Socializing the knowledge transfer problem

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CHAPTER 3

SOCIALIZING THE KNOWLEDGE TRANSFER PROBLEM

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Abstract

A central issue in acquiring knowledge is its appropriate transfer beyond the contexts and contents of first acquisition. In contrast to dominant "common elements" transfer theory, an *interpretive* perspective is developed, according to which "appropriate transfer" is a concept socioculturally rather than objectively defined. "Elements" perceived by the thinker as common between the current and a prior situation are not given in the nature of things but "read" in terms of the thinker's culturally-influenced categorization system, of problem types. A synthesis of cognitive research findings identifies specific features of thinking-skills instruction effective for promoting transfer. These include learning about and practicing knowledge application in multiple contexts of use, constructively participating in bridging instruction across school and nonschool problem situations, thinking and self-management skills taught within domains, and synergistic integration of the learning of different subjects. Recommendations are made for developing new learning technologies that build upon these conditions for enhancing knowledge transfer.

Introduction

Transfer of knowledge is a multifaceted problem at the core of learning. Knowledge transfer is not only an individual achievement but a cultural problem, encompassing the study of history. And education is the attempt to transfer knowledge from the culture to the individual. The interpretive or sociocultural perspective on knowledge transfer developed in this paper is designed to accommodate to these complexities.

The question of knowledge "transfer" is typically portrayed as one-directional: How can knowledge acquired in formal education be transferred appropriately to everyday life and work situations? What is lamented is common evidence from the workplace, home, community, and from educators' reports, that wisdom acquired in formal education is not applied outside schooling. But from a developmental perspective, it is essential to add the reverse question, and define the problem more inclusively: How can formal education ensure use in its settings of the concepts, skills, and strategies people have acquired and applied effectively in everyday life and work situations?

Another major direction of transfer of skills, strategies, concepts, and other knowledge is between the traditional curriculum divisions. Greater curricular synergy is needed so students may acquire and apply knowledge in an integrated manner that matches the demands of everyday problem solving.

A last direction of transfer is so pervasive that it blurs with the concept of learning. Transfer studies have been used as a means for assessing learning. If students can only solve specific problems which they have been taught to solve in the classroom, and fail to solve related problems in a series, one would not attribute mastery of the material to them.

Any comprehensive transfer theory for education will need to encompass these multiplicities. This paper analyzes research and theory bearing on these questions, and briefly explores ways in which information technologies may contribute to an effective education for knowledge acquisition and transfer.

Why the Transfer Problem Has Taken on Special Significance

I first consider influences that have contributed to the recent attention to the knowledge transfer problem. There is widespread anxiety about the irrelevancy of most of today's curricula, largely derived in their topical divisions and sequencing from 19th century curriculum theory, and dominated by fact-oriented learning. Such curricula clash with an information age where the basic facts are changing rapidly, where information is stored and conveyed digitally, and in which the "basic knowledge" citizens need is under debate in most fields as computers are able to carry out mechanical aspects of problem solving activities, as in mathematics.

This contemporary fear has been met with grassroots movements initiated by educator organizations to teach "thinking skills". Many thinking-skills curricula have been largely developed and taught independently of course content. It has recently become clear that transfer of learning with such materials to either valued school outcome measures or the quality of everyday life problem solving has rarely been evaluated (Chipman, Segal & Glaser, 1985; Resnick, 1985; Segal, Chipman & Glaser, 1985).

A third contribution to transfer-problem awareness among cognitive scientists came from comparative cross-cultural studies in the 1970's designed to test the cognitive consequences of formal schooling and of literacy. Bruner (1966) had suggested that the remote nature of school thinking from referent situations, such as mathematical reasoning with symbols and equations, fosters abstract thinking and formal operational thought. But contrary to expectations, research generally revealed meagre connections made between what was learned in school and everyday life problem solving (Laboratory of Comparative Human Cognition, 1983).

A fourth influence came from cognitive science studies showing even university physics students to regress from Newtonian theory to mistaken physical explanations based on everyday experiences about moving objects. Shaken from the frame of their textbook explanations, they resort to nonformal qualitative explanations (diSessa, 1983). Shweder (1977) presents similar findings for statistical reasoning among presumably statistical literates. Practical cognition is not, it appears, very affected by instruction in formal science or mathematics. Some consider the external validity of much school "learning" questionable if it does not impact on students' practical cognitions.

A fifth, broadly based influence is the belief not only throughout the U.S. but in foreign educational rationales from Belgium, China, France, Great Britain, Japan, The Netherlands, and Sweden, among others, that learning computer programming will condition the mind to think systematically, precisely, planfully, and more rationally in contexts beyond programming. The current instruction of over a million American students in programming each year is in part a measure of the depth of educators' commitments to this expectation.

Although this list of influences is probably incomplete, it attests to the diverse sources of present attention to problems of knowledge transfer in education. The historical roots of the dominant theoretical perspective for transfer of learning now require illumination.

The Transfer Problem and "Common Elements" Theory

Early in the century, Thorndike did many studies of learning transfer to test William James' hypothesis on the specificity of learned habits. It was then common for students to learn Latin, not so much for its utility, as for its alleged promotion of "mental discipline" for learning about other curriculum topics. The negative findings (Thorndike & Woodworth, 1901; Thorndike, 1924) devestated the discipline hypothesis and helped open up a period of vocationalism in American schooling (Cremin, 1961). One hears similar arguments advanced today for the study of logic, mathematics, science, and programming. Where spontaneous transfer outcomes have been carefully assessed for programming, findings have not been promising (e.g., Kurland, Pea, Clement, & Mawby, 1986; Pea & Kurland, 1984). milojkovi 198

In contrast to the belief that learning rigorous topics generally disciplines the workings of a young mind, Thorndike and Woodworth (1901) offered a specific transfer theory based on the idea of identical elements. On this theory, transfer of knowledge or learning will occur between two tasks insofar as the tasks share identical elements. Versions of this common element theory have persisted ever since Thorndike's connectionist theory came to prominence in education (Brown, Bransford, Ferrara & Campione, 1983; see Ellis, 1965; Gagne, 1968; Osgood, 1949).

Common elements theory is under revival in artificial intelligence (AI) theories of transfer of learning, common-sense reasoning, metaphor comprehension, and humancomputer interaction. Elements are defined in the knowledge representation programming languages in which such AI reasoning systems are written (Carbonell & Minton, 1983; Winston, 1978, 1979). A common elements approach to transfer also appears in Polson, Muncher and Engelbeck's (1986) account of learning different word processing systems.

The units of the transfer metric in such theories differ from the physical or symbolic problem elements of Thorndike's theory, but the logic of the approach is identical. Instead of common physical elements in situations, theorists now count either nodes in a knowledge network or overlapping production rules in a production system as a measure of the likelihood of knowledge transfer.

Child Development Studies of Access and Availability

Other key findings emerge from cognitive development. Many investigations building on Piaget's work had by the early 1970's documented the conceptual inadequacies of preschoolers. They could not reason causally or arithmetically, could not conserve number, had bizarre ideas about animacy, and so on. On closer inspection, it could be shown that 2 to 4-year-olds had much greater logical, conceptual, and social understanding than they had been credited with. Why?

The secret resided in the construction of the situations for assessing children's skills or knowledge. Working with familiar materials in familiar settings with simpler experimental instructions, research thoroughly documented the rich and precocious understanding of the world possessed by the preschooler (Donaldson, 1978; Gelman & Brown, 1986). This distinction between *availability* and *access* of knowledge, earlier elaborated for adult memory by Tulving and Pearlstone (1966), is central. The relevance to the transfer problem in education is that the preschooler had available the requisite knowledge to accomplish the experimental task, but it had not been accessed as it should have been — from the experimenters' perspective — in earlier investigations.

Voss on Two Types of Transfer

Voss (this volume) helps clarify the distinctions and data that cognitive science has brought to bear on transfer. We briefly summarize his observations, and introduce related findings as appropriate. Voss states that transfer, which he argues is a more fundamental concept than learning or memory, must be viewed in relation to the individual's prior knowledge that is utilized in the transfer situation. The study of transfer in psychology and education therefore requires re-evaluation of the traditional transfer paradigm, i.e., Learn A, Learn B versus Do Not Learn A, Learn B. Indeed, the preceding consideration leads to the following distinction. Transfer may be studied by observing performance as a function of prior knowledge, as in the expert–novice paradigm, or transfer may be studied in the traditional paradigm, bearing in mind that knowledge utilization is taking place. Transfer in these two circumstances is now considered.

Transfer Involving Utilization of Prior Knowledge

Knowledge utlization is often assessed by comparing how well learners spontaneously transfer knowledge they possess or have acquired recently to a new problem context. Voss *et al.* (1983) showed that experts in Soviet political science, when asked to solve a problem of poor agricultural productivity, carry out a two-phased problem-solving process. They both develop a problem representation and state and justify their solutions by means of two fundamental processes: *categorization* and *knowledge retrieval*. In categorization, the problem solver acts to link the problem statement contents to known problems, or some comprehensive principle (Larkin, McDermott, Simon & Simon, 1980). Experts' knowledge is considered to be hierarchically defined in terms of inclusive problem types and tokens, principles and cases, whereas novices create problem representations based on specific concepts found in the problem statement. Scribner and Cole (1973) argued similarly that formal education prepares the learner to consider new problems as class members rather than as unique.

Voss *et al.* (1983) also found novice–expert differences in knowledge retrieval. If a problem could not be typed, experts, unlike novices, used a goal-directed and constrained search in their knowledge retrieval, guided by specific reasoning strategies such as stating arguments, rebutting counter arguments, qualification, analogies, and problem-solving methods like problem decomposition.

Related Difficulties with Knowledge Utilization Transfer from School Learning

Early arithmetic and algebra instruction provide salient examples of failed knowledge utilization from school learning (Resnick, 1985). For both equation transformation rules necessary for algebra equation solving, and symbol manipulation in solving written multi-digit subtraction problems, students often have difficulties and make errors when syntactic operations they carry out with the formal, written system are not connected to actual problem situations that could render the written expressions meaningful in terms of represented quantities. While the point of abstract expressions may ultimately be to allow context-free calculations, the end goal is not a pedagogical recommendation.

Pettito (1985) argues that inappropriate transfer from school arithmetic is revealed in Scribner and Fahrmeier's (1982) study comparing the reasoning of dairy workers versus high-school students in a series of tasks involving calculations for milkcrate packing. The dairy workers were highly flexible in the arithmetic strategies they used, whereas the high-school students were very inflexible; when new practical arithmetic problems demand revision of calulation strategies for optimization, students inflexibly continued to apply their school-learned procedural rules.

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In their work on "mapping instruction", Resnick and Omanson (1987) have shown that one can integrate young children's practical experience in mathematics with school knowledge. Children may display skill in using base-ten manipulables (Dienes blocks) to represent written numbers and carry out matching operations in the two representational media, while making errors in manipulating place value in written subtraction and addition problems. The intensive mapping instruction used has the teacher guide the child to link the semantics of the base system with the syntax of the written algorithms. The written form is depicted as marking a record of block manipulations as the children alternate between subtracting written and manipulable media. Children with former procedural bugs in written arithmetic did not make errors even 3–6 weeks after such instruction. It appears to have taught children *where to look* for the links between their practical knowledge of base-ten relationships and the written arithmetic algorithm (Pettito, 1985).

Related Difficulties with Knowledge Utilization Transfer from Everyday Mathematics

There is a related lack of transfer from invented mathematics that works to contexts of school mathematics, where performance falters. This was an early finding of Gay and Cole (1967), who showed how Liberian farmers successfully used measurement and calculational systems in areas that affected their well-being, although they had little understanding of mathematics as a generally useful abstract knowledge system. Carraher, Carraher, and Schliemann (1985) discovered that young Brazilian children use informally-developed counting procedures to solve many arithmetic problems in the marketplace that they cannot solve in school.

Recent ethnographic studies of thinking point to the same result for schooled adults, whose everyday mathematics in practical activities such as shopping, managing money, and dieting (Lave, 1987) or loading rucks with dairy orders in the factory (Scribner &

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Fahrmeier, 1982) "works" but does not transfer to school tasks such as written mathematics testing. Analogously, Resnick (1985) notes that many children fail to see that the formal rules taught in school and their own independently invented mathematical intuitions are related.

The sensitive nature of how the thinker *reads* a problem situation as one appropriate or not for transfer of mathematical competencies is revealed in Lave's (1987) discussion of an experiment by Capon and Kuhn (1979). They attempted to simulate best-buy supermarket shopping outside a store where customers were requested to compare actual pairs of different sized store containers of a product for the best buy. Lave (1987) suggests that subjects' inadequate use of proportional reasoning in the Capon and Kuhn study, which dramatically contrasts with near-perfect performance in her own best-buy studies within supermarkets, is due to circumstances in their experiment that reminded subjects of school-learned arithmetic algorithms, specifically, asking subjects to write out their work for comparing best buys (process) rather than just selecting the best buy (answer). In reading the situation as a school-based task and thus as requiring a particular type of mathematical activity, Capon and Kuhn's subjects did not appropriately transfer knowledge they (presumably) had available to the problem situation in the experiment. This concept of "situation reading" is an important one for the study of knowledge transfer, and highlights a deep problem in current cognitive theories of transfer to be shortly discussed.

Transfer Involving Knowledge Utilization in the Traditional Transfer Paradigm

Assessments of knowledge acquisition transfer provide the paradigm case of educational transfer studies, such as Thorndike's studies on transfer of learning from Latin, or the studies of Polson *et al.* (1986) of how learning to use a first word processor affects the ease of learning to operate a second one. Voss (this volume) observes that this transfer paradigm involves superimposing the transfer instructional treatment upon the subject's existing knowledge base. Thus one needs to know how pre-instructed knowledge (such as Latin, or a programming language: Pea & Kurland, 1984) influences subsequent learning. Voss suggests that classical studies of transfer may yield nonsignificant effects because the new learning is unimportant relative to the influence of prior knowledge in transfer task performance.

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Data bearing on this hypothesis is available from cross-cultural studies of the cognitive consequences of formal schooling. Scribner and Cole (1973; also see Sharp, Cole & Lave, 1979) found that schooled students were more capable of transferring problem solution methods learned early in a problem sequence to different but related problems than were nonschooled students. But as Pettito (1985) cautions, since these were all school tasks, generalization of learning to practical activities remains an open question.

Relation to Analogical Reasoning

A psychology of analogical reasoning is fundamental to an understanding of the knowledge transfer problem (Carbonell, 1983; Gentner, 1983), since it is a process of recognizing the similarities between a past situation x (source) and current situation y (target), and then using details of one's memory of x to structure and elaborate one's understanding of

y. Such "analogical mapping" consists of transferring information from the source to the target domain. The success of this proocess requires: (1) that the thinker has rich knowledge of the source domain that is applicable to the target (supporting Voss's claim that an understanding of the prior knowledge base of the thinker is essential to an analysis of transfer), and (2) that there is no radical translation problem between the conceptual schemes of the learner for the source and target domains. But similarity comparisons of source and target domains may be simplistic: Since novices do not understand the target domain, mapping appropriately onto it may be quite difficult (Carbonell, 1983; Carey, 1986; Ortony, 1979).

Redefining the Dimensions of Selective Transfer

Selective Knowledge Transfer is the Goal

The development of intelligence has long been defined as a shift from context-dependent knowledge use, where knowledge and skills resources are "welded" to their initial context of acquisition, to more context-free generalizations of the use of intellectual resources. In this sense, the lack of transfer of learning to new contexts was equated with rigid intellectual functioning, or "mechanization" (Luchins & Luchins, 1959). But it has rarely been alleged that to transfer knowledge *indiscriminately* to new situations is a hallmark of high intelligence. More is involved in the transfer problem than transfer in terms of "common elements" regardless of circumstance: It is *selective* knowledge transfer, that is "appropriate," which "works", which defines the valued outcome of thinking. In this section, different dimensions of the knowledge transfer problem are sketched so as to re-situate it as a cultural and interpretive problem.

In the cognitive science accounts of knowledge transfer earlier described, the learner is alone and a "cognitive" being. But accounts of transfer restricted to the individual and to cognitive aspects of the transfer problem must be considered a theoretical legerdemain. Other influential dimensions of the problem involve basic concerns about the sociology of knowledge use and acquisition, anthropological and cross-cultural issues about the interpretation situations for thinking and learning, and how motivational and attitudinal states may affect the likelihood of transfer.

Important questions arise about the *purposes* of knowledge transfer, and to the related *values* issues buried in the concept of "appropriate transfer." Since desired transfer is selective, where do the selection principles come from? Addressing only the conditions of learners' knowledge states which causally incline them to knowledge transfer ("cognitive mechanics") will fall short of explaining the selectivity of transfer. We are reminded of Dilthey's remarks that "no real blood flows in the veins of the knowing subject constructed by Locke, Hume, and Kant; it is only the diluted juice of reason, a mere process of thought" (1833/1976, p. 162). Insofar as a cognitive mechanics is possible, it will only be likely to suffice for a highly restricted set of knowledge use and acquistion situations.

Writers often mention "appropriacy" of knowledge transfer but not the social construction of such categorizations: "true computer literacy is not just knowing how to make use of computers and computational ideas. It is knowing when it is appropriate to do so" (Papert, 1980).

"Inappropriate" transfer refers to cases when one has not transferred when one should have, or when one has transferred and should not have. Such prescriptions reveal that "appropriate transfer" is not a natural kind, but defined by cultural and individual value systems. Particular transfers of learning from the learning context to a new situation are never intrinsically "appropriate," but only as judged against a set of conventions reflecting the values of the culture to which the learner belongs (Shweder, 1986).

A continuum of four cases conveys the spectrum of conventions that enter into judgements of the appropriacy of transfer. The child overgeneralizes a lexical term, calling any cloth a "towel" that is wet from a spill. He has confused the incidental and vital features of "towel" because his first acquaintance with the term was with a wet cloth. Judged from community standards, this is inappropriate transfer, but from the child's perspective, these naming tasks share certain "common elements."

In a second case, the grocery shopper who has learned the decision analysis method of multi-attribute utility theory in her thinking-skills course applies ~~them~~ it to the decision problem of picking a tomato at the greengrocer for a stew. She explicitly defines the various criteria that matter to her for judging tomatoes, weights their importance, and evaluates each tomato option by each criterion. Several hours later, after lengthy calculations, she optimizes and selects the best tomato. While we would deem this transfer of a higher-order thinking-skill inappropriate, because the effort expended is disproportionate to the seriousness of the problem, the same approach might be appropriate if the task were diamond selection by a gemstone carver for the queen's tiara.

Similarly, the military strategist may think that since people can be counted like objects, they are like objects, subject to cost-benefit analysis, and thus minimizing body counts is a desiderata in battle planning. Depending on one's value theory, this may be considered "inappropriate" transfer. Similar cases could be detailed in risk analysis for nuclear waste disposal and other science–technology–society problems.

Finally, to take an extreme case, if one taught terrorists to define goals, to plan and do progress-monitoring, and to use precision in their thinking, these skills would very likely be transferred to their terrorist activities. Such transfer is channeled toward the purposes such individuals consider relevant to their life-space. But the terrorist's purposes are negatively-valued goals for transfer from a pro-social perspective.

Common Elements are Interpreted, Not Given in Nature

Hoffding (1892) brilliantly argued against Thorndike's seminal treatment of transfer, urging that the issue is not, as Thorndike supposed, one of measurable physical elements of problem environment, but of the learner's construal of task domain similarity. Although physical similarities can influence likelihood of transfer, *perceived* similarity is fundamental. What matters is how the new situation is connected with the thinker's trace of a previous situation, which may be quite idiosyncratic. In this respect, this approach is congruent with Dilthey's 19th century work on "moral sciences" such as history, psychology, sociology, literary criticism, and "hermeneutics", the interpretive methodologies humans apply to understanding the meaning of situations and social phenomena as if they were texts. Similarly, Dewey (1922, p. 131) critiqued psychologies such as Thorndike's that asssume the lists and categories they construct represent fixed collections *in rerum natura*, when lists serve only as classifications for a purpose.

Unfortunately, anthropological study of perceptions of contexts for transfer of learning has been minimal until recently. In contrast, societal influences on the selective principles controlling attention have been a concern linking psychology and anthropology since early in the century (e.g., Evans-Pritchard, 1934). More recently, Cole and colleagues at the Laboratory of Comparative Human Cognition (1979, 1983, 1984) have critically reviewed contributions of developmental and cognitive psychology, anthropology, and sociology to the understanding of how individuals in a culture come to acquire belief systems that detail how experienced events are connected. They argue for a "cultural practices" theory (1983), according to which the kinds of social contexts children participate in contribute the fundamental categories of experience out of which cognitive development and knowledge transfer arises. These contexts are *not* defined in terms of physical features of settings, but in terms of the *meanings* of these settings constructed by the people present. Such an interactional conception of cognition in culture provides an important foundation for investigating the dimensions of the knowledge transfer problem in education.

In the case of the current cognitive theories of transfer, this question of interpreted rather than objectively given "elements" as the basis for transfer is begged, since the productions in production systems or the nodes in knowledge representation networks are part of the *theorist's* construction of the problem situation. It is begged because the problem solving context is *interpreted*, not an experimental variable defined invariantly across subjects. The elements of situations said to determine the suitability of transfer are treated as reified entities rather than socially constructed, situated realities. It seems likely that using an interpretive approach to the problem of selective knowledge transfer will offer a more productive orientation to educational activities design for promoting transfer than the traditional common elements one.

It is perhaps not surprising that the renowned cognitive studies that fail to find transfer of problem-solving strategies involve puzzle problems such as Tower of Hanoi and Missionaries and Cannibals, which are "formally identical" (in terms of problem-solving operations required for solution) but have different "surface structures" (Reed, Ernst & Banerji, 1974; Simon & Hayes, 1976). Note here that the "common elements" between such problems are not physical problem features as in Thorndike's initial formulation of transfer theory, but problem-solving production rules. In terms of the important role of problem categorization on transfer likelihood, why should the college student in such studies have seen those puzzle problems as belonging to the same type? They were not taught or discussed as a class of problems of similar type; it is only at an abstract level of analysis that they are formally identical. The same point applies to Gick and Holyoak's (1980, 1983; also see Perfetto, Bransford & Franks, 1983) work on transfer of problem solving solutions from a divide-and-conquer battle story, to Duncker's radiation problem and related problem analogs. In each case, subjects had to be prompted that information given to them was relevant to solving the problem posed, for without the prompt they did not use the information.

Need for a Cultural Practices Framework

How do socially organized activities come to have consequences for human thought? No clear theory of the mechanisms by which the social affects cognitive variation is available. But recent theory influenced by Vygotsky's (1978) cultural–historical theory of higher mental functioning suggests one promising direction. Scribner and Cole (1981) have provided an important framework, developed in over a decade of cross-cultural cognitive research, for thinking about how "cultural practices" influence thinking. Rather than focusing on the features of a technology (e.g., formal schooling, written language) alleged to influence cognition, they approach a set of practices, such as literacy, as "a set of socially organized practices which make use of a symbol system and a technology for producing and disseminating it" (p. 236). "Practice" involves technology, knowledge, and skills. It is defined as a recurrent, goal-directed sequence of activities using a particular technology and particular systems of knowledge. "Skills" are the coordinated actions involved in applying this knowledge in particular settings. This framework on practices has dramatic consequences: "Literacy is not simply knowing how to read and write a particular script but applying this knowledge for specific purposes in specific contexts of use. The nature of these practices, including, of course, their technological aspects, will determine the kinds of skills ('consequences') associated with literacy (p. 236). "

In terms of their framework they can make sense of their careful studies on the cognitive consequences of literacy in relation to those of schooling, which documented an asymmetry of schooled and nonschooled literacy effects. School and nonschool contexts for using literacy skills involve different tasks, even for the "same" practice of reading and writing. The most profound effects of schooling were found for experimental tasks requiring verbal explanations for why a problem was solved in a particular way; they suggest the skills required in teacher–student dialog practices in the classroom contribute to these distinctive school effects of literacy on cognitive tasks.

An important consequences of the cultural-practice approach to transfer is that since cognitive achievements are largely unique in their contextual characteristics, and yet clear influences of prior learning on present activity are evident, one must "look to the organization of the environments in which interactions occur" (Laboratory of Comparative Human Cognition, 1983, p. 341), and recognize that "transfer is arranged by the social and cultural environment . . . . Overlap in environments and the societal resources for pointing out areas of overlap are major ways in which past experience carries over from one experience to another" (ibid). I draw several implications: First, that promoting knowledge transfer in education will depend on more effective arrangement of environments for bridging knowledge utilization across contexts of value within a culture. Second, that the new interactive symbolic environments that can be constructed in the computer medium could dramatically extend a student's experiences of the environments in which available knowledge is viewed as appropriate for transfer.

On Transfers "Not Taken"

In any given situation, an individual has a vast storehouse of prior knowledge that could be related analogically to the present occasion. Many potential transfers are never contemplated, and not all transfers that the thinker contemplates are actually followed through, either in thought or action. Why are some transfers "not taken"? Two answers to this difficult question will be explored for present purposes: (1) because they are not "appropriate", (2) because they take "too much effort". The cultural groundings of each will be briefly discussed.

Appropriacy of Transfer

Culture dictates constraints on "appropriate" transfer in its conventions and mores. Sometimes transfer applications are censored becuse of taboos that vary cross-culturally (e.g., on dirtiness, sexuality, incest). Some potential transfers of knowledge are so incongruous and unexpected that they provide humor or the exotic literatures of James Joyce or Jorge Luis Borges.

It is common to read that students need to acquire skills of analogical thinking, of generating analogical connections from knowns to unknowns as a means of understanding. This crucial fluency aspect of intellectual functioning is the subject of much experimentation in modern cognitive psychology (e.g., Sternberg, 1985). What is less commonly noted is that there is a complementary control skill required if analogical thinking is to support the problem-solving of the learner. Not only should the learner be able to productively *generate* analogies, but the learner should be able to *evaluate* the utility of the generated analogy for the problem-solving purposes at hand. In other words, not all analogies are good ones. Most importantly, *the goodness of the analogy depends on the purposes of the analogizing*. Whether the analogical transfer of knowledge is judged to be "good" depends on who is doing the evaluation. The goodness or utility of a transfer depends on the satisfaction criteria for the thinking task. analogica

Halcz and Moran (1982) argue, for example, that in learning about software such as word processing programs, not all analogies are useful. But they tacitly assume learning efficiency as their utility criterion. They note that many analogies people use are misleading and may, as in electricity, even be deadly if assumed to be true. Resnick (1985) notes how overtransfer of taught reading strategies can disrupt reading if overapplied. In each case, sociocultural standards provide cognitive control schemas for judging transfer appropriacy.

The Cognitive Economics of Transfer

The cognitive economics of transfer is another complex of factors influencing whether contemplated transfers of knowledge are pursued or not. The pervasiveness of the principle of minimal effort in mental as well as physical action is well documented. In relation to contemplated transfers of prior knowledge to the present problem situation, the thinker asks, even if he or she thinks that transfer might work: Is it worth the cost to carry out? I may project that the mental work of analogical mapping is sufficiently difficult that it does not outweigh the possible benefits I could derive from the transfer. Evaluations of simulated mental effort may influence the likelihood of knowledge transfer even when students have availability and access to transfer-relevant knowledge. Such mental effort conservation is fundamentally cultural because perceived transfer benefits are value-dependent. What one considers transfer of learning to be "worth" in one's effort calculations (whether tacit or explicit) is influenced by cultural concerns such as the value of time, and accountability to others. Determination of such costs will in part depend on an individual's idiosyncratic history of costs and benefits for knowledge transfer in what he or she perceives to be similar situations to the current one. Furthermore, one's projections of the likely cognitive effort of knowledge transfer activities is itself probably influenced by the sophistication of one's prior knowledge.

On a related point, diSessa (1983) describes the potency of phenomenological primitives (p-prims) — schemas for understanding situations that are purpose-relevant for the reasoning one does in one's "niche" of problem-solving situations. Thus if one has available a set of p-prims for everyday physical reasoning and is then presented with formal physics problems in school, there may be no mapping between the two contexts, because of a radical translation problem between the two systems of problem representation. There are additional issues in cognitive economics concerning conceptual change. What is the new value of the formal physics concepts and methods for the physical reasoning I consider important? Is there significant payoff to adapt my current conceptual schemes with these new ideas? Or do I just learn formal physics as a separate conceptual system with school-linked conditions of application?

Transfer Attitude

Additional influences on knowledge transfer may be introduced. A distinction has been drawn between one's *access* to and the *availability* of knowledge and skills during a problem situation. Critical to the access problem are *affective* and *motivational* factors that are ill-understood. How students feel about their capabilities of performance in learning tasks can drastically affect their interest not only in knowledge transfer but in learning itself. How is the disposition to engage in persistent memory search for transfer-relevant knowledge in a problem situation influenced by self-efficacy, fear of failure, anxiety, intolerance of mistakes, or other emotional blocks (Meichenbaum, 1977)?

Research on achievement motivation indicates that if children conceive of intelligence as a stable "entity" whose adequacy is revealed through performance, rather than an "incremental" set of skills to be increased through effort, then they are likely to view errors as personal failures, and approach the problem solving events not to learn from, but as occasions to look smart or fail (Dweck & Elliot, 1983). Diener and Dweck (1978) distinguish "mastery-oriented" and "helpless" strategies for processing failure feedback in problem solving. We unfortunately know little about how such different achievement goals arise. Yet the entity view and helpless strategy can have crippling consequences for learner motivation when the false starts inevitably ingredient to learning and knowledge transfer are viewed as failures.

The sociocultural orientation to selective knowledge transfer outlined here implies that such affective and motivational influences on knowledge transfer are best studied in the cultural systems that give rise to them rather than as traits of individuals. This runs counter to the common treatment in the literature of children as "intrinsically motivated" or not, or the tendency to seek out the characteristics of a software game that make it intrinsically motivating (Lepper, 1985; Malone 1981)..

From Redefining the Transfer Problem Toward Its Solution

The sociocultural dimensions of the knowledge transfer problem have been acknowledged. What might education do to better provide for the kinds of activities and emphases that will support students in learning for appropriate transfer? Some answers are suggested by psychological research on instruction in thinking skills.

Generalizable thinking skills can be successfully taught, including problem-solving heuristics in mathematics (Schoenfeld, 1985); word list learning and recall strategies

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(Belmont, Butterfield & Ferretti, 1982); planning, goal monitoring, and revisionary strategies in writing (Bereiter & Scardamalia, 1986); reading-comprehension skills (Palincsar & Brown, 1984); and skills of allocating effort while studying (Dansereau, 1985; Weinstein & Mayer, 1985). What are some elements of success in these efforts? Many directly address aspects of Dweck and Elliot's (1983) statement of children's learning difficulties for intellectual tasks (unlike physical tasks): "children may be less likely to know what they are aiming for [goals], why they are aiming for it [purpose], how to get there [method], and when they have gotten there [evaluation] (p. 677)".

I will summarize observations and recommendations that suggest how one might foster the development of appropriate transfer of learning from education. A variety of measures are suggested, including knowledge acquisition in functional contexts, providing multiple-domain knowledge application examples and experiences, creating bridging instruction across school and nonschool problem situations, and integrating subject learning with synergistic design. The higher-order goal of creating cultures of transfer thinking in which these measures play enabling roles is briefly characterized.

Where is Learning Spectacular and Transfer Common?

In seeking features of effective education, Bransford, Sherwood, and Hasselbring (1985) ask where learning is *spectacular*. It so happens that where it is, one can find remarkable transfer of what is learned. Such spectacular learning occurs in the first five years of life as children acquire concepts, language, motor skills, spatial, and social skills quickly, with little explicit intervention, and seem to willfully learn during that period with little obvious effort (Bransford *et al.*, 1985). They do so despite lack of knowledge, few available conscious learning strategies, and probable limitations on working memory. Bransford *et al.* (1985) describe distinctive features of these spectacular learning contexts:

(1) *Learning takes place in context.* Children learn during the first five years during culturally meaningful ongoing activities, and receive immediate feedback on the success of their actions.

(2) *Learning is often effectively mediated.* Parents, friends, and peers not only serve as models for imitative learning, but help the children learn by providing structure to and connections between their experiences, highlighting task-relevant information in a situation, and establishing continuity to functional learning contexts in which children can come to take over part activities of a whole problem-solving task (Bruner, 1983).

(3) *Learning is functional.* (1) and (2) together help provide children with an understanding of the *functions* of information for problem solving. Concepts and skills are acquired as tools with a range of purposes.

To Bransford's description of features of spectacular learning settings I would add that the functions of new knowledge are not only shown but also often explicitly stated. For example, successful studies for teaching thinking skills for transfer have been explicit in describing for learners the need for and purpose of these new learning activities, e.g., that they will benefit performance (Bereiter & Scardamalia, 1986; Palincsar & Brown, 1984; Pressley *et al.*, 1984; Schoenfeld, 1985). These findings suggest that we should explain to students that the transfer of the knowledge they are acquiring is important and why. Otherwise, student improvement tends to be highly task-specific. This technique may be effective because orienting children toward what they perceive as high-value learning goals, regardless of their level of perceived self-competence, leads to mastery-oriented striving (Dweck & Elliot, 1983).

The instructional implication is that one should teach concepts, strategies or skills in a problem-solving context where their functions are rendered apparent. Such functional presentations and the emphasis on learning by doing will make more likely that the knowledge will be accessed and transferred to new problems.

The Utility of Multiple Examples and "Bridging Instruction" to Promote Knowledge Transfer

Multiple contexts of acquisition and application of new knowledge (e.g., in different problem domains) are important since then the encoding of that knowledge in memory has multiple functions associated with it for future retrieval. Consequently, the likelihood decreases that the knowledge is welded in memory to a specific problem context (Brown *et al.*, 1983; Gagne, 1985). Gagne (1985) offers the familiar suggestion that learning transfer is a circumstance influenced by the number of common cues between learning and transfer situations. Transfer is enhanced if the cues available in the situation in which transfer is appropriate are increased at the time of learning, by linking rules with other concepts, or to a more meaningful context such as a schema. Note that Gagne's account is similar to Thorndike's "identical elements" theory. Even though more "interpretive" in its consideration of situation elements, Schank's (1982) theory of dynamic memory also takes a multiple-cue approach.

There is an added complexity to the recommendation of providing multiple examples in knowledge acquisition for subsequent appropriate transfer. Not just any combination of multiple examples will suffice, and which range of examples are chosen will probably influence the breadth of selective transfer one will observe students making, other things being equal. Yet very little research has examined desirable characteristics of example selection.

One case suggests the importance of the sociocultural relevance of the examples offered. Children's native cultural experiences were used as bridging activities in the successful school-based KEEP program of text comprehension instruction with Polynesian Hawaiians (Jordan, 1985). In contrast, de Bono's (1985) CoRT program to teach thinking skills offers multiple examples, but they are all real-life situations such as planning for holidays or choosing a career, and one expects the transfer of such thinking skills to school topics such as mathematics unlikely. Glaser's (1984; also see Frederiksen, 1984) recommendations that higher-order thinking skills be taught within subject matter domains appears overly restrictive in the reverse direction. Until research is available on the issue, it is reasonable to suggest that a broad range of culturally-deemed appropriate contexts for transfer, including in and out of school problem situations, should provide the basis of instruction.

Feuerstein *et al.* (1980) train for transfer of concepts or skills in their thinking-skills program with "bridging". Bridging involves teaching a general principle and then helping students see how it works in multiple situations, e.g. in science or social encounters. Bransford, Stein, Arbitman-Smith and Vye (1985) discuss how Feuerstein's program has students create their own examples and evaluate the adequacy of examples others offer. Such bridging has four justifications: (1) it prompts students to draw on their own experiences; (2) it restricts the potentially infinite range of application of principles to the students' life experiences; (3) generating examples serves as an index of understanding, so one can see whether students have understood the principle precisely; and (4) instantiating the principle in a variety of contexts encourages transfer. Brown and Campione (1981) describe this approach as explicit instruction in the range of knowledge applicability. The assumption is that this instructional strategy will encourage access of transferable knowledge and skills in the future.

Bridging is only one small part of the "transfer problem". Perhaps more difficult as an educational barrier to promoting transfer is the problem of radical translation between two different situation–perception systems: the child's — derived from everyday experiences — and those promoted by the formal education of schooling. Establishing the appropriate mapping between the familiar and unfamiliar domains in metaphor comprehension is a challenging process.

Although such bridging activities appear promising as an instructional technique for promoting knowledge transfer, little is known about what may be the best way to convey these bridging relations, for example, through knowledge network diagrams, or verbally (as in Feuerstein *et al.*, 1980), or in terms of multimedia materials (Bransford *et al.*, 1985b).

But conflicts exist between this approach and influential proposals of why schooling has powerful consequences for cognitive abilities as measured by experimental tasks. Bruner (1966) argued that it is the very removal of everyday life experiences from the formal learning situations of school that makes possible deeper learning for its own sake rather than as a subgoal of practical activity! Lave (1986) suggests that the accepted wisdom is that school must provide preparation for life in context-free terms; as it does, then cross-situational transfer will follow. The specific social organization of knowledge utilization should not, by this classic account, affect its meaning, value, or use. The enhancement of abstract symbolic representations taken to undergird the power of formal reasoning through schooling presumably depends on this detachment from the here and now. Pettito (1985) suggests resolving this conflict by considering that schooling offers learning of rules and principles for *potential* transfer if appropriate links can be made to practical knowledge. In designing a future education promoting transfer, we will need to synthesize the abstract treatment of reasoning considered as the support for transfer of learning, and the embedding of concept learning in problem-solving activities taken from everyday life. Otherwise, students may not notice occasions for school-type reasoning outside school settings.

Teaching Cognitive Self-Management Skills

From cognitive research in the past decade, we have come to understand in a way we never did before the specific characteristics of thinking that define an independent, directed, effective learner and thinker. Cognitive studies of how experts regulate their mental processes when defining and solving problems, as well as instructional interventions designed to teach and coach general cognitive self-management skills reveal that such skills do exist, can be taught, and are transferred to new materials and domains of study. Many difficulties learners have are not due to lack of basic knowledge or to unavailability of relevant problem-solving strategies alone, but to executive problems of managing their mental resources. Recent studies show that learners need to acquire self-management skills for thinking and learning, not only problem-solving strategies.

For example, when Belmont and Butterfield (1977) reviewed 114 studies on cognitive strategies instruction, none taught executive, self-management strategies and none achieved transfer of skills taught. Since that time, many investigations have directly taught self-management cognitive skills and found dramatic and maintainable transfer effects (reviews by Belmont *et al.*, 1982; Brown *et al.*, 1983). For example, Brown, Campione and Barclay (1979) taught self-monitoring techniques for estimating test readiness and found learners transferred these new skills from word list learning to prose recall.

Our ultimate goal for learners is that they become teacher-independent thinkers, learners, and problem solvers. To this end, students need to learn executive thinking skills, such as goal setting, strategic planning, checking for accurate plan execution, goal-progress monitoring, plan evaluation, and plan revision. Yet we know from classroom studies of reading (Beck, 1983), writing (Bereiter & Scardamalia, 1985), math (Schoenfeld, 1985), and science instruction (Herron, 1971), that the fundamental *executive processes* for controlling thinking and learning processes are under the teacher's control, not the student's. The contrast case is the effectiveness of passing on of control processes in the informal education reflected in apprenticeship relations, as in weaving or tailoring (Greenfield & Lave, 1982). Schools rarely embark on the necessary fading process in which students take over these executive roles. Many learners initially require and benefit from explicit support in managing and controlling their cognitive activities in learning and thinking. Any teaching that aims to foster complex thinking processes for students should therefore be developmentally responsive in the following sense; that the prompts or other structures it provides for fostering the development of complex thinking should fade as students manifest capacity to handle these processes autonomously (Collins & Brown, in press-b; Rogoff & Lave, 1984).

Integrate Subject Learning with Synergistic Design

The discussion thus far of promising directions for promoting knowledge transfer in education have not dealt with interdisciplinary knowledge transfer. Yet many school reformers advocate linking the learning of different subject domains for greater knowledge transfer in contexts of application or acquisition. Bransford *et al.* (1985b) call such curriculum initiatives "synergistic design", in which the whole is greater than the sum of the parts, with the goal of making interlinked learning offer greater yield of understanding than the study of disaggregated subjects.

As a superintendent of schools during the 1870's, Francis W. Parker eliminated the prevalent rote teaching methods in favor of an emphasis on having children observe, describe, and understand curriculum topics by building on their everyday experiences. Dewey considered Parker "the father of progressive education" (Cremin, 1961, p. 129). Parker's program was an astounding success as reading, writing, spelling, and arithmetic performance soared. Parker (1901–02) also developed innovative approaches to interrelating curriculum subjects to make their significance more obvious to the child. Many of his techniques are familiar today, including children's creation of their own stories for reading and writing, the combination of studies of grammar, penmanship, reading and spelling in the motivating contexts of conversation and writing, and the interweaving of science studies with art, mathematics, and writing in the service of understanding nature through fieldwork and laboratory observations. Dewey's famed Laboratory School took a similar approach, starting with the familiar and continuing to enlarge its meanings with the bounties of artistic, literate, and scientific cultural experiences.

These historical notes are worth making because these special efforts were by all accounts highly successful at engaging children's interests and transfer of learning across curriculum boundaries and beyond school walls. From the problems of unrelated learning in the different curriculum subject discussed in commission and research reports, a revisitation of methods for linking the knowledge attained in the study of different subjects within school would be worthwhile. Although the problem of cross-curriculum segregation has not changed much in 110 years, we have much more sophisticated understanding than Parker or Dewey did of the knowledge structures, task analyses, and information technologies — including integrated software problem solving tools that require the use of knowledge and skills across the curriculum — that could contribute to more integrated subject–domain instruction.

Creating Cultures of Transfer Thinking

Bridging instruction, teaching that conveys knowledge and skills in functional contexts, the provision of multiple examples of knowledge transfer, synergistic curriculum design — all of these activities could contribute to the creation of an educational culture that encourages transfer-enhancing learning and thinking processes. Unfortunately, the culture notion is elusive. It is perhaps more comprehensible when it arises as a descriptive term from anthropologists than as prescriptive term from educators, psychologists, and technologists. Yet it seems essential to try to understand how to build such cultures, especially since we have seen how, descriptively, cultural practices seem to be the guiding forces in a student's "reading" of a problem situation as one for which transfer of previous knowledge is possible, or important, or worth the effort.

It is highly significant that when the American Association for the Advancement of Science (1984) looked at several hundred precollege programs for teaching mathematics and science in which minorities and women performed as successfully as white males, they found the programs to share a number of features. The statistical picture reveals that successful programs were those in which there was vertical and horizontal integration of the school educational setting with community learning. Vertically, there was continuity across the grade levels up through college in the quality and commitment of offerings and educational practices involving these groups. Horizontally, there was parental, industry and workplace, and community involvement that was invested in having the students' math and science learning work. In essence, these successful programs had been able to define a culture that said to students that transfer of learning has consequences.

Research is needed on how to create such thinking cultures, which I take to be closely related to creating cultures for selective knowledge transfer. Resnick (1985) has summarized tacit assumptions for characteristics of such environments for learning to think independently: self-directed classrooms (on what to work on; how to schedule activities; who to work with); discussion rather than lecture-recitation classes; and small cooperative group emphasis.

Social interactions in which thinking processes are made explicit, or *modeled*, seem to provide important fostering conditions for learning to think well and transfer what one knows to new problem contexts within a broad domain such as reading, writing, or mathematics (Collins & Brown, in press-b; Palincsar & Brown, 1984; Scardamalia, Bereiter & Steinbach, 1984; Schoenfeld, 1985). They appear to enhance the "disposition" to think (Resnick, 1985). It is unclear what the locus of such effects are, but in part they may provide a culture for thinking in which such activities come to be seen as valued contributions (Schoenfeld, in press). Observation of modeling alone is insufficient. Students need to try out thinking themselves, and subject their own thinking processes to community reaction and supportive critique. In participating in this social "zone of proximal development" (Vygotsky, 1978), a child may better envision the new capabilities he or she would have if only the knowledge the other person had contributed were acquired. These think-aloud activities may also positively alter a child's self-concept, their beliefs in whether their intelligence can be developed or is "given", and their feelings about anxiety, failure, and other potentially disabling emotional blocks to either the knowledge acquisition or application sides of transfer of learning.

Teachers will also need to learn to understand how to promote a culture for transfer in their classrooms by teaching knowledge in use, concepts as tools for understanding, and transfer of thinking skills as an activity central to the social contract of learning. Such changes may be threatening, because in an education which takes seriously conveying functional knowledge in multiple problem-solving contexts, and which tries to build on prior experiences the child brings to the classroom from the thinking of everyday life, the locus of authority in the classroom will have shifted. The primary discourse of the classroom would need to move from the familiar "Do you know X?" frame (Mehan, 1979), a continual regurgitative role for knowledge with the teacher in authority role, to one in which he or she plays a functional role, that instead stresses "Do You Know X to do Y?" or "What can you do with X to arrive at Y?" Regular working collaborations between the research community and educators, and input to the research agenda on knowledge transfer from teachers will be essential aids to this process. In particular, we will need better methods for helping teachers learn how to diagnose knowledge students already have from everyday experience, and to refocus and build on it for the purpose of thinking toward which education is directed.

Roles for Technologies in Promoting Selective Transfer

It is worthwhile asking about possible schemes for using technology to foster appropriate transfer of knowledge in education. Apart from providing new opportunities for process-oriented intervention research on knowledge transfer, the novelty of computers makes curricular change more viable. There are several directions that appear particularly promising. The general aim is to create tools that enhance the chances that students adopt a self-aware transfer state of mind, and that they be provided with the transfer-relevant access skills and heuristic strategies, and a sufficiently rich taxonomy of problem types for each domain of study to make the application of such search heuristics worthwhile. All the measures to be suggested involve the interpretive activities of a normative group for a culture (e.g., teacher, community) whose "situation readings" suggest what transfers are appropriate or not. Such "interpreters" can provide opportunities for students' specific thinking activities to be appropriated into multiple conceptual frameworks.

We can also dramatically change the cognitive economics of transfer activities by making the knowledge-application process easier to enact (a common strategy in the design of computer-based cognitive technologies: Bloomberg, 1986). Problem-solving tools could guide the application of prior knowledge, such as problem-solving methods in algebra or composition-planning techniques in writing.

Tools for Building and Linking Knowledge Representations

One approach is to build tools that make it feasible for students to represent and connect the substantive details of in-school and out-of-school thinking experiences, and link their within-school experiences across curriculum domains. Students would be able to construct labelled representations of their knowledge (Novak & Gowen, 1984) on an electronic blackboard that would be used to make transfer possibilities to a current problem situation open for discussion or teleconferencing by teachers and others. Such representations would be available for the student's use in future problem solving, in a sense as a software placeholder of one's conceptual understanding to be built upon, and within which new knowledge would need to be integrated. I predict that the experience of explicitly articulating one's knowledge would render the organization of this knowledge more amenable to retrieval for transfer because it has been given greater structure.

Modeling of Multiple Bridging Activities in Thinking

Successful examples of teaching transferable thinking skills by Bereiter and Scardamalia (1986), Palincsar and Brown (1984), and Schoenfeld (1985) all utilize techniques for making transfer processes explicit (Collins & Brown, in press-b). For a given concept or cognitive skill, live modeling of its application to multiple cases could be recorded via videodisc for a selected range of problems or domains, and where one expects the student to make appropriate generalizations from the cases selected. The system would be interactive, enabling levels of help if a student had difficulties in carrying on with new knowledge transfer activities after observing modeling of multiple bridging involving that knowledge. Reflective analysis of the details of one's own transfer performances as well as those of others should be possible, by replaying problem-solving episodes (Collins & Brown, in press-a). The modeling activities selected would ideally be based upon task analyses of knowledge application to the problem situations of everyday life (Sternberg, 1986), and bridge these with the problem classes of formal education in mathematics, science, literacy. "Everyday life" here is a placeholder for the culturally defined norms of activities that constitute cultural practices.

Ethnographic studies are needed to contribute to a theory of situations, what Scribner and Cole (1981) call "cultural practices," that help shape what people in a culture *read* as the tasks or problems facing them in a situation. How do these interpreted "common elements" of situations come to be understood or perceived? If we had a better understanding of answers to these questions, our selection of domains could have more theoretical grounding. Since the everyday life settings found will vary across cultural groups, cross-cultural cognitive studies will be central to the design of instructional activities supported by the technologies.

We are exploring the feasibility of a multiple bridging approach in the software research and development project on cognitive skills called IDEA (Interactive Decision Envisioning Aid). Our goal is to help young adolescents learn elementary decision theory for application to school and everyday decision-making situations. In the design, a familiar specific domain of decision making — family chore planning — is used to introduce generalizable aspects of systematic decision-making skills (such as defining the space of alternative choices; establishing evaluative criteria; utility analysis of attributes of alternatives). Multiple examples of applications of general decision-making methods are available through the software, so that at any time the learner can explore or be guided to learn generally useful aspects of methods they are learning to apply in this and other specific cases (such as selecting courses or a high school, or purchasing records). We find that young adolescents spontaneously identify other decision problems (e.g., party planning, allocating study time, consumer purchasing) for which they expect such systematic decision methods might improve their decision outcomes.

Cross-Curricular Problem-Solving Tools

There is a high priority on providing a generation of interactive thinking tools for students that can be used across the curriculum. Cross-disciplinary integration of methods and knowledge is the hallmark of problem solving in today's increasingly complex society. But education, particularly in high school, is a collection of disaggregated topics with no strategy for forming relationships. With new technologies, we have the opportunity to fit them into a context and help students understand disciplinary interrelationships and open systems thinking. Such business tools as outliners, word processors, database-management systems, electronic conferencing systems and bulletin boards, electronic "notebooks" with integrated math/science/ report writing facilities are already available. But they are by and large agenetic, presupposing users possess the various thinking skills needed for their flexible use. There should therefore be an emphasis on creating *developmental* cognitive technologies that will have layers of functions asociated with students' competencies that learners will shed like skins as they no longer need them, and easily-programmable options so that learners can mold their tools to serve their unique style of thinking and learning. They will provide the kinds of task scaffoldings an expert teacher would offer a novice who is learning the system, which would then fade as the student takes on more control of the system's use (Collins & Brown, in press-b).

Conclusions

Our analyses lead to a situating of knowledge transfer as an *interpretive* problem, not as amenable to a static cognitive analysis that reifies "common elements" in problem solving situations as traditionally supposed. What observations led to this conclusion?

The first observation is that transfer is *selective*. "Appropriate transfer" is socioculturally defined for particular purposes, tasks, and thinking situations. When transfer involves more than retrieval and straightforward knowledge application, complex personal issues arise of cognitive economics (predicting whether knowledge transfer is worthwile or not), analogical mapping between prior and present situations, and transfer monitoring (evaluations of knowledge transfer effectiveness). These judgements are *also* rooted in cultural practices and values.

The second conclusion is that the "elements" perceived by the thinker as common between a prior situation and the current one, upon which knowledge transfer appears to depend in terms of processes of reminding, *are not given in the nature of things* but "read" as texts with multiple possible interpretations according to the thinker's culturally-influenced categorization system of problem types. Knowledge transfer thus requires *situation analysis*, a determination of whether prior knowledge bears on the situation because the problem reminds the thinker of a previous problem or type. There are thus likely to be significant developmental, individual, and cultural differences in the *situation perception* upon which knowledge transfer depends.

The implication is that education could positively influence the likelihood of transfer by addressing these problems directly. It might do so by making everyday situations and school situations part of the same classification scheme for problem types, making explicit the links the student is now expected to draw spontaneously. Such a transfer-promoting categorization method could be implemented for many different curriculum topics. This is not to say it is an easy process. Extending this approach would involve two steps: making explicit (in a symbolic representational system such as a semantic network) a student's situational elements for the targeted task setting, and pedagogical activities to help the student transform their belief-structure so that it corresponds with the conceptual scheme promoted by formal education. More instructional attention should go into defining common perceived elements across the spectrum of problems for which transfer of knowledge such as concepts, procedures, or high-order thinking skills is desired. One could then perhaps teach ways of *analyzing situations* in school with out-of-school ideas and out-of-school with in-school ideas. This bridging should be considered legitimate classroom activity.

The third set of conclusions involves a series of recommendations for enhancing conditions for knowledge transfer in education, based upon a synthesis of research findings on teaching thinking skills. These conditions include learning about and practicing knowledge application in multiple contexts of use, creating bridging instruction across school and nonschool problem situations, fostering thinking and self-management skills taught within domains, and synergistic integrations of the learning of different subjects. The higher-order goal of creating cultures of transfer thinking with these measures was described, and its likely connection to affective motivational variables postulated.

Finally, I sketched some directions for new technologies, consonant with these promising transfer conditions and activities, that might enhance knowledge transfer. These included tools for students to use for building and linking knowledge representations of prior experience with new knowledge acquired in school, and interactive systems to help students acquire and practice the application of thinking skills across multiple domains by "live" modeling of multiple bridging activities of new knowledge application.

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