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EDUCATION FOR THE KNOWLEDGE AGE: DESIGN-CENTERED MODELS OF TEACHING AND INSTRUCTION

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This chapter deals with recent efforts to reshape teaching and instruction in response to perceived new needs arising from a shift from a manufacturing-based to a knowledge-based economy (Drucker, 1994). Accordingly, it does not deal with models of teaching and instruction in general (cf. Reigeluth, 1999) or with such perennial concerns as the teaching of basic academic skills and content, motivation, retention, and transfer, except insofar as changing conditions require a new look at these. Instead, the focus is on objectives and methods that are tied in some way to the rising importance of knowledge creation and knowledge work.

We begin with a necessarily cursory examination of larger economic and social trends that have implications for teaching and instruction. A key question is whether these trends have created a need for any new skills, abilities, and forms of knowledge or substantially altered traditional educational priorities. In seeking an answer to this question, we consider what is different about knowledge work from other types of skilled work. Two insights emerge from this analysis: (1) In the world of knowledge work, knowledge has acquired a thinglike or artifactual status, making it something that can be treated as a product, material, or tool. This is a radical departure from how knowledge has traditionally been treated in both epistemology and education. (2) Directly or indirectly, knowledge work typically serves design goals rather than "truth" goals. This puts knowledge work in diametrical contrast to school work. Together, these insights point to two educational reform objectives: (1) bringing design work into the formal or academic part of the curriculum and (2) developing in students the ability to work creatively with knowledge per se—as distinct from working creatively on tasks that *use* knowledge. Several contemporary educational approaches are examined in light of these reform objectives.

We then look more deeply into the *creativity* part of the Knowledge Age challenge. According to contemporary theories, creative ideas can only be explained as emergent results of a self-organizing, Darwinian process. The same can be said of understanding. Creating new knowledge and understanding existing knowledge are both emergent processes. We examine emergence more broadly as an educational phenomenon and note that "systems thinking" can illuminate other learning issues as well. Finally, we consider technology as support for education adapted to the Knowledge Age.

We must emphasize at the outset that, although economic changes may be driving educational changes at the policy level, it by no means follows that what happens at

the classroom level need be or should be framed in terms of economic expediency. A broader and more humanistic view is suggested by A. N. Whitehead's dictum that education should enable students "to appreciate the current thought of their epoch." In our epoch, which is coming to be known as the Knowledge Age, the "current thought" is not a collection of beliefs but a dynamic process of advancing the frontiers of understanding and efficacy on all fronts. In this chapter we consider the possibility that students can participate in this process rather than only viewing it as spectators.

THE "KNOWLEDGE SOCIETY" IDEA AND ITS IMPLICATIONS FOR EDUCATION

The concept of *knowledge society* is derived from the seminal work of management scientist Peter Drucker (1968,1993). Central to Drucker's conception is the idea of *knowledge work*, which he portrayed as gaining ascendancy over manufacturing work, just as manufacturing work at an earlier time gained ascendancy over agricultural work. A difference highlighted by Drucker is that the learning required for an individual to shift from agricultural to factory work is relatively slight, whereas a shift from manufacturing to knowledge work requires extensive learning. Hence the escalating importance of education: "Education will become the center of the knowledge society, and the school its key institution" (Drucker, 1994, p. 53). This conviction was reiterated by the 30-nation Organization for Economic Co-operation and Development: "Education will be the centre of the knowledge-based economy"(OECD, 1996, p. 14). The importance of both formal ("codified") and informal ("tacit") knowledge has been recognized and even the connection between the two: "*Tacit knowledge* in the form of skills needed to handle codified knowledge is more important than ever in labour markets" (OECD, 1996, p. 13; emphasis in original).

In the hands of management specialists, the ideas of knowledge society, knowledge work, and knowledge management have become elaborated into concepts such as "intellectual capital" (Stewart, 1997) and "knowledge-creating companies" (Nonaka & Takeuchi, 1995). In economics, ideas such as "knowledge-based economy" and "knowledge capitalism" emerged, signaling a fundamental shift in the bases of wealth and productivity:

> Economic historians point out that nowadays disparities in the productivity and growth of different countries have far less to do with their abundance (or lack) of natural resources than with the capacity to improve the quality of human capital and factors of production: in other words, to create new knowledge and ideas and incorporate them in equipment and people. (David & Foray, 2003, p. 21)

David and Foray added: "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). How education can serve this "need to innovate" is the focal problem addressed in this chapter.

Education's Response to the New Economic Challenges

According to Peters (2003):

> Knowledge capitalism and knowledge economy are twin terms that can be traced at the level of public policy to a series of reports that emerged in the late 1990s by the OECD . . . and the World Bank . . . before they were taken up as a policy template by world governments in the late 1990s. In terms of these reports, *education is reconfigured as a massively undervalued form of knowledge capital that will determine the future of work, the organization of knowledge institutions and the shape of society in the years to come.* (p. 364, emphasis added)

Policy template is an appropriate term for the response of education authorities to the perceived economic sea-change. Wherever we travel we are handed attractive documents that set out an official plan for shaping education to the new conditions of globalization and knowledge economy. The common elements of these plans are (1) equipping the schools with computers and Internet connectivity, (2) training teachers in the appropriate use of this technology, and (3) developing in students a set of "soft" skills, which include collaboration, learning-to-learn, self-direction, creativity, and a lifelong readiness to learn and unlearn. As judged by the allocation of funds and the spilling of ink, the first two elements have received by far the most attention. We regard this as a transitory phenomenon, however, bound to diminish as technology becomes more taken for granted in school life. It is instead the "soft" skills element that represents a major and continuing challenge and that, accordingly, we take as the focus of this chapter.

The issue here is not that the traditional "basics" are irrelevant to Knowledge Age needs. Obviously they are highly relevant. The issue is that a new and qualitatively different set of needs has arisen, and the schools are not devoting anything like the attention to those that is being lavished on schooling's traditional tasks.

The Increasing Significance of "Soft" Skills

In 1998, the University of Washington's Office of Educational Assessment surveyed about 3,000 graduates, asking them to rate the importance of various abilities

in their present lives (Gillmore, 1998). Half the graduates were 5 years beyond graduation, the other half 10 years. There was little difference between the ratings of these two groups. The top-rated ability was *defining and solving problems.* Other abilities receiving an average rating of 4 or more on a 5-point scale were *locating information needed to help make decisions or solve problems, working and/or learning independently, speaking effectively,* and *working effectively with modern technology, especially computers.* These were the top-rated abilities regardless of major field of study. Abilities directly deriving from university courses varied in rating from field to field, but never made it into the top five.

These top-rated abilities are very general in nature, applying to a wide variety of activities, in contrast to job-specific skills or the more discipline-specific knowledge and skills taught in university classes. In the business skills training literature they are referred to as "soft" skills. The term "generic" skills also covers approximately the same range. (See National Centre for Vocational Education Research, 2003, for a discussion of equivalent terms used in different countries.) The terms *hard* and *soft skills*, although ubiquitous, remain vague and metaphorical, usually defined only by examples. The following contrasts, however, are frequently noted and give a general idea of what the terms imply:

Hard Skills	Soft Skills
Often job-specific	Not job-specific
Objectively testable	Assessed subjectively
Directly teachable	Not directly teachable

In an Educational Testing Service report titled *The Economic Roots of K-16 Reform*, Carnevale and Desrochers (2003) documented the rising educational requirements for Knowledge Age jobs, adding:

> The kind of education and skill demanded also has changed as a result of the shift to a service and information-based economy. Skill requirements have expanded to include soft skills, such as problem-solving and interpersonal skills, that supplement the more narrow cognitive and occupational skills sought in the industrial economy. Attitudinal skills, such as a positive "cognitive style," also are growing in importance because they allow workers to cope with the accelerating pace of change in the workplace. (p. 15)

In summary, the conditions motivating an increased emphasis on soft skills include:

- Uncertainty about future job requirements, which makes teaching of vocational hard skills questionable for students not yet in the job market
- Global competitiveness, with soft skills representing a way for individuals or organizations to gain a competitive edge
- Information abundance, reducing the need for teachers to act as information providers and increasing the need for ability to locate and select task-relevant information
- Increased specialization, making critical hard skills increasingly tied to advanced specialist training
- Technical de-skilling, reducing the hard-skill requirements for use of common software and complex tools.

PROBLEMS WITH SOFT SKILLS

There has been amazingly little "problematization" of pedagogy with respect to soft skills. Yet almost every aspect of teaching soft skills is, from the standpoint of contemporary learning science, deeply problematic. Here we discuss three broad problems.

What Are They?

Is there such a thing as problem-solving skill, in anything like the sense that there is keyboarding skill or automobile-driving skill? It would seem that an answer is required before one can hope to design a program to turn students into good problem solvers. Yet there is not an obvious answer, and—what is worse—there does not seem to be much awareness among educators that there is a question here deserving of thought. Or consider the second-ranked ability in the University of Washington survey: *locating information needed to help make decisions or solve problems.* A common practice in schools, and one that teachers would surely allude to in claiming that they are teaching Knowledge Age skills, is the research project in which students gather information from the Web and other sources and compile it to produce a report—often an electronic presentation. But note that the highly ranked ability is not simply that of locating information relevant to a topic. With contemporary search engines, 10 minutes of training should suffice to enable anybody to do that. What is hard is finding information that advances understanding relevant to the solution of a problem. The typical school "research" project provides little experience in dealing with this task, yet we do not find educators bemoaning this lack and discussing what to do about it.

The "what are they?" problem reaches an extreme in expressions like the one appearing in the previously quoted statement by Carnevale and Desrocher (2003): "Attitudinal skills, such as a positive 'cognitive style.'"

What on Earth is an "attitudinal skill," and how could cognitive style be an example? It would appear that any desirable personal characteristic may count as a soft skill. This, however, raises the question whether soft skills should be regarded as skills at all. In a later section we will consider a number of alternative conceptualizations.

Learnability/Teachability

The terms *learn* and *teach* are used very loosely in the soft skills literature and in curriculum standards and guidelines referring to them. Any activity that calls for a certain soft skill is said to teach it, and students who carry out the activity are said to learn it. A bland optimism prevails in the commercial and teacher-oriented literature. For instance, one Web page, from a vendor of wall climbing equipment, proclaimed:

> Through a variety of challenge activities and climbing wall initiatives, individuals and teams have:
>
> - Learned to work cooperatively
> - Gained in trust of self and others
> - Increased their self confidence and willingness to take positive risks
> - Developed leadership skills
> - Enhanced their interpersonal communication skills (listening, speaking, and writing)
> - Increased their creative problem solving skills (Everlast Climbing Utilities, n.d.)

Such ungrounded optimism is not limited to the low end of the scholarly ladder, however. For instance, in the U.S. National Research Council's guide for implementing the National Science Education Standards, we find:

> The *Standards* seek to promote curriculum, instruction, and assessment models that enable teachers to build on children's natural, human inquisitiveness. In this way, teachers can help all their students understand science as a human endeavor, acquire the scientific knowledge and *thinking skills important in everyday life* and, if their students so choose, in pursuing a scientific career. (Olson & Loucks-Horsley, 2000, p. 6) (emphasis added)

Transfer

Transfer of learning is a massive and much discussed issue in education (Bransford & Schwartz, 1999; McKeough, Lupart & Marini, 1995). What is seldom recognized, however, is that transfer is largely a soft skills problem. If one has learned how to add a column of figures (a "hard" skill), one can presumably do this in any situation where it is called for. Of course, one may fail to apply the right arithmetic operation or may apply it to the wrong figures or may draw the wrong conclusion from the result; but those are soft skill problems. They are problems of the intelligent use of arithmetic. Bereiter (1995) has argued that this is the essence of the problem of transfer: What fails to transfer from one situation to another is not the skill itself but the intelligent use of it. Situativity theorists (e.g., Lave, 1988) make a similar argument: Through continued participation in a particular sphere of action one's actions become increasingly well adapted, resourceful, and flexible—in a word, intelligent—but in a different situation one has to start over learning the ropes, mastering what constitutes intelligent action in the new context.

The problem of transferability of soft skills is so vast and intractable that the commonest approach in the Knowledge Age skills literature is simply to ignore it. There seems to be a tacit assumption of unlimited transfer. In the examples cited in the previous section, optimism about learnability and teachability carry over into optimism about transfer. The advertisement for wall climbing equipment concludes, "By learning to trust each other and by working together, you begin to develop the skills that are integral to successful team functioning. This transfer of learning moves beyond the team and has additional application at home, in school, and in the community." Possibly all of this is true. But generations of research on generalization and transfer give us reason to doubt it and to demand either evidence or at least a plausible rationale for expecting widespread benefits to come from a situation so remote from most normal spheres of action. But do we have reason to believe that the exercise of the same soft skills in a school science laboratory, for instance, will have any greater transferability? The authors of the National Research Council document on implementing science curriculum standards evidently believed so, when they wrote of students acquiring, through their science study, "thinking skills important in everyday life."

A more realistic view of the transferability of soft skills would make use of Bransford and Schwartz's (1999) concept of judging transfer by savings in future learning. Students who have learned to cooperate in carrying out school projects may not automatically be better than others at cooperating as members of a road building crew or a legal defense team. Much specialized learning of social as well as technical kinds will be required in order to cooperate effectively in these different contexts. But it is not unreasonable to suppose that prior experience in cooperative work might facilitate the new social learning, speeding up adaptation to new situations where cooperation is called for. We cannot assume that, however, nor can we assume that one kind of cooperative experience is as

good as another. Once transfer of soft skills is recognized as problematic, it becomes important to analyze situations and identify learning situations that have deep similarities to situations to which transfer is intended (Greeno, Smith, & Moore, 1993).

ALTERNATIVES TO SOFT SKILLS

Some so-called soft skills, such as cooperativeness, creativity, and self-directedness, might equally well be regarded as personality traits. Soft skills also map on to Gardner's "multiple intelligences" (1983). "People" skills, for instance—which figure prominently among business-related soft skills—correspond to "interpersonal intelligence" in Gardner's scheme. Other concepts that cover all or part of the territory of soft skills are habits of mind (Costa & Kallick, 2000) and talents. In quite a different conceptual framework, soft skills may be regarded as situated practices (Lave & Wenger, 1991)—as ways of acting that come about as one moves from peripheral to full participation in a community of practice. From still another viewpoint, soft skills may be viewed as behavioral norms or rules of wide scope. These are not merely semantic variations on the same idea. They carry quite different implications as to ontology, learnability/teachability, and transfer. Table 30.1 summarizes these implications.

Table 30.1 suggests that these alternative conceptions are all over the map as regards implications for learnability, teachability, and transfer. Some of these implications have to be wrong; the differences cannot be written off as mere differences in perspective. Thus there is a place for hypothesis-testing research to identify those conceptions that are due for elimination or revision as bases for Knowledge Age pedagogy.

A DISTINCTIVE KNOWLEDGE AGE TALENT

In their review of "Economic Fundamentals of the Knowledge Society," David and Foray (2003) asked:

> Are "new skills and abilities" required for integration into today's knowledge economy? If so, what are they? Are they really as new as some might like to make out? Beyond the levels of proficiency needed for the use of information technologies, there do appear to be a number of set requirements: teamwork, communication and learning skills. But these sorts of "soft skills" can hardly be described as new. (p. 31).

It is surely true that these and other frequently mentioned soft skills are far from new and have been well recognized. But is it true that there are no new skills and abilities required for integration into today's knowledge economy? If the question is whether there are any previously unknown skills needed for contemporary knowledge work, the answer is surely no. But if the question is whether there are skills important for contemporary knowledge work that have received little attention in education, and that remain little recognized, we have an issue deserving of serious inquiry, not least by educational psychologists.

TABLE 30.1. Alternative Conceptions "Soft Skills" and Their Implicit Assumptions

Concept	What Are They?	Learnability/Teachability	Transfer
Soft skills	Learned capabilities of very wide applicability. No distinction between nominal coherence and psychological reality.	Assumed teachable like any other skills.	Sometimes acknowledged as a problem, but ignored in practice.
Traits (including multiple intelligences, cognitive styles)	Deeply ingrained characteristics. Possible genetic component. Trait coherence based on psychometric evidence.	Modifiable, but only with difficulty and over long time span. Not teachable in any normal sense.	Unavoidable. Traits condition person's response in many situations.
Situated practices	Systemically constituted appropriate and effective ways of acting within a particular community of practice.	Highly learnable in context; limited role for teaching.	Believed to be very limited.
Habits of mind	Acquired habits, like any others, except enacted at a cognitive level.	Learned through repeated enactment; can be fostered or modified but not taught.	May or may not be triggered in new situations; may or may not prove appropriate.
Talents	Things everyone can do (given required hard skills) but with greatly varying proficiency.	Improvable through practice.	Variable and easily overestimated: e.g., transfer of musical talent.
Rules	Imperative statements. No claims of psychological reality.	May be adopted by individuals or groups. Teachable through advocacy, reminding, modeling, reward structures.	Wherever the norm applies and makes sense.

To put a finer point on the question, we may ask whether there are any soft skills important in the new economy that did not already figure prominently in the early history of flight—one of the signature achievements of the Industrial Age. The Wright Brothers displayed innovativeness and creativity, a high order of collaboration, and Wilbur at least was quite good at communication. Entrepreneurship? They successfully pursued patents and patent lawsuits and were noted for aggressive business practices (Shulman, 2002). The Wright Brothers have, in fact, been used as models of the kind of thinking required in today's business environment (Eppler, 2004). But now we have instances of complete new aircraft being designed entirely on computers (Petrowski, 1996). This seems like a profound shift, but—except for the obvious need for computer skills—does it present any new intellectual or educational challenges? The present authors have argued that it does, 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. To convey what this means, however, we must back off and introduce a more general concept—conceptual artifacts—and a distinction between two modes of dealing with knowledge and ideas—what we call "belief mode" and "design mode."

Conceptual Artifacts

Somewhat simplistically, *conceptual artifacts* may be defined as ideas treated as real things (Bereiter, 2002b). This is in contrast to treating ideas as mental content, as tacit knowledge, as embedded in actions or tools, or as semiotic objects—all of which are legitimate ways of dealing with ideas, but not the same as treating them as objects in their own right. Patents provide a familiar anchor for the concept of conceptual artifact. Patents are awarded for ideas, not concrete devices or verbal or other representations. But patentable ideas are not ideas in people's heads or ideas implicit in their practice. Expressing the same idea in different words does not warrant a patent; it is the idea itself, not any particular expression of it, that is protectable. Although most conceptual artifacts—such as theories, problem formulations, and interpretations—are not protectable as property, they have all the other characteristics. They are human creations, intended for some purpose. They have most of the properties of artifacts in general: They have histories; they can be described and compared, variously used and modified; importantly, they can be discovered to have attributes not known to their creators (Bereiter, 2002b, p. 65). Unlike most artifacts, however, they are immaterial and they can stand in implicative relations to one another.

When treated as real artifacts, ideas can be made objects of inquiry and development, can be adapted to novel purposes, and so on. In knowledge-based organizations, conceptual artifacts figure prominently as products and as tools. It could, in fact, be claimed that conceptual artifacts constitute the knowledge that makes a knowledge-based organization knowledge-based; for although there are other valuable kinds of knowledge (tacit, situated, personal, social, and so on), these are of such long-standing value that they cannot be taken as marks of a new era.

Inasmuch as all kinds of work depend on knowledge, identifying what is distinctive about knowledge work has not been easy. Robert Reich (1991), one-time Secretary of Labor in the United States, coined the term *symbolic analyst*. His elaboration of the term is consistent with the preceding discussion, but the term itself is unfortunate: *symbolic* is too inclusive (religious rituals, for instance, are typically symbolic), whereas *analyst* is too narrow. The idea of conceptual artifacts can be useful in delimiting the field: Not all work involves conceptual artifacts, but arguably all knowledge work does. Working with conceptual artifacts, as distinct from working primarily or exclusively with material things, might therefore serve as a defining characteristic of knowledge work. In this light other, more familiar aspects of knowledge work take on a different hue. Collaboration in knowledge work is not the same as collaboration in wall-climbing, for instance, because feedback to the collaborative process is likely to be intangible and to require analysis in its own right. "Lifelong learning" becomes increasingly problematic if the learning must include not only facts and skills but also an effective grasp of difficult ideas. Only rarely, of course, is knowledge work purely conceptual. At some point conceptual artifacts have to make contact with real people, real shoes, real money, or something of that sort, where the mapping between conceptual artifacts and physical reality has real-world consequences, and these consequences are fed back into the work with conceptual artifacts.

In the school world, however, some formidable intellectual artillery is arrayed against work with abstract knowledge objects. Dewey (1916, pp. 183–185) was wary of it. Piaget's distinction between the stages of concrete and formal logical operations has been interpreted by many as a basis for concentrating elementary education on the concretely manipulable and deferring work with abstract ideas until adolescence. More recently, situativity theory has perhaps inadvertently steered educators away from conceptual artifacts, through the idea of knowledge as constituted in practice and accordingly not

o be treated apart from its constitutive practices (Lave, 1988).

All these objections can be answered. In the first place, here is no suggestion that work with conceptual artifacts should go on in isolation from concrete reality. Experimental science provides a paradigm: Experimental scientists are in the business of producing conceptual artifacts, but they carry on this business in intimate congress with some kind of concrete reality. When "hands-on" school science goes on in isolation from the production of conceptual artifacts, however, it can be argued that this is not science at all. Furthermore, it can be argued that working with conceptual artifacts *is* a variety of "learning by doing." The claim that preadolescents are incapable of and uninterested in abstract thought has come under considerable experimental attack (Goswami, 1998). And the objection from situativity theory evaporates if schooling is modeled on communities whose practice includes sustained and creative work with conceptual artifacts (Bereiter, 1997). A deep-seated anti-intellectual bias (Hofstadter, 1963; Howley, Howley, & Pendarvis, 1995) may render all such arguments inconsequential, but it is also possible that societal pressure toward innovativeness may overcome traditional tendencies to restrict schooling to the concrete, practical, and factual.

Belief Mode Versus Design Mode

Historically, the main concern of epistemology has been the bases of true or warranted belief—hence, the name *belief* mode. Activity in belief mode covers a broad expanse, from indoctrination and propaganda on one extreme to the deepest critical analysis and the most open debate on the other. Schooling practices have covered this wide range. Such different approaches as lecture/recitation, inquiry learning , conceptual change teaching (Anderson & Roth, 1989), and transformative education (O'Sullivan, Morrell, & O'Connor, 2002) may be seen from this standpoint as variations all conducted within belief mode.

In knowledge-based organizations, however, work with ideas has taken a radically different direction, signaled by terms such as *knowledge-creating companies* (Nonaka & Takeuchi, 1995). In the pursuit of innovation, concern with truth and warrant has become incidental to pragmatic concerns such as

What is this idea (concept, design, plan, problem statement, theory, interpretation) good for?
What does it do and fail to do?
How could it be improved?

Work on such questions defines activity in "design" mode.

Formal education—the "academic" part of the curriculum, dealing with conceptual content as distinct from hard skills—has historically and to this day been conducted almost exclusively in belief mode. Questions about rationale, evidence, and logical consistency may be raised (cf. Kuhn, 1993), but design-mode questions, such as those just listed, receive little if any attention in textbooks, teaching materials, and curriculum standards or in the educational research literature of past years. Design mode activity does go on in schools, of course—in practical and fine arts courses, and in extracurricular activities such as drama and fund-raising—but it is alien to the academic curriculum. This marks a deep divide between knowledge as it is treated in schools and knowledge as it is treated in Knowledge Age organizations.

Conceptual Artifacts in Design Mode: Improvable Ideas

Conceptual artifacts can figure in both belief-mode and design-mode activity. A theory, for instance, may be treated in belief mode as a tentative statement of truth, and evaluated in terms of evidence. In design mode, a theory would be treated as a human construction aimed at serving some explanatory or instrumental purpose, would be evaluated on the basis of how well it served this purpose, and could be made an object of further improvement and elaboration. *Proofs and Refutations* by Lakatos (1976) provides a paradigm of theoretical work in design mode. It presents an imaginary dialogue among a group of mathematicians, who start with an empirically based conjecture about the relation between faces and vertices in space figures, attempt to construct a proof, discover cases that are inconsistent with the conjecture, modify the conjecture to exclude the anomalous cases, and proceed through further cycles of proof, refutation, and theory revision until they arrive finally at a provable theorem that withstands criticism.

Whereas dealing critically with conceptual artifacts in belief mode is a common characteristic of the "thinking curriculum" (Resnick & Klopfer, 1989), dealing with them in design mode has typically been the work only of advanced graduate students (cf. "making a contribution to knowledge" as the criterion that traditionally distinguishes doctoral theses from lower-level dissertations). In a "knowledge creating company," however, idea improvement becomes a core activity of the whole organization. Although the end result may be a new product rather than a new theory, the cycle of work leading up to the end result is similar to that portrayed by Lakatos.

This claim leads us back to the earlier discussion of the history of flight and to the question whether solving

design problems the way the Wright Brothers did is different in any educationally significant way from the way aircraft design problems are solved today, where all or most design problems may be addressed computationally. The obvious difference in medium does not in itself point to anything more profound than the need to learn how to use new tools, something that was true throughout the Industrial Age. However, there are three more significant educational implications. The first is that in solving design problems computationally one is solving them by manipulating conceptual artifacts—mathematical and theoretical abstractions—rather than tinkering directly with material things. This can have both advantages and disadvantages, but it is in any case something quite different and less "natural" than the way the pioneers of aeronautics went about it. The second implication comes from a second-order design task. Someone had to design the software that made it possible to solve aeronautic design problems computationally. The software had to embody accurate information and valid theories about flight; otherwise the end results could be disastrous. Furthermore, this knowledge had to be embodied in the software in such a way that users with less knowledge could employ it successfully. The common element in both the first- and second-order tasks is work with conceptual artifacts that map onto but are not simple representations of physical objects. The contrast between this approach and the hands-on problem solving carried out by the Wright Brothers epitomizes the fundamental change that makes the so-called Knowledge Age different from the Industrial Age. A third educational implication has to do with the kind of collaboration or teamwork required. Modern planning and design often involves hundreds of knowledge workers whose efforts must lead to a unified result. Unlike the hundreds of assembly-line workers whose efforts converge on the manufacture of an automobile, however, the knowledge workers are often engaged in nonroutine tasks and the things they are working with are often abstract objects. This represents a much more demanding kind of cooperation, for which schooling could but typically does not provide relevant experience.

On the basis of this contrast and the concepts introduced earlier, we may identify a distinctive Knowledge Age talent as follows:

A distinctive Knowledge Age talent lies in the ability to work collaboratively with conceptual artifacts in design mode.

If this definition is accepted, and if it is true that work with conceptual artifacts in design mode is virtually nonexistent in education below the advanced graduate level, this indicates a formidable and radical challenge in adapting education to needs of the Knowledge Age.

EFFORTS TO BRING DESIGN MODE ACTIVITY INTO THE ACADEMIC CURRICULUM

Terms such as "Learning by Design" (Kolodner, 2002) signal an effort, at least partly inspired by Knowledge Age priorities, to give design mode activity a more central role in education. A number of current experimental programs reflect this intent, four of which will be reviewed in this section. Our concern here is not the effectiveness of these programs in teaching scientific concepts, for instance, but rather (a) the extent to which they engage students in design work with curriculum-relevant ideas and (b) the context-limited as compared to context-general focus of student work (Bereiter & Scardamalia, 2003). Probably most creative knowledge work in the out-of-school world is context limited; it is work to design a particular product or solve a particular problem to serve the interests of a particular organization or community. The context-general end of the continuum is represented by basic research intended to advance the state of knowledge for a whole civilization. Education for the Knowledge Age would ideally prepare students in some fashion for work with knowledge and ideas across the whole spectrum. However, it should be recognized that formal education is properly concerned with knowledge of wide generality, and so a bias toward the context-general end of the continuum is appropriate. It is therefore noteworthy that most of the programs bringing design mode activity into the academic curriculum are oriented toward the context-limited end.

Learning by Design™

In Learning by Design, as described by Holbrook and Kolodner (2000, p. 221),

> Science learning is achieved through addressing a major design challenge (such as building a self-powered car that can go a certain distance over a certain terrain). . . . To address a challenge, class members develop designs, build prototypes, gather performance data and use other resources to provide justification for refining their designs, and they iteratively investigate, redesign, test, and analyze the results of their ideas. They articulate their understanding of science concepts, first in terms of the concrete artifact which they have designed, then in transfer to similar artifacts or situations, and finally to abstract principles of science.

Although design projects are now fairly common in school science (planning a trip to Mars has been a popular one for a decade), the approach taken by Kolodner and colleagues is distinctive. The challenge for students is to design something that can actually be built and tested. Moreover, the design challenges are planned so that faulty science will lead to performance failure. An example is to

maximize the distance traveled by a toy car driven by air expelled from a balloon through a straw (Kolodner, 2002). Trial-and-error design is followed up by systematic experimentation to determine how variations in the length and diameter of the straw affect performance. Note, however, that the inquiry is still very much context limited. The ultimate science-learning target is Newton's Third Law, but it is not clear how the design task and the related experimentation could lead to or raise questions leading to Newton's law. Teachers, according to Holbrook and Kolodner, wanted to teach the science first and then do the design work (thus shifting to a traditional rule–example pattern of instruction). More relevant to the present issue is an apparent shift from design mode to belief mode in order to get across the scientific idea.

Design problems can lead to engagement with deep scientific principles. In earlier work on Learning by Design, one of the problems was to design an artificial lung. Other problems in this vein would be designing a specific antibiotic and building a rain-making machine. Such design problems can only be solved by first gaining an understanding of the natural process that the design is intended to simulate or have an impact on. However, such design problems lie beyond the scope of what students could actually build and test. Consequently, Learning by Design depends on rather forced connections between the activity and basic ideas. As a result, teachers reportedly present the science separate from the design work, with basic ideas dealt with in belief mode, in parallel with, but not intrinsic to activity in design mode.

Project-Based Learning

Project-based learning covers a wide range. At one extreme is the traditional "project," which consists of choosing and narrowing a topic, collecting material, organizing and presenting it—differing from the projects of 50 years ago only in the use of digital media. At the other end are highly developed inquiry projects, mainly but not exclusively in science. As defined by Marx, Blumenfeld, Krajcik, & Soloway (1997, p. 341); "Project-based science focuses on student-designed inquiry that is organized by investigations to answer driving questions, includes collaboration among learners and others, the use of new technology, and the creation of authentic artifacts that represent student understanding." Of projects meeting these specifications, we may ask: To what extent do they engage students in design-mode as compared to belief-mode activities, and where do they lie on the context-limited to context-general continuum? Typically, the "driving question" is posed to the students: to predict the weather from real-time data (Lee & Songer, 2003), to collect and interpret observational data on schoolyard wildlife (Parr, Jones, & Songer, 2002), to explain the increasing incidence of deformed frogs (Linn, Shear, Bell, & Slotta, 1999). These projects are highly engineered, leaving little for the students or even the teacher to design. Not only the main question but also the information sources and means of information collection, and often a step-by-step sequence leading up to the final specified product, are set out for the students. However, in the weather prediction and the wildlife projects, students are expected to produce, share, elaborate, and test theories based on the information they have obtained. This is design work of a knowledge-creating kind. In the deformed frogs project, however, the opposing theories or positions are set out for the students and their job is to gather evidence for and against, leading up to a presented argument or debate. Thus the project is framed within belief mode, reflecting the idea, as put by one of the developers, that "Science *is* Argument" (Bell, 2002).

There are instances in which students design experiments and devise explanations, but the design task common across virtually all project-based approaches is the presentation—what Marx et al. referred to earlier as "the creation of authentic artifacts that represent student understanding." The presentation may usurp so much of the students' attention (and sometimes that of the teacher) that it overwhelms cognitive goals (Anderson, Holland, & Palincsar, 1997; Moss, 2000; Yarnall & Kafai, 1996). Interestingly, similar concerns have been raised about the amount of attention business executives lavish on their PowerPoint presentations and the accompanying neglect of content (Tufte, 2003). Thus there is a danger that bringing design-mode activity into the core curriculum via Project-Based Learning may force the core curriculum off the stage.

Problem-Based Learning

Although problem-based learning is often treated as synonymous with project-based learning, there are important differences, reflecting problem-based learning's medical school origins. As originally implemented in medical education, now spreading to other kinds of professional education, PBL, as it is called, engages students in solving problems modeled as closely as possible on problems they will actually encounter in their professional practice (Barrows, 1985). Unlike project-based learning, there is little focus on a tangible end product. The end product is a problem solution—a purely conceptual artifact.

As used in professional education, PBL is quite properly context limited. Harden and Davis (1998) proposed a "continuum of problem-based learning" in medical education, with what they called "theoretical learning" lying "furthest from the problem based end of the continuum"

(p. 318). They described theoretical learning as coming about through information transmission by lectures and textbooks and tending toward rote learning, with no effort at application. A PBL approach to theoretical learning finds no place on their continuum, which is consistent with PBL's focus on professional practice. The doctor's job is not to produce a theory of pain or to devise a comprehensive approach to pain management, but to deal with the pain in a particular patient's hip joint; PBL problems are usually posed with that degree of specificity, and PBL procedures are geared to the cooperative, evidence-based solution of such problems. Extensions of PBL into general education—even elementary education—have tended to retain this context-limited specificity (Torp & Sage, 2002). Thus, the problem is likely to be to explain why the bean plant died or to develop an environmentally sound plan for school waste disposal rather than to explain photosynthesis or biodegradability.

To what extent PBL engages students in design varies considerably. In the classic medical school version, an important phase of PBL is students working on a "learning issue," in which they identify and pursue what needs to be learned in order to solve the case. This is design activity in the realm of scientific facts and ideas. In school applications of PBL that we have located, this phase seems to have been eliminated. Without it, PBL is reduced to regular guided inquiry focused on cases rather than on more central conceptual issues (Bereiter & Scardamalia, 2000).

Although case-based problems are inherently context limited, they can acquire general significance when considered in the context of a more fundamental inquiry. Deep inquiry may start with an intriguing case: In an example provided by Hunt and Minstrell (1994), inquiry starts with the problem of what happens to an object on a spring balance as the air is evacuated from around it. But attention then shifts to the students' explanatory ideas and to the testing and revision of these ideas. Experiments are chosen that broaden the inquiry to general concerns about gravity, the difference between weight and mass, and weight of the atmosphere. In this shift from context-limited to context-general, the nature of the problem itself undergoes transformation. This expansion of the problem space is something that PBL was not designed to address. The next approach we consider is also "problem-based" in a broad sense, but the problems are more context-general problems of understanding, and the students' role as designers is given much more scope.

Knowledge Building

Knowledge building differs from the other approaches by emphasizing conceptual artifacts (theories, designs, plans, histories, etc.) as products, tools, and objects of inquiry (Scardamalia & Bereiter, 2003). Activities such as model building, conducting experiments, and producing reports are carried out in the service of a broader effort to produce some innovation or advance a knowledge frontier. Knowledge building, as thus conceived, is not an activity limited to education but characterizes creative knowledge work of all kinds. In keeping with its generative character, knowledge building is not highly proceduralized. Instead, a software environment (discussed in a later section as a "Knowledge Building Environment" or KBE) provides flexible support and coordination for sustained and creative work with ideas.

In educational applications, students are engaged in design in all phases and at all levels of the knowledge-building enterprise: defining problems, advancing initial ideas, using whatever resources and inquiry possibilities are available to improve those ideas, reformulating problems as the knowledge building advances, and presenting results (Hewitt, 2002). It is not uncommon for the entire year's work in a subject to be carried out as a single knowledge-building initiative. Where the main objectives are officially mandated, these are made known to the students as part of the problem space in which they will work. Thus it could be said that instead of assimilating design-mode activity into the academic curriculum the academic curriculum is assimilated into design mode.

Educational knowledge building can be focused at any point along a context-limited to context-general continuum. However, the bias is toward the context general end. This is partly because educational standards, which are usually highly context general, contribute to the students' defining of problems (we refer here to the standards themselves, not to the recommended learning experiences, which are often quite context limited). It is also because students' "epistemic agency" drives inquiry in that direction. For instance, in one seventh-grade class an inquiry that began with the question "What is it like to stop growing?" soon evolved into the question of what causes growth to stop and what determines at what height different people's growth stops (Bereiter, Scardamalia, Cassells, & Hewitt, 1997). On a topic such as gravity, electricity, or light, students free to generate their own theories and problems of understanding naturally come up with the question, "What is it?" Although they may hold the common misconception that these things are substances (Chi, Slotta, & deLeeuw, 1994), they are likely, through their own collective efforts at idea improvement, to discover problems with this conception. As one fourth-grader put it with reference to light: "It isn't a solid or a liquid or a gas, so what is it?" This started a line of inquiry that ended with the idea that light is a kind of energy.

COMPARISONS AND POSSIBILITIES OF SYNTHESIS

If the preceding section were aimed at prospective adopters of an educational approach, we should need to consider a number of pragmatic issues that developers address in different ways—for instance, how far to go in adapting to established expectations about the lengths of units, activity structures, and even the words in which approaches are described. However, the point of this chapter is the potential of different methods and models to equip students for creative knowledge work.

The differences among approaches such as the four discussed in the preceding section are often minimized, lumping them together as constructivist. Even the brief look "under the hood" offered here should make it clear that the approaches are far from interchangeable. They all bring design-mode activity into the main academic curriculum. They all deal with ill-structured problems, which sets them apart from many thinking skills approaches. But they differ in the kind of design work students do, how central it is to curriculum objectives, and where the problems they tackle lie on a context-limited to context-general continuum.

All four of the approaches aim to bring about understanding of the big ideas that make a knowledge society possible in the first place. Knowledge Building additionally aims at the fullest possible immersion in the work by which such ideas are created and improved, which necessarily means dealing with the big ideas in design mode rather than belief mode.

All the approaches place high value on authentic activities, problems, or questions; but *authentic* means different things in the different approaches. In Learning by Design it means designing things that actually work and that appeal to students' interests in toys and games. In sophisticated versions of Project-Based Learning, it means activities and issues drawn from real-life concerns and controversies. In Problem-Based Learning it means problems closely modeled on those that will actually be encountered in practice. In Knowledge Building it means problems and questions that the students actually wonder about. These are all legitimate meanings of *authentic,* but they point in quite different directions as to the sorts of experience students will have.

A case can be made for including all four approaches in a well-rounded program of education for the Knowledge Age, on grounds that they reflect the diversity of knowledge work that actually goes on in society—from product engineering to making evidence-based policy decisions to advancing basic knowledge. This would tend to result in a grab-bag of activities, however, an all-too-common practice that we presume advocates of all the approaches would oppose. An alternative is to consider whether any of the approaches is expandable to include the full range of working with ideas in design mode. Nominally, Project-Based Learning can serve this purpose, because all the approaches involve projects of some sort. However, that would seem merely to give a name to the grab-bag.

Of the four approaches, only Knowledge Building explicitly supports design-mode work at the context-general end of the continuum—that is, design work directly aimed at creating and improving broadly significant theories, problem formulations, interpretations, and the like. So committed is knowledge building to design mode that educators frequently ask the paradigmatic belief-mode question: What is to keep the students from ending up with wrong beliefs? A dismissive answer, appealing to the research on misconceptions, is that knowledge building would have to do very badly in order to come out worse than other instructional approaches on this count. A deeper level answer is that as long as students are working seriously to improve their ideas and are making constructive use of authoritative sources in doing so, they will inevitably move beyond the naive conceptions educators are worried about.

As actually implemented in classrooms, Knowledge Building already incorporates much of the design-mode activity of the other approaches. Students have designed, built, and tested solar cookers and model airplanes, but they have done so within the context of investigations aimed at understanding light and lift. Designing experiments to test their "theories" has begun as early as first grade. They have produced multimedia presentations, dramatizations, and other such project-like displays, but these have grown out of their knowledge-building accomplishments rather than representing the endpoint toward which they are directed. Thus Knowledge Building can incorporate the strongest parts of other approaches, while avoiding contrived projects whose main purpose is to develop soft skills.

Over and above providing particular learning experiences in design mode, a coherent approach to Knowledge Age education ought to provide a means of initiating students into a knowledge-creating culture—to make them feel a part of a long-term and global effort to understand their world and gain some control over their destiny. An eclectic or mixed approach, however worthy its components may be, cannot be expected to do this. To socialize students into an emerging Knowledge Age culture, while at the same time meeting societal expectations of knowledge and skill development, would seem to demand a comprehensive design for bringing creative work with ideas into the heart of the curriculum.

THE CHALLENGE OF SUSTAINED CREATIVITY

Traditionally, creativity training has focused on idea generation, fostered through brainstorming, lateral thinking, and other techniques; that focus continues in structured programs and commercial teaching materials up to the present day (Nickerson, 1999). Both in teaching and in testing, the typical task is what we may term *single-prompt idea generation* (e.g., generating novel uses for a coat hanger). This is quite remote from the creative work called for in modern organizations, where ideas must meet multiple constraints, where there is often a surfeit of novel ideas to choose from, and where the desired outcome depends on sustaining creative input to a development process that may go on for months or years (Bereiter, 2002a; Cooper, 2003). "The Mind of Microsoft" (Microsoft Monitor Weblog, 2004, March 12) describes one large organization's disciplined approach to idea development.

Although the Internet is full of confident claims, psychologists writing on creativity have for the most part steered clear of the question of teachability. An exception is Nickerson (1999), who, after reviewing training approaches, concluded that the evidence either for or against the teachability of creativity is "less than compelling" (p. 407). (Parenthetical question: What would constitute compelling evidence that something is unteachable?) On the more positive side, researchers have shown a growing interest in career-long creativity, a topic of obvious importance in a Knowledge Society. Some high points emerging from examination of creative careers are the following:

1. The "ten year rule," first researched and enunciated by Hayes (1989). In a wide variety of fields, it is found that significant creative contributions are not made until a person has devoted 10 years or more to relevant work and study. Notably, the early years of creative careers are often devoted to imitation rather than to efforts at originality (Weisberg, 1999).

2. Evidence that creative people sustain high levels of productivity, producing more unsuccessful results as well as more successful results than less creative people (Simonton, 1999). Prolific idea production is an essential part of what appears to be the only viable theory of the creative process now going, one that treats it as a form of Darwinian evolution (Dennett, 1995).

3. Extensive and deep knowledge as a necessary and sometimes sufficient condition for creative production (Weisberg, 1999). Weisberg argued, for instance, that Watson and Crick, whatever their creative talents, were the only people who possessed the knowledge required to solve the DNA riddle. The same might be said of Darwin and Wallace, independent solvers of the speciation riddle, who had remarkably similar and unusual knowledge backgrounds (Quammen, 1996).

4. Sternberg's (2003) hypothesis that the driving force in creative careers is the decision to be creative, to pursue particular kinds of creative goals within a chosen domain, and to develop the requisite abilities.

If this career perspective is taken seriously in schools, as Sternberg (2003) urges it should, then the emphasis should shift from teaching idea generating skills to launching students on a trajectory that will result eventually in their becoming creative contributors in their chosen fields or enterprises. The career perspective elevates the importance of knowledge, contrary to folk beliefs about antagonism between knowledge and creativity (Weisberg, 1999), but at the same time it makes transfer of school learning appear increasingly problematic. The "ten year rule" applies to serious goal-oriented work within a particular field; general education and development, although they may be important, do not count as part of the ten years. Early beginnings in the arts and in some sports are characteristic of those who later excel, but these lie mainly outside ordinary schooling (Bloom, 1985).

In view of the lack of convincing outcome research (especially the lack of evidence of transfer) and the shift of emphasis toward a career perspective, it would probably be desirable to abandon all talk about "teaching" creativity in schools. Such talk only leads to false claims, illusory curriculum standards, susceptibility to fads, and an overemphasis on originality at the expense of the imitation that has been found characteristic of those who later excel. Instead of an attempt to teach creativity, material reviewed thus far suggests the following components of an approach to creative talent development:

- Shift the curriculum toward design mode, especially as regards work in core subjects. Although work in belief mode is important, virtually all the world's creative work is done in design mode.
- Strive for depth of understanding. Deep principles underlie most knowledge work and the transfer value of shallow knowledge is especially questionable.
- Create a classroom ethos that makes striving for idea improvement the norm. Sternberg (2003) offers a number of pointers for doing this.

As a framework for implementing these suggestions, knowledge building constitutes an approach in which all these elements are salient and coordinated (Scardamalia & Bereiter, 2003).

KNOWLEDGE ABOUT KNOWLEDGE

If work with knowledge is indeed becoming the leading work in developed nations, understanding knowledge itself could reasonably be set as an educational objective. In their influential book *The Knowledge-Creating Company*, Nonaka and Takeuchi (1995) criticized Western business people for their Cartesian epistemology and their neglect of implicit knowledge. Moldoveanu (2000) criticized business people for a naive and uncritical approach to matters of fact and belief.

Although the term *epistemology* was not even indexed in the 1986 *Handbook of Research on Teaching* (Wittrock, 1986), there has since been extensive research on teachers' and students' epistemological beliefs and their influence on teaching and learning (Buehl & Alexander, 2001; Hofer & Pintrich, 2002; Mason, 2003). Although epistemological beliefs are found to be multidimensional, a major dimension that turns up in all the research is one ranging from a simplistic and absolutist conception of knowledge to a conception that recognizes in some fashion the tentative and contingent character of knowledge (Mason, 2003). Noteworthy in the context of this chapter is the fact that research on students' and teachers' epistemologies pertains to what we have termed *belief mode*. To what extent these epistemological beliefs would affect functioning within design mode is unknown.

More relevant to activity in design mode has been research on teachers' and students' conceptions of inquiry (Andre & Windschitl, 2003). Here the main distinction appears to be between those who see inquiry as the enactment of routines (often under the banner of "scientific method") and those who see it in more systemic terms, as an interactive process with understanding as an emergent. Unfortunately, however, research on beliefs about inquiry typically does not distinguish between experimentation carried out in belief mode (testing whether a guess or hypothesis is correct) and experimentation carried out in design mode, where it is part of an iterative process aimed at theory or product development. One study that did differentiate (Carey, Evans, Honda, Unger, & Jay, 1989) indicated that a design-mode conception of experimentation (Level 3 in their hierarchical scheme) was relatively rare among seventh graders, even though they had undergone 6 weeks of instruction on the nature of science that was effective in other respects.

In rough summary, research on teachers' and students' conceptions shows that various kinds of instruction and experience can produce a shift from seeing knowledge as absolute ("the way things really are") to seeing it as constructed; but understanding *how* it is constructed remains as a largely unmet challenge, one quite central to creative knowledge work.

Knowledge as an Emergent

As complex systems concepts such as self-organization and emergence make their way into mainstream educational psychology, it becomes increasingly apparent that there are no simple causal explanations for anything in this field. In general, what comes out of a sociocognitive process cannot be explained or fully predicted by what goes into it. Creative works, understanding, and cognitive development are all examples of complex structures emerging from the interaction of simpler components (Sawyer, 1999, 2004). Learning itself, at both neural and knowledge levels, has emergent properties (Pribram & King, 1996). So widespread and significant is the impact of systems concepts throughout the natural and behavioral sciences, moreover, that there is also an emerging educational objective: to teach the theoretical concepts and to foster "systems thinking" in students (Jacobson & Working Group 2 Collaborators, 2003; Wilensky & Resnick, 1999). Research has begun to appear identifying and tackling the difficulties of acquiring complex systems concepts (Charles & d'Apollonia, 2004).

A good case can be made for complexity theory (Byrne, 1998) as an essential part of a Knowledge Age curriculum. Complexity theory may represent what Case and Okamoto (1996) called a "central conceptual structure" or what Ohlsson (1993) identified as an "abstract schema." Its inclusion in the curriculum can be justified on grounds of its being a schema of very wide applicability and a valuable tool for advanced study in practically any discipline and for any complex knowledge work. The problems of teaching it naturally fall within the legitimate scope of educational psychology. But the assimilation of complex systems concepts into educational psychology itself is a different matter. It remains to be demonstrated what practical value this might have.

From a complex systems standpoint, effective teaching of every kind may be characterized as *constructive intervention into an ongoing self-organizing sociocognitive process*. This is a different conception from both instructivist and "guide on the side" notions of teaching. Examples of constructive intervention into self-organizing processes may be found in holistic medicine and in agronomy (maintaining a premium vineyard, for instance); but we are not aware of any general principles to guide such intervention.

Complexity Theory as a Scientific Basis for Educational Psychology

Complexity theory promises to play an important role in educational psychology as a way of comprehending

otherwise inexplicable phenomena and thereby steering a wiser course toward practical decisions. Why, for instance, does phonics work? It is easy to demonstrate that it cannot possibly work, at least not in English, with its famously irregular spellings (Smith, 1971), yet it demonstrably does work. Rule-based explanations are implausible, because they require too many rules (Simon & Simon, 1973). Yet in connectionist terms it is easy to explain how the input of a crude phoneme-by-phoneme sounding-out could produce accurate word recognition as output. This not only brings the familiar phenomenon within the scope of scientific explanation, it may also help steer instructional designers toward productive ways of eliciting and building on the sounding-out phenomenon (Harm & Seidenberg, 2004).

Another, even more puzzling phenomenon: The same scientific misconceptions appear in students of a certain age all over the world. Yet these naive conceptions are not normally taught or openly discussed (else it would not have required research to discover them), so they evidently arise spontaneously. How is this possible? To justify the misconceptions as reasonable does not answer the question, because similar reasonableness could be attributed to countless conceptions that do not arise. The problem here is to explain convergence, arrival at the same state from different initial conditions—as in the convergence of fish and aquatic mammals on a similar body shape. Such a phenomenon is easily modeled with connectionist networks, for instance.

More germane to the present topic, however, is the explanation of creativity. How do novel ideas originate? From Campbell (1960) to Simonton (1999), a growing number of theorists have maintained that creative ideas arise by chance, because there is no other way novelty could originate. But others, such as Sternberg, have found it "utterly implausible that great creators such as Mozart, Einstein, or Picasso were using nothing more than blind variation to come up with their ideas" (Sternberg, Kaufman, & Pretz, 2002, p. 112). This is the same argument used by Paley against Darwin: How could a structure as complex and beautifully designed as the eye have arisen by chance? That is the question addressed at length by Dawkins (1996) and more generally by Dennett (1995). Their answer is in what Dawkins called "cumulative selection," a process by which random variations are selectively incorporated into an emerging complex. For this to work, however, self-organization is also required. Furthermore, selection in the case of human creativity need not be limited to trial and error but may be guided by accumulated knowledge of what we have called "promisingness" (Bereiter & Scardamalia, 1993).

The larger issue here is whether educational psychology itself needs a postindustrial makeover in order to address the learning needs of the Knowledge Age. As other chapters in this volume indicate, there is no shortage of theoretical diversity in present-day educational psychology. If we move up a level, however, to *forms* of theorizing, a gap becomes evident. There is theorizing based on causal linkages, of which production system models provide impressive examples. There is theorizing based on (usually unspecified and unquantified) multivariate functions, often represented by box-and-arrow diagrams. Such theorizing is as pervasive as this familiar type of diagram. There is theorizing that relies on story lines or other literary devices to provide rich representations of ideas. Finally, there is concept-plus-example theorizing, in which concepts such as "legitimate peripheral participation" or "epistemic agency" are introduced and followed by examples that the concepts are shown to illuminate. Harder to characterize is what this varied theorizing is about. Broadly speaking, it is about individual or group processes and individual or group conditions.

Two things are notably absent from this theoretical mix:

1. Theorizing about ideas or knowledge as such. The outcome of an individual or group process is taken to be an individual or group condition (which may, however, be indexed by some objective sign such as a test score). Knowledge creation, reputedly the primary productive activity of the Knowledge Age, does not figure in educational theorizing, nor are ideas or knowledge treated as objects of inquiry.
2. Theorizing that makes substantial use of systems concepts such as self-organization or of dynamical systems methodologies. These concepts appear, of course, but they do not have the theoretical force that they are beginning to have in such fields as sociology of knowledge, memetics, child development, and cognitive psychology.

The result is that there is no theoretically grounded way for tackling the distinctive educational challenge of the Knowledge Age: developing in students a talent for creative knowledge work.

TECHNOLOGY FOR KNOWLEDGE AGE EDUCATION

As noted earlier, computers and computer use figure prominently in official plans for Knowledge Age education. Consistent with this emphasis, alumni in the University of Washington survey (Gillmore, 1998) rated *working effectively with modern technology, especially computers* as one of the abilities most important in their present lives. Note, however, that these alumni would have been

in university in the 1980s or early 1990s, before computers had become a normal part of student life. It has become increasingly doubtful whether the term *computer* marks off a meaningful class of activities or abilities. In 21st-century schools, computers, we believe, are best treated as infrastructure, with educational issues being defined on more fundamental bases. There is a persisting belief, however, that a school in which high-tech resources are well integrated into the curriculum is *ipso facto* a school that is adequately preparing students for the Knowledge Age.

The main reform task for Knowledge Age education, we have argued, is to carry out more of formal education in design mode. This has several implications for educational technology:

1. Because design typically involves different groups working on different problems, technology is needed to support idea diversity and coherence-producing efforts, without micromanaging the process.
2. Because design work is frequently collaborative, technology is needed to support collaborative work.
3. Because formal education in design mode often requires working with ideas rather than with concrete objects, technology is needed that can represent and preserve ideas for sustained inquiry and development.

Developers working in the field known as Computer-Supported Collaborative Learning (CSCL) have been active since the early 1990s and sometimes before in designing software to meet these needs. As Kozma (2003) found in an international on-sites survey, however, little of this software or the thinking behind it has made its way into school use, even in schools locally identified as innovative. Instead, the software used in schools consists mainly of "productivity" applications—word processors, spreadsheets, and presentation software primarily designed for business use and frequently bundled under the name "office"—plus course delivery systems primarily designed to support traditional university instruction. The World Wide Web is used, but mainly to collect material for reports.

CSCL technology covers a wide range, from discipline-specific programs such as ChemSense (Schank & Kozma, 2002) to general-purpose course development tools based on CSCL principles (Linn, Davis, & Bell, 2004), from structured inquiry tools such as the Collaboratory Notebook (Edelson & O'Neill, 1994) to relatively open exploratory environments such as Knowledge Forum (Scardamalia, 2002, 2003) and Boxer (diSessa, 2000). A useful distinction is between *tools*, which serve particular purposes within variously structured activities, and *environments*, which constitute a system of affordances and supports within which the main work of a learning or knowledge-building community may go on.

A knowledge-building environment (KBE), as defined in the *Encyclopedia of Distributed Learning*, is:

> *Any environment (virtual or otherwise) that enhances collaborative efforts to create and continually improve ideas* (Scardamalia, 2003).

This broad definition applies to knowledge work environments of all kinds, not limited to educational ones. Across this spectrum, however, Scardamalia identified several essential characteristics of KBEs that go beyond the more general requirements of CSCL environments. These include

- Support for social organization that goes beyond division of labor
- Support for collaborative creation and revision of conceptual artifacts
- Shared, user-configured design spaces with supports for citing and referencing one another's work
- Ways to introduce higher-order organizations of ideas (in contrast to threaded discussion that only permits downward branching)
- Ways for the same idea to be worked with in varied and multiple contexts
- Systems of feedback to enhance self- and group monitoring of ongoing processes
- Linking of persons and groups on the basis of shared goals and problems rather than on the basis of shared topics of interest

As applied to education, Rubens et al. (2003) describe KBEs as

> Sophisticated environments designed to support expert-like processing of knowledge by guiding students to work collaboratively to improve shared knowledge objects. . . . Through these kinds of environments, students may be guided to engage in productive working with knowledge objects in the same way as the scientific community is engaged with theory improvement. (p. 13)

Thus a knowledge building software environment does not merely promote Knowledge Age soft skills but embodies the essential characteristics of creative knowledge work.

CONCLUSION

A distinction between belief mode and design mode has framed the discussion in this chapter. Belief mode, we have emphasized, does not imply parroting or indoctrination; it can be critical inquiry of a high order. But it is concerned with evaluating and deciding among claims, whereas design mode—the principal mode in knowledge-based enterprises—is concerned with creating and

improving ideas. Both modes are important, and creative knowledge work involves skillful movement between them. For instance, a trial lawyer's courtroom performance is conducted in belief mode insofar as it is concerned with defending or refuting truth claims. But the background work—the devising of a strategy, the construction of a case, the searching out of legal angles, and so forth—is design work of a demanding sort, design work that is continually related to the belief issues at stake in the courtroom. Parallels can be drawn to the work of a sales representative. Different forms of interaction between truth issues and design issues are to be found in investment counseling, architecture, and virtually any kind of work that calls for complex problem solving. But formal education, by being conducted almost exclusively in belief mode, fails to provide students with experience in the productive, creative side of knowledge work.

An adequate educational model for the Knowledge Age, we have argued, must rectify the imbalance by conducting more of formal education in design mode. This is not something that can be done by bringing design activities in as incidentals or homework while the main educational effort continues to be concentrated in belief mode. It will not be sufficient for students to perform experiments to satisfy themselves that Newton's laws of mechanics are valid. They also need to consider Newton's laws from a design perspective, so as to appreciate why inertia and acceleration are important ideas and why there is value in Newton's complex conceptions as opposed to the simpler everyday meanings attached to these terms. It will not be sufficient for students to learn how laws are made in their country and to consider whether the method is just and democratic. They need to see lawmaking as a human invention, to consider the difficulties it poses and the different ways that these difficulties may be surmounted.

Four approaches to bringing design mode activity into the academic curriculum were described—Learning by Design, Project-Based Learning, Problem-Based Learning, and Knowledge Building. Although all are constructivist approaches, they differ in the goals students pursue. These range along a continuum from context-limited goals, specific to a task situation, to context-general goals, concerned with advancing a knowledge frontier. Modern societies depend on sustained creativity all along this continuum. A question of balance arises, however. Most of the design-mode approaches are biased toward the context-limited end of the continuum, whereas the goals of education, as reflected in curriculum objectives, generally lean strongly toward the context-general end.

The preceding sections suggest that a design-centered model of teaching and learning for the Knowledge Age should provide for

- An immersive environment in which idea improvement is a pervasive emphasis
- Design experience across a context-limited to context-general continuum
- Sustained as opposed to scatter-shot creative work with ideas
- Flexible movement between knowledge creation and understanding of existing knowledge
- Flexible movement between work with material and conceptual artifacts, with conceptual artifacts able to inform and drive interactions with material artifacts
- Emergence and self-organization at various levels from individual cognition to participation in work of extended communities

Although various approaches considered in this chapter meet some of these requirements, an elaborated knowledge building model has potential to meet all of them.

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