurrent, embedded, and transformative assessments might begin to save teachers' time; (d) *right mix of crowd wisdom and traditional validity*—"crowd wisdom" and traditional procedures can easily be combined in the environments we propose; (e) *information and data availability and usefulness*—we can directly explore what it takes to translate data into feedback to drive knowledge advancement; and (f) *assessments for 21st century skills that are* *activators of students' own learning*—through the use of scaffolds, adaptive recommender systems, stealth assessments, visualizations, and so on, we can explore assessments that facilitate students' own learning.

Specific investigations within the emergent competencies framework

We propose that an international network of pilot sites be established, both to cooperate in the multifaceted design research described below and to collaborate with local researchers in creating and testing new designs tailored to their own conditions and needs. A given site may collaborate in all or a subset of the specific investigations, but in any event the data they produce will be available for addressing the full range of research questions that arise within the network. The following, therefore, should be regarded as an initial specification, subject to modification and expansion.

Charting developmental pathways with respect to 21st century skills. As indicated in the sections on embedded assessment (pp.29ff) and technology to support the emergence of new skills (pp.34ff), computer-based scaffolds can be used to support the development of 21st century skills and formative assessments related to their use. An intensive program of research to develop each skill would allow us to determine what students at various ages are able and not able to do related to various 21st century skills, with and without supports for knowledge creation. We would then be in better position to elaborate developmental progressions set out in Table 2.

Replicating findings that suggest that knowledge building pedagogy may save educational time rather than adding yet another new separate set of skills to an already crowded curriculum. Currently, learning basic skills and creating new knowledge are thought by many to be competitors for school time. In knowledge-building environments students are reading, writing, producing varied media forms, using mathematics to solve problems—not as isolated curriculum goals but through meaningful interactions aimed at advancing their understanding in all areas of the curriculum. Rather than treating literacy as a prerequisite for knowledge work, it becomes possible to treat knowledge work as the preferred medium for developing multiliteracies. Early results indicate that there are gains in subject-matter learning, multiliteracies, and a broad range of 21st century skills. These results need to be replicated and extended.

Testing new technologies, methods, and generalization effects. The international network of pilot sites would serve as a testbed for new tools and formative assessments. In line with replication studies, research reported by Williams (2009) suggests that effective collaboration accelerates attainments in other areas. This "generalization effect" fits with our claim that, although defining and operationalizing 21st century skills one-by-one may be important for measurement purposes, educational activities will be better shaped by a more global conception of collaborative work with complex goals. Accordingly, we propose to study relationships between work in targeted areas and then expand into areas not targeted. For instance, we may develop measures of collaborative problem solving, our target skill, and then examine its relationship with collaborative learning, communication, and other 21st century skills. We would at the same time measure outcomes on an appropriate achievement variable relevant to the subject matter of the target skill. Thus we would test generalization effects related to the overall goal of educating students for a knowledge-creating culture.

Creating inclusive designs for knowledge building. It is important to find ways for all students to contribute to the community knowledge space, and to chart advances for each individual as well as for the group as a whole. Students can enter into the discourse through their favourite medium (text, graphics, video, audio notes) and perspective, which should help. Early results show advances for both boys and girls, rather than the traditional finding in which *girls* out-perform *bo*ys in literacy skills. This suggests that boys lag in traditional literacy programs because they are not rewarding or engaging, whereas progressive inquiry both rewards and engages. New designs to support students with disabilities will be an essential addition to environments to support inclusive knowledge building

Exploring multilingual, multiliteracy, multicultural issues. Our proposed research would engage international teams, thus it would be possible to explore the use of multilingual spaces and possibilities for creating multicultural environments. More generally, the proposed research would make it possible to explore issues of knowledge-building society that can only be addressed through a global enterprise.

Administering common tests and questionnaires. While there is currently evidence that high-level knowledge work can be integrated with schooling, starting no later than the middle elementary grades (Zhang et.al., 2009), data is needed to support the claim that knowledge building is feasible across a broad range of ages, SES contexts, teachers, and so forth, and that students are more motivated in knowledge building environments than in traditional environments. To maximize knowledge gains from separate experiments it will be important to standardize on assessment tools, instruments, and data formats. Through directed assessment efforts it will be possible to identify parameters and practices that enable knowledge building (Law, Lee & Chow, 2002).

Identifying practices that can be incorporated into classrooms consistent with those in knowledge-creating organizations. By embedding practices from knowledge-creating organizations into classrooms we can begin to determine what is required to enable schools to operate as knowledge-creating organizations and to design professional development to foster such practices. Data on classroom processes should also allow us to refine the developmental trajectory set out in Table 2, and build assessments for charting advances at the individual, group, and environment levels.

Demonstrating how a broader systems perspective might inform large-scale, on-demand, summative assessment. We have discussed the distinction between a "working backward" and "emergence" approach to advance 21st century skills and connections between knowledge building environments, formative assessments, and large-scale assessment. Within the emergence approach, connections between student work and formative and summative assessment can be enriched in important ways. For example, as described above, scaffolds can be built into the environments to encourage students to tag "thinking types." As a result, thinking is made explicit and analytic tools can then be used to assess patterns and help to inform the next steps. With students more knowledgeably and intentionally connected to the achievement of the outcomes to be assessed, they can become more active players in the process. In addition to intentionally working to increase their understanding relative to various learning progressions and benchmarks, they are positioned to comment on these and exceed them. As in knowledge-creating organizations, participants are aware of the standards to be exceeded. One of the authors of this paper recounts the story of a teacher who, toward the end of student work in a particular area, published curriculum standards in the students' electronic workspaces so they could comment on them, and on how their work stood up in light of them. The students noted many ways in which their work addressed the standards, and also important advances they had made that were not represented in the standards. We daresay that productive dialogues between those tested and those designing tests could prove valuable to both parties. Semantic analysis tools open up additional possibilities for an emergence framework to inform large-scale assessments. It is possible to create the "benchmark corpus" (the semantic field from any desired compilation of curriculum or assessment material), the "student corpus" (the semantic field from any desired compilation of student-generated texts such as the first third of their entries in a domain versus the last third), and the "class corpus" (the semantic field from all members of the class, first third versus last third), and so forth. Semantic analysis and other data mining techniques can then be used to track and inform progress, with indication of semantic spaces underrepresented in either the student or benchmark corpus, and changes over time.

Classroom discourse, captured in the form of extensive e-portfolios, can be used to predict performance on large scale summative assessments and then, through formative feedback, increase student performance. Thus results can be tied back to performance evaluations and support continual improvement. Teachers, students, and parents all benefit, as they monitor growth with ease and speed to inform progress. This opens the possibility for unprecedented levels of accountability and progress.

Technological and methodological advances to support skills development

Technological advances, especially those associated with Web 2.0 and Web 3.0 developments, provide many new opportunities for interoperability of environments for developing domain knowledge and supporting student discourse in those domains. Through coherent media-rich online environments it is possible to bring ideas to the centre and support concurrent, embedded, and transformative assessment. As indicated above, it is now possible to build a broad range of formative assessments that will enrich classroom work greatly.

A key characteristic of Web 2.0 is that users are no longer merely consumers of information but rather active creators of information that is widely accessible by others. The concomitant emergence of online communities, such as MySpace, LinkedIn, Flickr, and Facebook, has led, ironically and yet unsurprisingly, to a focus on individuals and their roles in these communities as reflected, for example, in the practice of counting "friends" to determine connectedness. There has been considerable interest in characterizing the nature of social networks, with social network analysis employed to detect patterns of social interactions in large communities. Web 3.0 designs represent a significant shift to encoding semantic information in ways that make it possible for computers to deduce relationships amongst pieces of information. In a Web 3.0 world the relationships and dynamics among ideas are at least as important as those among users. As a way of understanding such relationships we can develop an analogue of social network analysis—*idea* network analysis. This is especially important for knowledge building environments where the concern is social interactions that enable idea improvement (see Teplovs, 2008). Idea network analysis offers a means of describing relationships among ideas, much as social network analysis describes the relationships among actors. Visualizations of idea networks, with related metrics such as network density, will allow us to characterize changes in social patterns and ideas over time. The demanding conceptual and research challenge, therefore, is to understand and support the social dynamics that lead to knowledge advancement.

Through additional design work, aimed at integrating discourse environments, online knowledge resources and formative and summative assessments, we can greatly extend where and how learning might occur and be assessed. By tracking the semantics of participant discourses, online curriculum material, test items, texts of experts in the field and so on, we can map one discourse or corpus onto another and track the growth of ideas. With collaborative online discourse integral to the operation of knowledge-building communities, we can further enhance formative assessments so as to encourage participants to seek new learning opportunities and a broader range of experts.

Effectively designed environments should make it possible to develop communication, collaboration (teamwork), information literacy, critical thinking, ICT literacy, and so forth in parallel—a reflection of how things work in knowledge-creating organizations.

White Paper 4 Annex: Knowledge building analytic framework

Template for analyzing environments and assessments

1. DESCRIBE AN ENVIRONMENT AND/OR ASSESSMENT AS IT CURRENTLY EXISTS.
(*Use as much space as you need)*
2. INDICATE WHETHER THE EXAMPLE FITS PRIMARILY INTO AN ADDITIVE OR TRANSFORMATIVE MODEL OF SCHOOL REFORM. TO PROVIDE THIS EVALUATION YOU SIMPLY NEED TO ASSIGN A SCORE FROM 1 (definitely additive) to 10 (definitely transformative), AND PROVIDE A BRIEF RATIONALE. NOTE: Score = 1 (the goal is *additive* if the environment or assessment presented is designed to add a task or activity to school work that remains little changed in overall structure, other than through the addition of this new task, project, environment or assessment*); Score = 10 (the goal is transformative if the environments or assessment alters conditions of schooling in a substantial way, so students become enculturated into a knowledge-creating organization that is supported by a knowledge building environment integral to the operation of the community).*
SCORE _______
RATIONALE FOR SCORE: (*Use as much space as you need)*
3. PLEASE USE THE FOLLOWING EVALUATION FORM TO ASSESS THE CHARACTERISTICS OF THE ENVIRONMENT AND/OR ASSESSMENT IN ITS CURRENT FORM

21st Century skill (from Chapter 2)	**Characteristics of knowledge-creating organizations: a continuum that maps onto 21st century skills** **1 5 10**
Creativity and Innovation	SCORE FROM 1 (Internalize given information; beliefs/actions based on the assumption that someone else has the answer or knows the truth) to 10 (Work on unsolved problems; generate theories and models, take risks, etc; pursue promising ideas and plans) SCORE_______ RATIONALE FOR YOUR SCORE: (*Use as much space as you need)* DO YOU SEE A WAY TO IMPROVE YOUR ENVIRONMENT OR ASSESSMENT ALONG THIS DIMENSION? IF SO, PLEASE PROVIDE A BRIEF ACCOUNT OF HOW YOU MIGHT DO THAT, OR HOW THE IDEAS IN THIS WORKING PAPER MIGHT HELP. (*Use as much space as you need)*
Communication	SCORE FROM 1 (Social chit chat; discourse that aims to get everyone to some predetermined point; limited context for peer-to-peer or extended interactions) to 10 (Knowledge building/progressive discourse aimed at advancing the state of the field; discourse to achieve a more inclusive, higher order analysis; open community knowledge spaces encourage peer-to-peer and extended interactions) SCORE_______ RATIONALE FOR YOUR SCORE: (*Use as much space as you need)* DO YOU SEE A WAY TO IMPROVE YOUR ENVIRONMENT OR ASSESSMENT ALONG THIS DIMENSION? IF SO, PLEASE PROVIDE A BRIEF ACCOUNT OF HOW YOU MIGHT DO THAT, OR HOW THE IDEAS IN THIS WORKING PAPER MIGHT HELP.

	(*Use as much space as you need)*
Collaboration/Teamwork	SCORE FROM 1 (Small group work—divided responsibility to create a finished product; the whole is the sum of its parts, not greater than that sum) to 10 (Collective or shared intelligence emerges from collaboration and competition of many individuals and aims to enhance the social pool of existing knowledge. Team members aim to achieve a focus and threshold for productive interaction and work with networked ICT. Advances in community knowledge are prized, over-and-above individual success, while enabling each participant to contribute to that success) SCORE_______ RATIONALE FOR YOUR SCORE: (*Use as much space as you need)* DO YOU SEE A WAY TO IMPROVE YOUR ENVIRONMENT OR ASSESSMENT ALONG THIS DIMENSION? IF SO, PLEASE PROVIDE A BRIEF ACCOUNT OF HOW YOU MIGHT DO THAT, OR HOW THE IDEAS IN THIS WORKING PAPER MIGHT HELP. (*Use as much space as you need)*
Information Literacy/Research	SCORE FROM 1 (Inquiry: question-answer, through finding and compiling information; variable testing research) to 10 (Going beyond given information; constructive use of and contribution to knowledge resources to identify and expand the social pool of improvable ideas, with research integral to efforts to advance knowledge resources and information) SCORE_______ RATIONALE FOR YOUR SCORE: (*Use as much space as you need)* DO YOU SEE A WAY TO IMPROVE YOUR ENVIRONMENT OR ASSESSMENT ALONG THIS DIMENSION? IF SO, PLEASE PROVIDE A BRIEF ACCOUNT OF HOW YOU MIGHT DO THAT, OR HOW THE IDEAS IN THIS WORKING PAPER MIGHT HELP. (*Use as much space as you need)*
Critical Thinking, Problem Solving and Decision-making	SCORE FROM 1 (Meaningful activities are designed by the director/teacher/curriculum designer; learners work on predetermined tasks set by others.) to 10 (High-level thinking skills exercised in the course of authentic knowledge work; the bar for accomplishments is continually raised through self initiated problem finding and attunement to promising ideas; participants are engaged in complex problems and systems thinking) SCORE_______ RATIONALE FOR YOUR SCORE: (*Use as much space as you need)* DO YOU SEE A WAY TO IMPROVE YOUR ENVIRONMENT OR ASSESSMENT ALONG THIS DIMENSION? IF SO, PLEASE PROVIDE A BRIEF ACCOUNT OF HOW YOU MIGHT DO THAT, OR HOW THE IDEAS IN THIS WORKING PAPER MIGHT HELP. (*Use as much space as you need)*
Citizenship—local and global	SCORE FROM 1 (Support of organization and community behavioural norms; "doing one's best"; personal rights) to 10 (Citizens feel part of a knowledge-creating civilization and aim to contribute to a global enterprise; team members

value diverse perspectives, build shared, interconnected knowledge spanning formal and informal settings, exercise leadership, and support inclusive rights)

SCORE_______

RATIONALE FOR YOUR SCORE:
(Use as much space as you need)

DO YOU SEE A WAY TO IMPROVE YOUR ENVIRONMENT OR ASSESSMENT ALONG THIS DIMENSION? IF SO, PLEASE PROVIDE A BRIEF ACCOUNT OF HOW YOU MIGHT DO THAT, OR HOW THE IDEAS IN THIS WORKING PAPER MIGHT HELP.
(Use as much space as you need)

ICT literacy

SCORE FROM 1 (Familiarity with and ability to use common applications and web resources and facilities) to 10 (ICT integrated into the daily workings of the organization; shared community spaces built and continually improved by participants, with connection to organizations and resources worldwide)

SCORE_______

RATIONALE FOR YOUR SCORE:
(Use as much space as you need)

DO YOU SEE A WAY TO IMPROVE YOUR ENVIRONMENT OR ASSESSMENT ALONG THIS DIMENSION? IF SO, PLEASE PROVIDE A BRIEF ACCOUNT OF HOW YOU MIGHT DO THAT, OR HOW THE IDEAS IN THIS WORKING PAPER MIGHT HELP.
(Use as much space as you need)

Life and career skills

SCORE FROM 1 (Personal career goals consistent with individual characteristics; realistic assessment of requirements and probabilities of achieving career goals) to 10 (Engagement in continuous, “lifelong” and “life-wide” learning opportunities; self-identification as a knowledge creator, regardless of life circumstance or context)

SCORE_______

RATIONALE FOR YOUR SCORE:
(Use as much space as you need)

DO YOU SEE A WAY TO IMPROVE YOUR ENVIRONMENT OR ASSESSMENT ALONG THIS DIMENSION? IF SO, PLEASE PROVIDE A BRIEF ACCOUNT OF HOW YOU MIGHT DO THAT, OR HOW THE IDEAS IN THIS WORKING PAPER MIGHT HELP.
(Use as much space as you need)

Learning to learn / meta-cognition

SCORE FROM 1 (Students and workers provide input to the organization, but the high-level processes are under the control of someone else) to 10 (Students and workers are able to take charge at the highest, executive levels; assessment is integral to the operation of the organization, requiring social as well as individual metacognition)

SCORE_______

RATIONALE FOR YOUR SCORE:
(Use as much space as you need)

DO YOU SEE A WAY TO IMPROVE YOUR ENVIRONMENT OR ASSESSMENT ALONG THIS DIMENSION? IF SO, PLEASE PROVIDE A

BRIEF ACCOUNT OF HOW YOU MIGHT DO THAT, OR HOW THE IDEAS IN THIS WORKING PAPER MIGHT HELP.
(Use as much space as you need)

Personal and social responsibility—incl. cultural competence	SCORE FROM 1 (Individual responsibility; local context) to 10 (Team members build on and improve the knowledge assets of the community as a whole, with appreciation of cultural dynamics that will allow the ideas to be used and improved to serve and benefit a multicultural, multilingual, changing society) SCORE_______ RATIONALE FOR YOUR SCORE: *(Use as much space as you need)* DO YOU SEE A WAY TO IMPROVE YOUR ENVIRONMENT OR ASSESSMENT ALONG THIS DIMENSION? IF SO, PLEASE PROVIDE A BRIEF ACCOUNT OF HOW YOU MIGHT DO THAT, OR HOW THE IDEAS IN THIS WORKING PAPER MIGHT HELP. *(Use as much space as you need)*

Results obtained by means of analytic templates

Table 3 provides descriptive statistics of the ratings of environments and assessments selected by (a) Assessment and Teaching of 21st Century Skills project (ATC21S) volunteers versus those selected by (b) graduate students.

Table 3: Ratings of environments and assessments

21st Century Skills	ATC21S (N= 7)				Grad Students (N=11)			
	Mean	SD	Max	Min	Mean	SD	Max	Min
Creativity	7.57	1.81	10	4	5.73	2.53	9	2
Communication	8.00	1.29	9	6	5.50	3.46	9	1
Collaboration	7.86	1.35	9	5	5.59	3.23	9	1
Information literacy	7.57	2.15	9	4	5.55	2.50	10	2
Critical thinking	7.14	1.86	9	4	6.27	3.07	10	2
Citizenship	7.14	2.91	9	2	4.50	2.52	8	1
ICT literacy	7.71	2.69	10	2	4.27	3.10	10	1
Life/career skills	7.57	2.51	9	3	5.86	2.79	10	1
Meta-cognition	8.00	2.00	10	4	4.32	1.95	7	1
Responsibility	7.71	2.21	9	4	4.00	2.76	8	1

Figure 6 provides a graphical representation of the ratings of environments and assessments selected by (a) Assessment and Teaching of 21st Century Skills (ATC21S) volunteers versus those selected by (b) graduate students, as listed in Table 3.

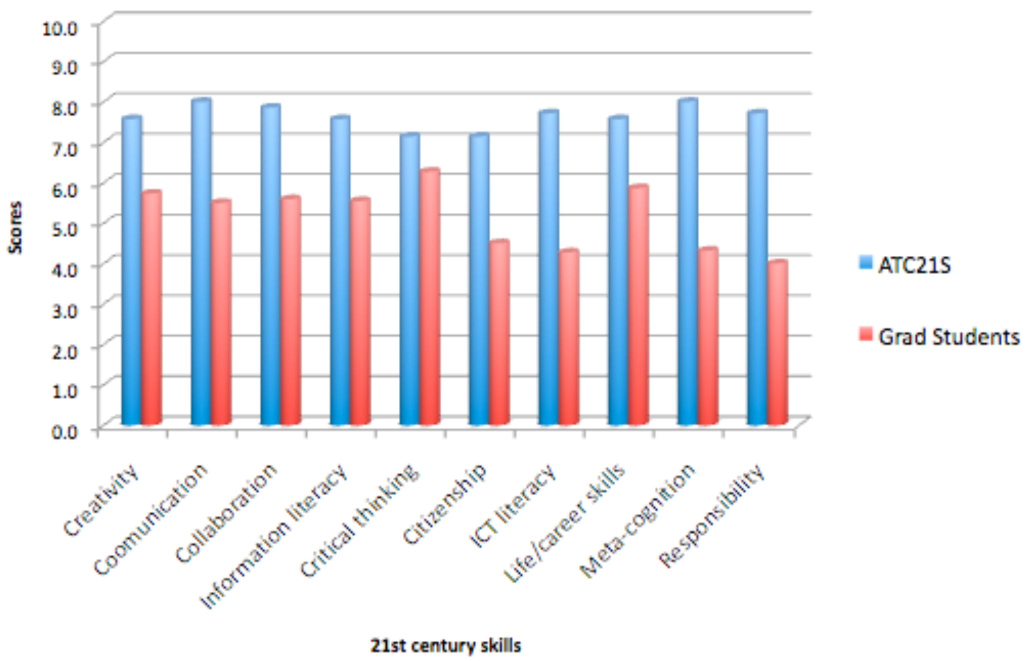


Figure 6: Ratings of environments and assessments

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