European Journal of School Psychology – Vol. 3, No. 1 (2005), 21–40

DOES EDUCATION FOR THE KNOWLEDGE AGE NEED A NEW SCIENCE?

Marlene Scardamalia and Carl Bereiter

Institute for Knowledge Innovation and Technology
Ontario Institute for Studies in Education of the University of Toronto (Canada)

The rising societal interest in innovation and knowledge creation has caught the behavioural sciences, and educational psychology in particular, unprepared. We know quite a bit about knowledge acquisition, but even such modern approaches as constructivism and situated cognition fail to address what, if anything, is distinctive about individuals and groups whose goal is the creation of new knowledge. There are theories about creativity, and strategies for fostering it, but they deal with the isolated novel idea. They have little to offer concerning the sustained, integrative creativity that produces, for instance, a mobile phone that takes and transmits pictures. A new educational science is needed, which recognizes the self–organizing character of learning and creativity and which takes as its goal the advancement of education toward higher levels of functional organization.

INTRODUCTION

The Knowledge Age, as it is coming to be called, has many aspects, some favorable and some threatening. Optimists foresee young people “growing up digital,” with vastly enhanced access to knowledge and ideas and a level of worldly sophistication that enables them to be effective activists rather than couch potatoes (Tapscott, 1998). On the other hand, it is appearing increasingly likely that there will be extreme winners and losers. There is concern about a “digital divide” (Warschauer, 2003), an “ingenuity gap” (Homer– Dixon, 2000), and a “creative class” that brings wealth to regions that attract it and leaves other regions to rust and decay (Florida, 2002). Educators tend, quite naturally, to look on the bright side and to take as their responsibility giving all students access to the marvels of digital technology and the skills needed to avail themselves of it. Recent developments, however, have brought the winner–loser aspect of the Knowledge Age into sharper focus.

We refer specifically to the outsourcing of knowledge work. This apparently accelerating trend, which is causing great alarm in North American labor unions, ought to be causing alarm in school systems as well. What it demonstrates is that the traditional academic skills, even when amplified by modern information and communication technology skills, are no longer sufficient as employment qualifications. The worldwide supply of people with such skills is increasing rapidly, distance is vanishing as a barrier, and so other considerations are determining what jobs will be located where and who will fill them.

Outsourcing, as a business strategy, calls for drawing a distinction between the core functions of a business and its subsidiary functions, which are the candidates for outsourcing. In Knowledge Age businesses, the core functions are the ones that generate innovative products and services that are the foundation of wealth creation in the business. The subsidiary functions, such as many kinds of computer programming, accounting, and engineering, may require skills of a high order, but they do not require commitment to the goals and vision of the outsourcing organization. To be part of the core business, however–the part that stays "home"–requires not only commitment but also the ability to contribute creatively to the achievement of the goals and vision. Thus creativity, of a distinctly mission–relevant kind, is coming to be regarded as the key qualification for good jobs that are safe from outsourcing. (At this writing, August, 2004, the most current information on outsourcing –from a business point of view–is to be found in the web journal, *Offshore Outsourcing World*, available at http://www.enterblog.com/.)

Educators and researchers we talk to seem inclined to turn away from economic considerations and to focus instead on the personal and social values of education. We share this value orientation, but we also believe it is essential for education professionals, including researchers, to be actively involved in this new challenge in talent development. The pronouncements of business leaders and writers and of educational policy–makers suggest that they believe creativity should be teachable simply by deciding to do it and by applying known procedures. The consequences of this radically mistaken belief are likely to prove detrimental, not only from an economic point of view but also from a humanistic point of view. The trivialization of education in the name of higher–order thinking skills is not a new phenomenon, but it has gained a new respectability by being harnessed to national economic goals.

The truth of the matter is that we do not know how to educate for innovation and knowledge creation. From international comparative studies, we know something about the general social conditions that favor such characteristics (OECD, 1993; Porter, 1998). But at this level of generality, all one can say is that education is important. Creativity workshops within organizations have sometimes shown positive effects on innovation (e.g., Thorn, 1987; Hill, 1988), but this is not reason to believe that the same kinds of workshops, carried out in schools, will produce effects that will endure and transfer to later nonschool situations. Creativity training in schools has produced effects on creativity tests (usually consisting of trivial kinds of performance), but whether they do anyone any lasting good remains to be demonstrated (Mansfield, Busse & Krepelka, 1978; Rose & Lin, 1984). Practicing educators may choose to cast their lot with whatever fad promises to "unleash" creative powers, or they can hold to a belief that constructivism, as represented in such forms as project–based learning, is a sufficient response to the creativity challenge. But the few long–term studies available indicate that the best long–range predictor of creative achievement is a record of past achievement (Bull & Davis, 1980; Howieson, 1981). A new educational science would identify ways to get onto that creative achievement trajectory at an early age.

If we did know how to develop marketable creative talent, equity considerations alone would require that we apply this knowledge as broadly as possible. But there is more to the issue than economic opportunity. Creativity has historically been treated as something apart from ordinary learning and cognition. It is often argued that creative thinking, along with other kinds of thinking, should be *infused* into the curriculum, but this still presupposes that there is some ordinary, plodding kind of educational growth, against which creativity stands in sharp contrast. This line of thinking rests on a psychology that is rapidly becoming obsolete. In a modern educational psychology, we shall argue, all significant educational growth will be seen as emergent from self–organizing processes within individuals and groups. Accordingly, an educational psychology adequate to address the problem of producing creative talent will also provide new means to address other educational problems, including especially the monumental problem of teaching for understanding.

Our goal in this paper is to describe the general character of such a science and to suggest the different kind of light it can cast on two problems: the relatively new problem of creative talent development and the older but still not fully recognized problem of teaching for understanding. This effort is guided by two working assumptions, which it is beyond the scope of this paper to defend:

1. The development of creative talent cannot be carried very far by special training devoted to creativity or by inserting brain–teasers and expressive activities into the conventional curriculum. Instead, it will require making schooling as a whole a more creative, thoughtful process (cf. Resnick & Klopfer, 1989).

2. The main intellectual challenge in general education is to build a coherent and functional understanding of the world (cf. Gardner, 1999). Accordingly, any effort to make schooling more creative should focus on making the pursuit of understanding a more creative process.

The challenge for a modern educational theory is to turn these working assumptions into operable design principles. The framework within which we shall take up this challenge is that of complexity theory or "systems thinking." We will argue for the relevance of systems thinking to education, with special attention to the twin problems of creativity and understanding. We will conclude with a description of knowledge building as an emerging systems approach to education for knowledge creation and understanding.

SYSTEMS THINKING VS. CAUSAL–CHAIN THINKING

Systems thinking is transforming all the behavioral sciences, and educational theory is a prime candidate for such transformation. By systems thinking we mean thinking that applies dynamic systems concepts such as emergence, self–organization, and constraint satisfaction. The central problem addressed by systems thinking is the emergence of complexity from the interaction of simpler elements - hence the umbrella term, *complexity theory* (cf. Byrne, 1998). Unless you can explain how complexity comes about, you cannot explain much of anything in evolution, embryology, creative thought, or learning. Far from being exceptional, emergence is to be found throughout nature and at all levels of organization.

Emergence is an old idea, but until recently it has served mainly a metaphoric function and was shrouded in mystery. Now emergence of many kinds can be simulated on computers (connectionist or "neural" networks are the kinds best known to psychologists). This has gone a long way to demystifying the concept and to resolving such difficulties as the so–called "learning paradox," according to which no one can possibly learn anything more complex than what they already know (Bereiter, 1985; 1991; Fodor, 1983). There is still a long way to go, however, from simulating an emergent process to designing ways of supporting, improving, or trouble–shooting the process. That is the main challenge for a new science in education. We will offer a few thoughts at the end of this article about how intervention in a self–organizing emergent process might work.

Systems thinking is an alternative to what we may term "causal chain" thinking, which seeks to explain phenomena by tracing back through a chain or network of causes. This type of thinking, which works very well in some cases, has been an unrealized ideal in educational theory. Causal connections have generally proved too weak to support it empirically. Two other kinds of explanatory thinking have vied with causal chain thinking in education. One is multivariate thinking. An outcome is explained as a function of a number of variables. The variables may or may not be quantified and the function may or may not be specified. To the extent that you have quantification and specification you have what is called “quantitative” research, and to the extent that you do not, you have what often passes for “qualitative” research. The other, more recent alternative to causal chain thinking is the narrative account. Narratives, of course, also involve causal chains, but they additionally provide context and a way of combining causal and intentional factors. These alternatives to causal–chain thinking share with systems thinking some ability to handle a web of interacting elements, but neither one provides a basis for design and problem–solving.

Any useful educational psychology must be such that a design science can be built on top of it (Scardamalia, 2004). Causal–chain theories, such as behaviorism, have given rise to instructional design systems (cf. Reigeluth, 1983), but with limitations that are by now well recognized. Multivariate and narrative approaches do not generally support design. They provide evaluation or criticism of existing approaches, and in that way can be useful, but they do not provide a basis for design improvement and innovation. This is partly because they are backward–looking, but more importantly because they do not identify the mechanisms by which effects are produced and accordingly they do not identify anything that can be tinkered with or replaced.

SYSTEMS THINKING APPLIED TO LEARNING

All learning is emergent. There is no such thing as knowledge passing from a book into your head. The information that goes from your eyes to your brain is already the emergent result of activity in the neural hardware of the eye. As a result, the information passed to your brain is more highly organized than the information projected on to the retina. Inside the brain, this information is reorganized and organized again until it emerges as knowledge, which an investigator may determine bears a very close resemblance to the knowledge the book’s author intended you to have. This is marvellous but it is not miraculous. In general terms we know how it comes about, and neuroscience is gradually nailing down the specifics. Even simple operant conditioning has this emergent quality. The rat has learned to press a bar with its forepaws to gain food. Prevent it from using its forepaws and it will try to move the bar some other way. It has learned something more abstract, something at a higher level of complexity, than a muscular reflex.

If all this is true, however, one might well ask how education has managed to get along and even make some progress without benefit of systems thinking. An answer is that for practical purposes of transmitting existing knowledge and skills, simpler conceptions rooted in folk psychology and epistemology are reasonably adequate. The belief that knowledge passes directly from the mind of the instructor to the mind of the student via the lecture leaves out a lot of steps but it has for many generations served instructors, good and poor, as a basis for planning their lectures. Furthermore, the constructivist dictum - that “students construct their own knowledge” - is not much of an improvement. In practice it often amounts to a naive belief that overt actions are directly converted to knowledge - a notion no less fanciful than the notion of pouring knowledge into the head of the learner.

The need for a systems approach to learning arises from the inability of causal–chain theorizing to account for and provide a basis for addressing the two large problems already noted: creativity and depth of understanding. Before moving on to those problems, however, we should note that a systems view has value in at least clarifying a number of other issues in education. The following are a few examples, to suggest that there is a range of application:

Origins of Misconceptions. Misconceptions of the kinds science education research has been turning up are as a rule not taught. Neither are they publicly aired (otherwise it would not have required research to identify them). Evidently, therefore, they are the private mental constructions of individual students. Yet the same misconceptions turn up all over the world. Some, such as the idea of impetus, may be explained as having a basis in ordinary experience. Others, such as the belief that an object hurled horizontally off a cliff will travel horizontally for a while and then drop, do not. Causal–chain thinking has great difficulty explaining the independent emergence of the same conceptions in millions of minds, whereas for systems thinking this is no more difficult than explaining the emergence of scattered tornados under certain combinations of weather and topographic conditions.

Why Phonics Works. Opponents of phonics instruction have delighted in pointing out why it cannot possibly work, especially in English, with its quirky relations between spelling and pronunciation: "puh–ih–guh" does not yield "pig." Yet, more remarkable than the fact that phonics instruction demonstrably does work is the fact that virtually everyone learns phonics, even if they have never been taught it. They can demonstrate this ability by reading aloud unfamiliar or pseudo–words. Causal–chain thinking would have it that people learn rules that get them from "puh–ih–guh" to "pig," and so on. But hundreds of imperfectly reliable rules would be required in order for this to work, far more rules and more complicated ones than it is reasonable to suppose children actually learn. Given word recognition as a self–organizing process, however, it is only necessary that sounding out produce something in the phonological neighborhood of the intended word, so that "pig," for instance, is the most likely word for the recognition system to settle on, given "puh–ih–guh" as input. What we refer to vaguely as the "word recognition system" must obviously be very flexible in order to succeed with the great phonological variation that occurs in ordinary speech. Phonics, we might say, co–opts this system in the service of decoding written words. This is quite a different view from that of both traditional advocates and opponents of phonics instruction.

Classroom Discipline. Conventionally, classroom discipline is treated as a matter of having a clear set of rules of conduct, which are endorsed by the students and consistently enforced by the teacher. However, the rules that typically appear on classroom walls are of such a general nature that it is not clear what it means to accept, abide by, or enforce them. If, however, the social life of a classroom is viewed as a self–organizing process, then the posting and discussion of rules and the teacher's efforts to enforce them may be seen as inputs to the process. They interact with other inputs to produce equilibrium of greater or lesser stability, greater or lesser dependence on continual input from the teacher. Predicting the effect of any particular action or event on classroom discipline is much like predicting the effect of a particular action or event on the economy: Prediction is neither wholly reliable nor unreliable and prediction is essential for wise action, but the situation is too complex for causal–chain reasoning to be effective in choice of actions.

Systems thinking is difficult. Quite possibly our brains are built for causal –chain and narrative thinking but not for systems thinking. Although more than 100,000 Web pages contain the term "systems thinking," the most popular of them misrepresent it. They define it in terms of flexibility, seeing the big picture, and taking many variables into account. Those are ways that competent people will deal with a complex situation. Systems thinking deals with how that complexity comes about.

CREATIVITY: BIG IDEAS AND CUMULATIVE INVENTION

Historically, people attempting to explain creativity have assumed that the “act of creation,” as Arthur Koestler (1964) called it, is an extraordinary event, which accordingly requires a special explanation beyond what is needed to explain ordinary thought and action. Correspondingly, training to enhance creativity has focused on ways to make this special thing happen: brainstorming, lateral thinking, right–brain thinking, and the like. With the advent of connectionism and other system models, however, and with the detailed analysis of ordinary behavior such as speech and motoric action, it has become evident that the uniqueness assumption is simply and colossally wrong. Virtually everything you say and do turns out, on close analysis, to involve improvisation and, hence, some originality (Sawyer, 1999). To program such spontaneity into a robot has proved extremely difficult; a realistic robotic dog currently represents the summit of behavioral simulation.

The misconception underlying the traditional view of creativity is that ordinary behavior can be adequately accounted for by a causal chain. Much as in an explanation of the working of a steam engine, event n is taken to cause event n+1, and so on. Thinking–aloud protocols often give this impression, and they have been the empirical foundation of rule–based models of problem solving and reasoning (e.g., Newell & Simon, 1972). However, scattered through the typical protocol are ideas that affect subsequent steps, and the protocol never reveals how these ideas came about. In terms of rule–based (e.g., production system) models, creativity may be defined as all those mental events that the model fails to explain.

Once it is acknowledged that creative behavior is normal behavior and vice–versa, the problem shifts to explaining exceptional results rather than exceptional processes. Even if it is true that everything we do is creative, only rarely is the result something that will be heralded as brilliant, revolutionary, or even clever. Exceptional results may take two different forms, which we may term Big Ideas and Cumulative Invention. The classic example of a Big Idea is Darwin’s idea of natural selection, the full implications of which are still being worked out and disputed a century and a half later. A notable example of Cumulative Invention is the Macintosh computer, which – along with its derivative, Windows - brought the information age out of the back room and on to people's desktops. As reported by Sculley (1987), Kawasaki (1990), and others, the Macintosh was the result of a passionately dedicated group of designers and builders, solving one problem after another, under a guiding vision. Many of the most conspicuous innovations did not originate in that group but were gleaned from the work of others. Yet it can hardly be disputed that the Macintosh was a creative accomplishment of a high order.

At a deep level, Big Ideas and Cumulative Invention may not be very different. The Big Idea may be arrived at only through a succession of creative achievements and Cumulative Invention may depend on a Big Idea. But insofar as their pursuit involves different practices, there can be little doubt that Cumulative Invention is the more significant educational target. A whole generation or a whole nation may produce few if any Darwins, and education's role in producing them is uncertain to say the least. But the possibility of playing a role in Cumulative Invention is open to a much wider range of people; indeed, it is now taken for granted that Cumulative Invention (going by the more familiar name of "innovation") will be the driving force in any Knowledge Age organization. For education to play a role in promoting it, however, we need a theory that can explain Cumulative Invention and provide guidance for the Cumulative Invention that must take place within education itself.

KNOWLEDGE CREATION AND UNDERSTANDING

Both psychologists (Piaget & Garcia, 1988) and philosophers of science (Popper & Eccles, 1977) have noted that the process of transforming information into knowledge is, in its essential aspects, the same as the process by which knowledge new to the world is created. According to this line of thought, the students who master Newton's laws are creating a theory of physics, although using different informational inputs from those available to Newton. It may also be said, more conservatively, that the students are not creating a theory about forces and motion but are creating a theory about Newton - a theory of what Newton's laws mean. Nevertheless, this is authentic theory building, much in the manner of an archaeologist or hermeneuticist who in effect reinvents an ancient artifact or text by applying theoretical processes to partial information.

The concept of *knowledge building*, as we have elaborated it, is based on the continuity between knowledge creation and understanding. Knowledge building is defined as "the production and continual improvement of ideas of value to a community" (Scardamalia & Bereiter, 2003). To what extent those ideas are new to the world can vary considerably between the classroom community and the research institute, but the same socio–cognitive principles apply.

Knowledge building is inherently and unavoidably a self–organizing process, but this does not distinguish it from ordinary learning which, we have already indicated, is also a self–organizing process. Knowledge building is defined by a set of 12 principles, which include *Real Ideas/Authentic Problems, Idea Improvement, Epistemic Agency, Constructive Use of Authoritative Sources, and Pervasive Knowledge Building* (to name only some whose names are most self–explanatory; see Scardamalia, 2002, for the whole set). In keeping with the idea of an emergent system, however, the knowledge building principles (which may be considered as norms, design principles, or descriptions, depending on point of view) are considered to interact so as to produce the emergent phenomenon of collaborative creation of knowledge new and useful to the community. Knowledge building, thus, is not an activity or a set of activity structures. This creates a substantial obstacle to dissemination and scaling up. Practitioners are accustomed to being provided with explicit procedures or descriptions of activities that they can directly adopt. Most developers of research–based innovations comply with this expectation, even if they do not entirely condone it (cf. Brown & Campione, 1996; Holbrook & Kolodner, 2000). But in our experience with knowledge building, reduction to procedures or activities is deadly. Self–organization takes place, of course, but it is self–organization around overt activities rather than around ideas and idea improvement. Although a progression from concrete activities to creative work with ideas sounds like an attractive scenario, we have found it doesn't actually happen in classrooms. Unless ideas are at the center of attention from the beginning, they remain peripheral; instead, classroom life centers around activities that bear at best a superficial resemblance to real–life work with ideas.

The desired progression in knowledge building is not from activities to ideas, but from ideas treated as playthings to ideas treated as improvable objects. (Activities, both concrete and symbolic, naturally play a role throughout, but always in the service of idea development and preferably arising out of the students' own efforts to make progress.) Students take naturally to the playful generation and sharing of theoretical ideas. This provides a starting point. Left to themselves, however, students are liable to remain satisfied with their own ideas, various as they may be, and make no serious effort to improve upon or move beyond them. What emerges through self–organization in this case is a stable system in which ideas do not progress. The challenge for the teacher is to prevent this premature settling and to promote a self–organizing process in which ideas keep getting better. From an intellectual standpoint, this is virtually the whole educational challenge; if it is met, the classroom becomes one of collective advancement toward higher levels of both creativity and understanding. But how is this challenge to be met?

SELF–ORGANIZATION AS THE BASIS OF A NEW EDUCATIONAL PSYCHOLOGY

Educational psychology, as we declared earlier, needs to be a design science. Following Dennett (1995), we will apply the term "design" to evolved systems, whether or not intentional design is involved. Almost always the systems of interest in education involve some deliberate design deeply enmeshed in self–organizing processes.

The key issues from a system design standpoint are

1. What is the system self–organizing around? That is, what kind of state is it settling into? This question may be raised at a number of levels, but as regards school learning, the most important levels are those of individual cognition and socio–cognitive processes.
2. How can a teacher influence what the system self–organizes around or settles into?

To move beyond explanation to design principles we need to articulate design objectives, and distinguish more advanced designs from less advanced ones (keeping in mind that we include designs that may have evolved without conscious direction). Education organized around learning can be claimed to be more advanced than education organized around doing school work in the same sense that the mammalian brain is more advanced than the reptilian. Both work well within their respective bodily systems, but the mammalian brain is much more complexly organized and complex in a highly functional way. It incorporates the reptilian brain structure into a system where it serves to support functions beyond those the reptilian brain is called upon to serve. Similarly, the schoolwork–centered classroom may function very well by various standards, but activity in the learning–centered classroom exhibits design that is more complex in a way that is functionally highly relevant to what classrooms are for. It incorporates schoolwork into a system that serves more complex purposes than those of the schoolwork–centered classroom. Knowledge building, we would claim, is a yet more advanced system, which incorporates the structures and mechanisms of the learning–centered and the project–centered classroom in the service of a more complex objective.

The discussion up to this point makes a case for the pervasiveness of self– organization in learning and behavior. Self–organization is adaptive; adaptation favors survival. Such basic processes cannot be held up as educational virtues or ideals. The value of integrating concepts such as emergence and self–organization into our educational discourse follows from the new set of constructs and understandings they enable.

If you visit a well–managed classroom at mid–term, you are likely to observe a socio–cognitive system that has already settled into a stable state. In some classrooms, it will have settled around the doing of schoolwork. Students have their jobs to do - their worksheets to complete, their essays to write, their "experiments" to complete and record–and they go about these in an orderly and cheerful manner. Other classrooms are organized around meeting learning objectives, either competitively or cooperatively. Sadly, some classrooms are organized around test preparation. Some classrooms are organized around students' well–being: they resemble therapy or support groups. With increasing frequency, much of the classroom activity is organized around projects. Commonly it is said that the teacher has intentionally organized the class in one of these ways. It is true that the teacher's intentions usually profoundly influence the kind of organization that takes place, but a systems perspective suggests that the shape and focus of classroom organization is the emergent result of a number of interacting factors.

The weakness of the "teacher–as–organizer" description becomes evident in attempts to reorganize classroom activity around a markedly different kind of socio–cognitive process - such as knowledge building. It will seem as if activity keeps wanting to slip back to one of the other forms - to projects, for instance, or to schoolwork routines. Dynamic systems analysts often describe the situation as one of a surface with hills and hollows. The state of the system is like a ball that may roll around for a bit but eventually comes to rest in one of the hollows. Outside influences, such as a skilful teacher, may nudge the system toward a preferred hollow, but cannot create a new hollow. Schoolwork, competitive or cooperative learning, self–expression, and projects represent well–established hollows in the classroom terrain. They were not created arbitrarily but evolved over many years through the interaction of recurring elements and conditions, most of which are probably unrecognized and certainly not under planful control. Pathological forms include activity organized around test preparation or a dumbed–down textbook. Much of what occurs cannot be explained on the basis of classroom factors alone; the whole social, political, and commercial system within which schools function needs to be taken into account.

Pursuit of understanding is an example of a widely approved socio–cognitive process that does not represent a hollow the educational ball can settle into. Classrooms with an emphasis on understanding do exist, but they appear to be ones that require a sustained investment of talent and effort (cf. Hunt & Minstrell, 1994). It is as if the pursuit of understanding represents a hill, not a hollow, so that energy is required to keep the ball from rolling down into the schoolwork hollow, the projects hollow, or whatever.

A systems view encourages us to look at classroom processes in terms of mutual and reciprocal adaptation of students and teachers to each other, to fixed constraints, and to the constraints that evolve through the self–organizing process itself. One conclusion that may be reached is that the typical classroom represents a system in which the easiest and most adaptive course in the short run is for students not to try to understand (Scardamalia & Bereiter, 1996). Pursuing understanding is uneconomical of time and energy, has a low short–term return on investment, and is liable to end in disappointment. Tests and content coverage requirements are part of the system that can make understanding maladaptive. To say that they are part of the system is to say that they, too, are emergent results, adaptive to conditions.

This kind of analysis can lead to the conclusion that everything must change in order for anything to change, but if that were true nothing would ever change. The positive side of a systemic approach is that it encourages us to envisage an end state in which the desired socio–cognitive process would be self–maintaining. There are examples of systems that foster the pursuit of increasingly high level goals; where the participants themselves are engaged in continually raising the bar for what is to be accomplished. Such enterprises include Olympic teams, innovation–driven companies, and productive research centers and laboratories. They are what we call "knowledge building communities" (Scardamalia & Bereiter, 1999). The energy required to hold the community together and keep it advancing comes from all the members.

Willingness to invest energy does not come primarily from the individual thirst for knowledge or from inspiring leadership. It comes from the simple fact that if you want to belong and be valued within that community you have to contribute to the community's knowledge advances. Rewards in turn come from the sense of collectively achieved advances in the state of knowledge. As in many other human endeavors, progress is its own reward – one that is arguably built into our genes (Burnham & Phelan, 2000).

There is accumulating evidence, from many different cultural and subcultural settings, that classrooms can become knowledge building communities. It is beyond the scope of this article to discuss how this is accomplished. It does require a high input of talent and energy by the teacher to get such a community started, but once it is started, normal guidance and stimulation are enough to keep it going and moving ahead. The knowledge building community does not dissolve when the teacher leaves the room. In fact, the students become a powerful force for sustaining and disseminating knowledge building as they move through the grades.

This optimistic account may suggest that either the "new science" already exists or the "old science" is sufficient. That is far from the case. A key objective in everything we have discussed in this paper is *sustained idea improvement*. It is the essence of creative knowledge work; it is the essence of pursuit of understanding. Yet we know very little about how it occurs and how it can be fostered. In the knowledge building classrooms we hold up as models, impressive idea improvement does occur, but it is neither as widespread nor as sustained as in knowledge creating organizations. A new educational science is needed that gets at the deep structure of socio–cognitive processes that create new knowledge - whether in science laboratories, design shops, poetry clubs, or book discussion groups–and elaborates and tests ways of helping classroom processes to self–organize around the creation and improvement of knowledge and ideas.

Cultural evolution can backslide to a simpler form. This was evident in the European "Dark Ages," and around the world today there are groups passionately and often violently dedicated to dragging their civilization back to a simpler state of organization. Similar tendencies are at work in the world's classrooms, although usually with less passion and violence. "Back to basics" is a typical slogan. But the challenge for a new educational science is how to move education to a more advanced state. Surely, it must start with a recognition that there *is* a more advanced state. Vague and encompassing terms like "constructivism" imply that the ultimate state is already in view. Implicit in a systems view of education is the assumption that there is always a more advanced state, which is not just an elaboration or fine tuning of the existing state but an emergent organization qualitatively different and unpredictable from the existing states. Of course, aspiring to a more advanced state is not enough; there is also a need for method. That is also the responsibility of a new science. But, true to the idea of self–organization, it is not the need for a method of installing a more advanced form of education in the classroom; it is the need for ways of initiating and sustaining a process that drives toward more advanced forms of organization in educational processes.

The question that calls for original thought, research, and theorizing is how to recreate schools as knowledge building communities, where higher standards for knowledge advancement emerge as a natural outcome of life in the community.

CONCLUSION

Learning and knowledge creation are both emergent processes, sufficiently similar to suggest that they are the same process, attaining different levels of result. To say that they are emergent is to say that the output of the process (an advance in personal understanding, a new theory, a design innovation, etc.) is not a deducible result of the inputs. Yet all that educators really have in hand to influence learning and development are inputs and limited control over environmental conditions. Some past and present instructional theories, especially those of a behaviorist type, rely on predictable input–output relations. Others imply a horticultural metaphor, in which teachers, like gardeners, nuture and to a limited extent guide developmental processes over which they have no ultimate control. More recently, socio–cultural theories have arisen in which the assimilation of the young into ongoing communities of practice is the dynamic and the teacher is simply a particularly well placed mature member of the community. All these types of theories have evident value as well as limitations when the concern is with the transmission of existing knowledge. None of them, however, are attuned to the modern challenge of developing in people a talent for the creation of new knowledge.

An educational science for the Knowledge Age must, we believe, treat ideas as real things and treat minds–whether individual or collective - as dynamic systems (Bereiter, 2002). Knowledge building (Scardamalia & Bereiter, 2003) a principled approach that spans education and creative work with ideas as carried on in knowledge–based organizations. It has the distinctive characteristic of treating ideas as real, improvable things that are emergents of a partially describable socio–cognitive process. Thus it has the potential to serve as a test case for modern educational theory development.

REFERENCES

Bereiter, C. (1985), "Toward a solution of the learning paradox", in *Review of Educational Research*, 55, 201–226.

Bereiter, C. (1991), "Commentary", in *Human Development*, 34, 294–298.

Bereiter, C. (2002), *Education and mind in the knowledge age*. Mahwah, NJ: Lawrence Erlbaum Associates.

Brown, A., & Campione, J. (1996), "Psychological theory and the design of innovative learning environments: On procedures, principles, and systems", in L. Schauble, R. Glaser (Eds.), *Innovations in learning: New environments for education,* Mahwah, NJ: Lawrence Erlbaum Associates, pp. 289–325.

Bull, K. S., & Davis, G. A. (1980), "Evaluating creative potential using the statement of past creative activities", in *Journal of Creative Behavior,* 14, 249–257.

Burnham, T., & Phelan, J. (2000), *Mean Genes*, Cambridge, MA: Perseus Publishing.

Byrne, D. (1998), *Complexity theory and the social sciences: An introduction,* London: Routledge.

Doyle, W. (1983), "Academic work", in *Review of Educational Research,* 53, 159–199.

Eichinger, D. C., Anderson, C. W., Palincsar, A. S., & David, Y. M. (1991, April), *An illustration of the roles of content knowledge, scientific argument, and social norms in collaborative problem solving*. Paper presented at the meeting of the American Educational Research Association, Chicago, IL.

Florida, R. L. (2002), *The rise of the creative class: and how it's transforming work, leisure, community and everyday life,* New York: Basic Books.

Fodor, J. A. (1983), *The modular theory of mind: An essay on faculty psychology,* Lexington, VT: Bradford Books.

Hill, P. (1988), "Innovation using creative problem–solving techniques: A corporate case example", in *Creativity and Innovation Yearbook,* 1, pp. 106–111.

Holbrook, J., & Kolodner, J. L. (2000), "Scaffolding the development of an inquiry–based (science) classroom", in B. Fishman, S. O'Connor–Divelbiss (Eds.), *Fourth International Conference of the Learning Sciences*. Mahwah, NJ: Lawrence Erlbaum Associates, pp. 221–227.

Homer–Dixon, T. (2000), *The ingenuity gap: Facing the economic, environmental, and other* *challenges of an increasingly complex and unpredictable world,* New York: Knopf.

Howieson, N. (1981), “A longitudinal study of creativity – 1965–1975”, in *Journal of Creative Behavior,* 15, 117–134.

Kawasaki, G. (1990), *The Macintosh way: The art of guerilla management,* Chicago: Scott, Foresman.

Koestler, A. (1964), *The act of creation,* New York: Dell.

Mansfield, R. S., Busse, T. V., & Krepelka, E. J. (1978), “The effectiveness of creativity training”, in *Review of Educational Research,* 48(4), 517–536.

Messina, R. (2003, December), *Classroom implementation of knowledge building*. Presentation at Taipei World Trade Centre, Taipei, Taiwan.

Newell A. (1982), “The knowledge level”, in *Artificial Intelligence,* 18, pp. 87–127.

Newell, A., & Simon, H. A. (1972), *Human problem solving,* Englewood Cliffs, NJ: Prentice–Hall.

OECD. (2003), *Composite indicators of country performance: A critical assessment,* Paris: OECE.

Perkins, D. N. (1981), *The mind’s best work,* Cambridge, MA: Harvard University Press.

Piaget, J., & Garcia, R. (1988), *Psychogenesis and the history of science*. (H. Fieder, Trans.), New York: Columbia University Press (Original work published in 1983).

Popper, K. R., & Eccles, J. C. (1977), *The self and its brain,* Berlin: Springer–Verlag.

Porter, M. (1998), *The competitive advantage of nations: With a new introduction,* New York: Free Press.

Reigeluth, C. (Ed.) (1983), *Instructional design theories and models: An overview of their current status,* Hillsdale, NJ: Lawrence Erlbaum Associates.

Resnick L.B., & Klopfer, L.E. (Eds.) (1989), *Toward the thinking curriculum: Current cognitive research,* Alexandria, VA: Association for Supervision and Curriculum Development.

Rose, L. H., & Lin, H. T. (1984), “A meta–analysis of long–term creativity training programs” in *Journal of Creative Behavior*, 18(1), 11–22.

Sawyer, R. K. (1999), “The emergence of creativity”, in *Philosophical Psychology,* 12(4), 447–469.

Scardamalia, M. (2002), “Collective cognitive responsibility for the advancement of knowledge”, in B. Smith (Eds.), *Liberal education in a knowledge society,* Chicago: Open

Court, pp. 76–98.

Scardamalia, M. (2004), “Instruction, learning, and knowledge building: Harnessing theory, design, and innovation dynamics”, in *Educational Technology,* 44(3), 30–33.

Scardamalia, M., & Bereiter, C. (1999), “Schools as knowledge building organizations”, in D. Keating, C. Hertzman (Eds.), *Today’s children, tomorrow’s society: The developmental health and wealth of nations*, New York:Guilford, pp. 274–289.

Scardamalia, M., & Bereiter, C. (2003), “Knowledge building”, in *Encyclopedia of education* (2nd Ed.), New York: Macmillan Reference, pp. 1370–1373.

Scardamalia, M., Bereiter, C., McLean, R. S., Swallow, J., & Woodruff, E. (1989), “Computer–supported intentional learning environments” in *Journal of Educational Computing Research*, 5, 51–68.

Sculley, J. (1987), *Oddyssey: Pepsi to Apple... the journey of a marketing impresario,* New York: Harper & Row.

Tapscott, D. (1998), *Growing up digital: The rise of the Net generation*, New York: McGraw–Hill.

Thorn, D. (1987), “Problem solving for innovation in industry”, in *Journal of Creative Behavior*, 21(2), 93–107.

Warschauer, M. (2003), *Technology and social inclusion: Rethinking the digital divide*, Cambridge, MA: MIT Press.