Efficiency and Innovation in Transfer

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Abstract

The transfer literature includes a variety of seemingly conflicting perspectives. Some argue that transfer is rare; others argue that transfer is ubiquitous; still others worry that transfer is an unworkable concept. Is the transfer literature filled with inherently contradictory claims, or is there a framework that can help illuminate how and why the varied positions on transfer are each pieces of the truth that can be reconciled through a broader theoretical foundation? We argue for the latter. To develop our ideas we divide the chapter into four sections that: (a) Rethink the classic definition of transfer and show how it tends to misdiagnose important forms of knowing. (b) Differentiate "transferring in" to situations from "transferring out" of them. (c) Discuss studies that show that new ways to think about transferring "in" and "out" can reveal advantages of interactive instructional techniques that remain hidden from more traditional measures. (d) Propose a tentative learning and performance space that differentiates two dimensions of transfer -- innovation and efficiency -- and provide an example of what research on optimal trajectories through this space might look like. We end with some potential next steps –including new thoughts about assessments that complement but go beyond many standardized tests.

Efficiency and Innovation in Transfer

As cognitive scientists who design and evaluate instructional interventions, we are often asked whether our classroom work has taught us anything that informs our basic understanding of cognition. One answer to this question is that classroom research has led us to question prevailing methodological and theoretical approaches to transfer (Bransford & Schwartz, 1999). For example, in a recent meeting with several school superintendents we asked what, if anything, they wished we could help their children learn. The surprisingly unanimous answer (they were surprised as well) was that they wanted us to help students make their own choices in the future. They wanted the students to be able to "learn for themselves" and make informed decisions. They believed that well-designed school experiences could transfer to help children continue to learn once they left school.

Ideally, strategies for achieving these goals would be clarified by introducing the superintendents to the research literature on learning and transfer. But this literature is filled with a variety of seemingly conflicting perspectives. Some argue that it is very difficult to find evidence for transfer (e.g. Detterman, 1993). Others argue that transfer is ubiquitous, if we know where to look for it (e.g. Dyson, 1999). Still others worry that transfer is an unworkable concept (e.g, Hammer, Elby, Scherr & Redish, this volume). Carraher and Schliemann (2002), for example, argue that the benefits of improving the concept of transfer are too small to outweigh its metaphorical baggage. Pessimism about transfer has led many educators to attempt to avoid transfer problems by instructing people in the particular situations where the target skills and knowledge will be utilized, and by building cues for transfer into the environment. Dunbar (1997), for example, found that biologists have databases for retrieving near analogies that serve as transfer candidates to explain novel findings. So, support for analogical transfer has been “built into” these people’s worlds.

Is the transfer literature filled with inherently contradictory claims, or is there a framework that can help illuminate how and why the varied positions on transfer are each pieces of the truth that can be reconciled through a broader theoretical foundation? We argue for the latter and use an analogy involving well-known proverbs. Consider “Many hands make light work” versus “Too many cooks spoil the broth”; “Look before you leap” versus “He who hesitates is lost”; “Absence makes the heart grow fonder” versus “Out of sight out of mind.” On the surface they contradict one another (Bransford & Stein, 1993). But if we look below the surface we can begin to see that each seems applicable in certain contexts (e.g. “Many hands make light work” is appropriate when tasks are well defined and can be modularized so that the pursuit of each can proceed independently). Our goal is to provide a framework that helps reconcile seemingly conflicting views about transfer. To develop our ideas, we divide the chapter into five sections that:

1. Rethink the classic definition of transfer and show how it tends to produce assessments that make people “look dumb” rather than “look smart” (Norman, 1993).
2. Differentiate “transferring in” to situations from “transferring out” of them.
3. Discuss studies that show that new ways to think about transferring “in” and “out” can reveal advantages of a variety of interactive instructional techniques that remain hidden when we use more traditional measures.

4. Propose a tentative learning and performance space that differentiates two dimensions of transfer -- innovation and efficiency -- and provide an example of what research might look like that explores optimal trajectories of learning and development through the innovation-efficiency space.

5. Summarize our arguments and suggest some possible future directions – including new ways to create learning and assessment environments that complement but go beyond many frequently used assessments tests.

1.0 Classic Definitions and Measures of Transfer and How They Make us "Look Dumb"

The book Transfer on Trial (Detterman & Sternberg, 1993) provided a timely and important focus on transfer as a major issue in need of clarification. In the introductory chapter, Detterman writes the following:

> "…most studies fail to find transfer …and those studies claiming transfer can only be said to have found transfer by the most generous of criteria and would not meet the classical definition of transfer" (p. 15)

Detterman describes the classic definition of transfer as "the degree to which a behavior will be repeated in a new situation" (p. 4). If transfer is as difficult to demonstrate as Detterman describes, it raises serious questions about how we frame our educational goals.

We believe that the classic definition of transfer is too narrow. Accepting it results in many cases that appear to show "failed transfer," because people do not apply the identical procedures they learned previously when in a new transfer context. Lave

(1988), for example, found that educated adults did not apply school-based algorithms to make shopping comparisons. Based on this evidence, she argued that transfer does not occur across cultural settings (e.g. from school to everyday life). Given the classic definition of transfer, Lave's arguments make great sense.

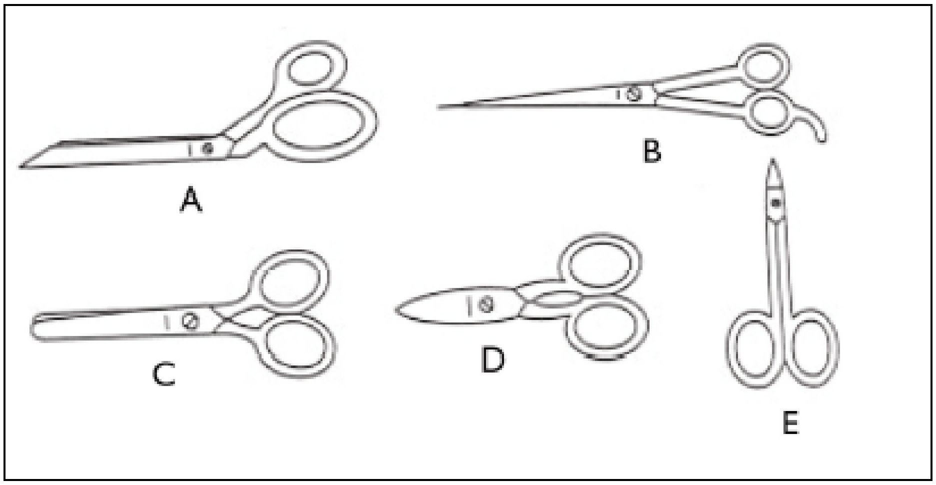


Figure 1. Noticing function-structure relations in scissors. (Bransford & McCarrel, 1974).

Moving beyond the classic "stimulus generalization" view of transfer (where an old response is performed in a new context) provides some new ways to think about transfer. For example, imagine helping people learn about different pairs of scissors like those illustrated in Figure 1. One group simply memorizes letter names for each pair of scissors. A second is helped to explore carefully how the structure of each pair of scissors is designed to support particular kinds of functions (e.g., the flat bottom blade of A allows dressmakers to rest the blade on the table when cutting; the long handle of E creates extra leverage for cutting hard substances). For a transfer assessment, the two groups might receive a new task where they need to use a pair of scissors, and receive a large set of options from which to choose. When appropriate, we assume that the group that was helped to focus on structure-function relations would be more likely to choose a new pair of better-adapted scissors rather than merely repeat an old choice. It seems to us that we want to include these kinds of "modified responses in new contexts" as instances of transfer.

If we apply this line of thinking to Lave's findings about the mathematical practices of shoppers, we might argue that the shoppers experiences with school-taught mathematics may have helped them invent or more quickly learn new techniques that were suited to a shopping context. Data exist suggesting that this line of thinking has merit (e.g., Beach, 1999). Schleimann and Acioly (1989), for example, compared Brazilian bookies with different levels of schooling. Although all of them used similar procedures for routine bets, the bookies with more schooling were more flexible and could generate methods for handling novel problems. These are correlational studies, of course. However, a number of experimentally controlled studies also suggest that the degree of flexible adaptation to new settings is related to the degree to which concepts, procedures and tool designs are understood by learners rather than simply learned by rote (e.g., Adams et al., 1988; Bransford, Zech, Schwartz et al., 2000; Judd, 1908; Wertheimer, 1959).

Even expanding the classical definition of transfer to include "flexible adaptation of old responses to new settings" is, in our view, still too restrictive a framework for exploring issues of transfer. The reason is that most studies of transfer also include an unnecessary constraint that stems from measuring people's abilities to <u>directly apply</u> what they have learned previously in new settings (see Hammer et al., this volume, for a different perspective on this theme). Tests of the "direct application" view typically place people in sequestered environments where they have no access to "contaminating" information sources other than what they have learned previously, and where they receive no chances to learn by trying out an idea and revising as necessary. An alternative to the “direct application” view of transfer and its associated “sequestered problem solving” (SPS) assessments is one that expands the definition of transfer to include “preparation for future learning” (PFL) (see Bransford & Schwartz, 1999). As we argue below, this is a very simple change in the definition of transfer but its implications for designing effective learning experiences and measuring their effects are actually quite major.

We want to reiterate a point made in our earlier writings on transfer (Bransford & Schwartz, 1999); namely, that we are by no means claiming that we are inventing the idea of PFL transfer. Exceptions to the use of the “sequestered problem solving” paradigm have been around for a long time. They occur primarily in the skill acquisition literature, where it makes no sense to expect people to transfer without opportunities for more learning (e.g. to transfer from word processing program A to program B). When people’s abilities to learn new skills are assessed, one often finds negative transfer initially, with positive transfer showing up after a number of learning trials (e.g. Singley & Anderson, 1989; Sander & Richard, 1997.) However, in most studies that involve conceptual transfer, participants receive a single trial to solve a problem and receive neither feedback nor opportunities to revise. In our earlier article, we noted that we found ourselves slipping between these different views of transfer (SPS vs. PFL) without noticing it, and that making the differences explicit had a major, generative effect on our thinking about educational issues. Our conjecture was that we were not the only ones in the field who were switching between SPS and PFL thinking without realizing it. So, one of the goals of our original article was to make this distinction clear.

One of the implications of a switch from SPS to PFL thinking links to Norman's (1993) work on designs that "make us look smart" versus "make us look dumb". Many SPS assessments of learning (based on "direct application" views of transfer) make people look much "dumber" (or "less educated") than is actually the case. Wineburg (2003) discusses how the use of psychometric principles for test construction can provide information about learning that makes outcomes look disappointing. In the discussion below, we provide additional examples of ways that SPS assessments can make people "look dumb."

1.1 Burgess' Original Eagle Challenge.

The idea that SPS measures of transfer can make people "look dumb" is nicely illustrated by an experiment designed and conducted by Kay Burgess that was discussed in our earlier article on rethinking transfer (Bransford & Schwartz, 1999). In the discussion below, we remind the reader of the original study and discuss a recent extension.

Burgess gave groups of 5th-graders and college students the problem of developing a statewide recovery plan to increase the bald eagles in their state. None of the students had studied eagle recovery plans before. The study was meant to see if the college students' general educational experiences would transfer to solve this problem. The first part of the transfer task involved sequestered problem solving; people were asked to directly apply anything they knew from the past to solve this problem.

The college students and the 5th-graders gave answers to this problem that were totally unworkable. Eagle recovery is a difficult problem, so it is not surprising that they did poorly. Still, it would have been comforting to see that the college students did a better job than the 5th-graders. The college students' plans were written with better sentence structure and punctuation, but they were still so far from the expert model that their answers had to be counted as almost totally wrong.

For the second part of her experiment, Burgess moved from a test of sequestered problem solving to a test that provided at least an initial indication of how well people were prepared for subsequent learning. Here, she asked the students to generate questions that they would like to have answered to help them <u>learn</u> more about eagle recovery plans. Under these conditions, major differences between the 5th-graders and college students were revealed.

The 5th-graders' questions focused on isolated eagle traits (What do they like to eat? What size are they? What kinds of trees do they live in?). The college students asked system level questions about the relation between eagles and their habitat (What kinds of ecosystems support eagles? Do other animals need to be recovered to repopulate eagles? What caused problems for the eagles in the first place?).

The questions generated by the college students were more sophisticated and should ultimately provide better guides for future learning than the questions asked by the 5th-graders. Nevertheless, even the 5th-graders' questions revealed that they knew more about survival than "nothing" (which is what they scored on the first test of SPS transfer). Even this simple shift toward question generation provided a picture of peoples' competencies that, in Norman's words (1993), can move us from "dumb" to "competent."

1.2 An Extension of the Eagle Challenge

Burgess's Eagle Challenge was recently used in workshops with several groups of K-12 principals who were first asked to generate possible solutions based on their existing knowledge. Except for one person who had been a biology teacher, the principals were unable to generate workable recovery plans. Example solutions that they generated included finding adult eagles from more populous areas and bringing them to the state; raising baby eagles in zoo-like environments and then releasing them, and so forth. These solutions reveal transfer in the sense that the responses rely on previous knowledge about re-populating animals (e.g. moving wolves or bears to new areas in the wild). These analogies are faulty, however, because they do not take into account a host of important considerations that apply to eagles (e.g., eagles imprint on their territory and on humans). According to the transfer literature, the use of these analogies would count as instances of "negative transfer." So again, the SPS assessment made people "look dumb."

Despite their dismal failure on the SPS assessment, the second part of the exercise demonstrated a number of strengths of the principals. Instead of asking the principals what questions they would like answered, as in the first study, they were asked to say what they would do to learn to solve the problem. A very important finding was that the principals were cautious about their analogies and did not presume their prior knowledge was sufficient to solve the problem. This "resistance to premature assimilation" is an extremely important aspect of transfer that is often overlooked in the literature. High confidence coupled with low "competence" is a dangerous combination for the prospect of future learning. The principals' tentative confidence (a better term is probably "high cautiousness") was a definite strength. It motivated them to continue to learn rather than to go with their existing ideas. For example, they spontaneously started to use the wireless network that was available to them to find relevant information, and they were making headway to a solution as the workshop ended.

The principals also generated questions and made suggestions that went considerably beyond those suggested by the college students. Examples included concerns about how to get the community to support and sustain the eagle recovery efforts, plus thoughts about social networks of people whom they knew to have relevant knowledge and skills. These seem to be clear examples of transfer based on the principals' experiences of working with the community to implement and sustain changes. Most college students have not had these kinds of experiences and very few students mentioned points like this.

Overall, everyone who participated in the Eagle Challenge (5th-graders, college students, principals) looked a lot "smarter" on the PFL measures than on the SPS measures that are typically used in conjunction with the "direct application" view of transfer. It is noteworthy that most high stakes achievement tests are also SPS measures, and they too may be underestimating our students' abilities to continue to learn throughout their lifetime. We return to this issue at the end of the chapter. For now, however, our goal is <u>not</u> to claim that PFL measures show that education is better than we thought and hence we can rest on our laurels. Instead, our goal is to use new ways of thinking about and measuring transfer to explore the effectiveness of teaching, learning, and assessment strategies that may look poor from an SPS perspective yet, in reality, have the potential to greatly improve people's motivations and abilities to learn throughout life.

2.0 Transferring In to versus Transferring Out of Learning Situations

2.1 Broudy's three kinds of knowing

In our earlier writing, we referred to Broudy (1977), who discusses three kinds of knowing. With concerns similar to the superintendents discussed at the beginning of this chapter, Broudy has attempted to understand the kinds of educational experiences that prepare students for life rather than simply for test taking:

> "Ever since formal schooling was established, it has been assumed that knowledge acquired in school would be used to enhance the quality of human life. The investment in schools was supposed to yield a return in the form of greater adequacy in occupational, civic, and personal development" (p. 2).

Broudy discusses the "replicative," "applicative," and "interpretive" aspects of knowing and notes that most assessments have focused almost exclusively on the first two. For example, he argues that students rapidly forget the facts that they learn in school, hence they do poorly as measured by tests of "replicative" knowing. He also argues that most students have difficulty applying previously acquired knowledge to solve new (transfer) problems; hence they do poorly in what he calls "applicative knowing." In fact, Broudy emphasizes that a sole reliance on replicative and applicative tests of knowing lead to the conclusion that schooling has very disappointing effects on lifelong learning. Replicative and applicative tests make school "look dumb," and there is pressure to provide more memorization and procedural training so students do better on those types of tests. However, Broudy proposes a third aspect of knowing called the "interpretive," which he considers an important but neglected outcome of schooling.

For many new situations, people do not have sufficient memories, schemas or procedures to solve a problem, but they do have interpretations that shape how they begin to make sense of the situation. We know from a number of literatures — including the perceptual learning literature, the expertise literature, the problem solving literature, and the cognitive therapy literature— that what one notices about new situations and how one frames problems has major effects on subsequent thinking and cognitive processing (e.g. Bassok & Holyoak, 1989; Bransford & Stein, 1993; Chi, Feltovich & Glaser, 1981; deGroot, 1965; Gibson & Gibson, 1995; Greeno, Smith, & Moore, 1993; Marton & Booth, 1997; National Research Council (NRC), 2000; Schuyler, 2003). This (we believe) is a major part of what Broudy meant by the interpretive. Broudy also argued that an increase in the sophistication of one's interpretations by no means guarantees that one can immediately come up with concrete applications of the ideas that underlie these more sophisticated interpretations. For example, knowing about imprinting is probably insufficient for resolving the eagle challenge, but this information can provide important guidelines for learning to solve the challenge. Moreover, people are often unable to articulate explicitly the particular ideas that changed their interpretations; hence Broudy's emphasis on "knowing with" information even if they cannot remember acquiring specific facts ("knowing that") or remember how to carry out a particular set of actions ("knowing how").

2.2 How traditional transfer assessments miss interpretive knowing.

Broudy's analysis is important for several reasons. One is that it highlights that traditional answers to the "what gets transferred" question have been restricted by an emphasis on replicative and applicative measures. These two "direct application" measures typically identify discrete memories and mature concepts or skills. Broudy's emphasis on interpretive knowing points to other forms of knowing that are involved in transfer but that are unlikely to reveal themselves in SPS assessments. Broudy argues that evaluating interpretive knowing can demonstrate positive benefits of school practices for most people.

The Eagle Challenge results that were discussed earlier can help clarify Broudy's arguments. When the 5th-graders, college students and principals solved the eagle challenge in an SPS paradigm, they were far from a correct solution. They had not explicitly studied this topic before, so they had no way to use replicative knowing. Ideally the rich educational and real-world experiences of the college students and principals would have had some degree of measurable impact on their ability to apply previously acquired knowledge to solve the challenge (applicative knowing). People's responses indicated that there were indeed strong influences of previously acquired knowledge. They all looked like instance of "negative transfer" rather than "positive transfer." So, things looked bleak. But when Burgess began to explore how people interpreted the Eagle Challenge, as revealed by the kinds of questions they asked and strategies for new learning, she found important differences in interpretive knowing. Unlike SPS measures of transfer, PFL measures allow us to see people's initial interpretations. The college students and principals brought more sophisticated questions, plus knowledge of how to use technology and social networks of expertise. We also found that the instances of negative transfer (e.g. treating the eagle problem like a "repopulate the wolves" problem) were lightly held conjectures. The principals did not interpret the analogies they suggested to be perfect applications; they were cautious and continued to check their assumptions. This willingness to question and even "let go" of initial assumptions is an extremely important aspect of "adaptive expertise" (e.g. Hatano & Inagaki, 1986; Wineburg, 1998) that we discuss in more detail later on.

2.3 The significance of interpretive knowing for "transferring in".

A second important aspect of Broudy's interpretive knowing is that it focuses on analyzing "seeds for new learning" rather than on direct application. When people do not have full-blown skills that they can apply directly to solve a problem, they need to learn, and their interpretations play a large role. For example, in the Eagle Challenge, Burgess's assumption was that the adults' superior interpretive knowing (as revealed by their questions) would put them on a path that would make it more likely that they would <u>learn</u> to solve the Eagle Challenge (given further opportunities to interact and to access additional resources). Burgess did not have the time to actually allow people to learn and track their progress, so the enhanced potential for learning is only an inference from this study. As we show below, however, other studies are beginning to show that enhanced learning does indeed occur when people have an opportunity to develop the interpretive knowledge that prepares them to learn.

An emphasis on interpretive knowing and the need for further learning suggests the need for different research paradigms for studying transfer. The traditional view of transfer (e.g. see Detterman, 1993; Hammer et al., this volume) has treated transfer as something that happens after a particular type of learning experience. We refer to this as an emphasis on "transferring out" of situations. From this perspective, the paradigm for studying transfer is illustrated in Figure 2.

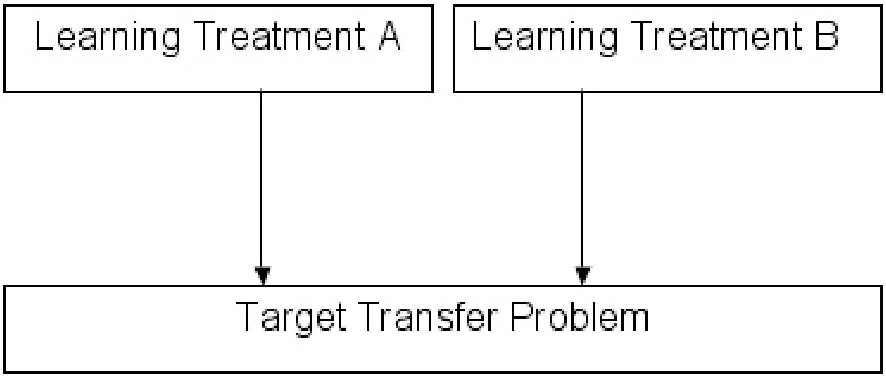


Figure 2. The standard “transfer out” methodology. (Schwartz & Martin, 2004).

People not only “transfer out” of situations to solve problems, they “transfer in” to situations to learn (Schwartz & Nasir, 2003). The ways and interpretations that people transfer in can have major effects on their learning and subsequent abilities to “transfer out” from that learning. Whenever we assert that new learning builds on previous learning, we are assuming that some sort of transfer is involved (e.g. see NRC, 2000).

In the basic research literature, issues of “transfer in” are often handled by attempting to control for them. For example, Ebbinghaus (1885) knew that prior knowledge affected subsequent learning so he invented nonsense syllables to control for this potential confound. Bartlett (1932) argued that people spontaneously tried to make sense of the nonsense syllables, hence using them to study learning and memory simply increased the variance of interpretations (compared to using stimuli like high frequency words where particular normative properties tended to hold for most people).

In educational settings, researchers need to focus on learning academic content; hence it becomes crucial to ask what learners bring to a situation as they begin their learning (Lobato, 2003; NRC, 2000). Research on preconceptions provides an example of paying attention to what people transfer in because it will profoundly affect what they learn (e.g. see Clement, 1993; Mestre, 1994, Mestre, Thaden-Koch, Dufresne, & Gerace, in press; Minstrell, 1989; Redish, 2004). Similarly, research on peoples' interactions with computers and media suggest that they bring many assumptions about the nature of human interactions to their interpretations and interactions (e.g. Biswas, Schwartz, Bransford, & TAGV, 2001; Reeves & Nass, 1996).

Different views about the frequency of transfer (we noted earlier that some say it is ubiquitous while others say it is rare) seem correlated with the degree to which researchers are focusing on the processes involved in transferring "in" to a learning situation versus transferring "out" for subsequent problem solving. For example, the preconception literature noted above focuses on "transfer in". In a lovely example with young children, Vosniadou and Brewer (1992) show how children combine their perceptual experiences of a flat world to make creatively erroneous, though understandable, mental models of the claim that the world is round. Similarly, Dyson (1999) provides compelling examples of how children regularly transfer knowledge of popular culture into school tasks when thinking about social and literary issues. In contrast, many who lament the large number of transfer failures (e.g., Detterman, 1993) focus primarily on "transfer out" where people fail to apply acquired knowledge to solve a new problem with different surface features. A major challenge for educators is exploring how to make both transfer in and transfer out productive.

When we change from a traditional SPS to PFL view of transfer, we change at least two major factors simultaneously. One is to include an emphasis on Broudy's "interpretive" aspects of knowing, and the second involves considering both the "transfer out" of situations and the "transfer in." Merging Broudy's emphasis on the interpretive aspects of knowing with the idea of "transferring in" helps differentiate the "preparation for future learning" view of transfer from the "learning to learn" literature (e.g. Weinstein, 1978). The learning to learn literature is important, but it tends to stress content-independent strategies for learning information presented by others (e.g. mnemonic techniques, knowledge organization techniques), and it underemphasizes the important role of content knowledge for shaping people's interpretations of new situations. Broudy (1977) provides an example of the importance of knowledge for interpreting new problems:

> "The concept of bacterial infection as learned in biology can operate even if only a skeletal notion of the theory and the facts supporting it can be recalled. Yet, we are told of cultures in which such a concept would not be part of the interpretive schemata." (p. 12)

The absence of an idea of bacterial infection should have a strong effect on the nature of the hypotheses that people entertain to explain various illnesses. Hence, it would affect their abilities to learn more about causes of illness through further research and study, and the strategies they would use to solve new problems (e.g., reading a biblical text versus looking for vectors of communicability). Having accessible knowledge of imprinting in eagles—both with respect to establishing their partners (other eagles versus humans) and their territories—would presumably have similar, beneficial effects on the initial thoughts (interpretations) people would have about Burgess's Eagle Challenge. In addition, being aware of the "assumptive nature of knowing" and holding one's ideas "tentatively" pending further investigation is an extremely important part of people's interpretations of new situations. It is noteworthy that these aspects of knowing are rarely revealed when our assessments focus only on SPS measures of "transferring out" directly applicable knowledge.

3. Exploring the Effectiveness of Different Instructional Experiences

In the work discussed above there was not a precise control of the instructional conditions experienced by the participants. The studies discussed in this section give this kind of control and allow us to explore whether different measures of transfer can influence assumptions about the value of particular kinds of educational experiences. Our goal is not simply to suggest that we need new measures of transfer, but also, to suggest that we need to rethink the impact of different educational experiences for preparing people to learn. Our discussion in this section focuses primarily on ways that people "transfer in" to situations, which in turn affect how they learn. We first consider how "transfer in" can be influenced by the replicative, applicative, and interpretive aspects of knowing discussed by Broudy (1977). Then we examine how educational experiences that foster "transfer in" for learning can also lead to subsequent benefits on traditional measures of "transfer out" for problem solving.

3.11 Replicative Support for New Learning: Savings in relearning is an example of enhanced learning based on replicative aspects of "transfer in." For example, some students may learn a topic (e.g., algebra, a foreign language) faster than other students because they had learned it once before. Even if they have consciously forgotten most of it, they will often show faster learning compared to those who never studied the topic at all (e.g. MacLeod, 1988). Interestingly, opportunities to relearn something are closer to PFL measures of transfer than they are to SPS measures that simply ask people to apply what they know.

The importance of thinking about relearning is illustrated by a brilliant four-minute comedy routine by Father Guido Sarduci (Don Novello, 1980) of “Saturday Night Live. ” Father Sarduci begins by looking at the knowledge and skills that the average college graduate remembers five years after he or she graduates. He accepts these five-year-later memory performances as his standard and proposes a new kind of university that will have the same outcomes. His innovation is “The Five-Minute University”, which will cost only $20.00. Father Sarduci notes that $20 might seem like a lot for only 5 minutes, but it includes tuition, books, snacks for the 20-second spring break, cap and gown rental, and a graduation picture.

Father Sarduci provides examples of the things students remember after five years. If they took two years of college Spanish, for example, he argues that five years post graduation the average student will remember only "¿Como esta usted?" and "Muy bien, gracias.” So that’s all his Five-Minute University teaches. His economics course teaches only “Supply and Demand.” His business course teaches “You buy something and sell it for more,” and so forth. A video of Father Sarduci’s performance demonstrates how strongly the audience resonates to his theme of the heavy emphasis on memorization in college courses, and the subsequent high forgetting rates.

Father Sarduci’s analysis of the shortcomings of many approaches to teaching hit so close to home that they should not be ignored. On the other hand, if one used a relearning test five years after students graduated (as opposed to tests of replicative knowing), it seems probable that the advantages of a full blown course in Spanish, Economics or other topic would provide higher savings scores (savings in the number of trials needed to master something) than the very brief courses offered by the Five Minute University.

3. 12 Applicative Support for New Learning: At other times people can be helped to "transfer in" to a task through applicative knowing. For example, Bransford and Johnson (1972) provided students with a passage that included a paragraph which began: "The procedure is simple. First you divide things into groups depending on their makeup. Then you…." The passage was very difficult to learn and remember unless people were helped to access a previously acquired schema (washing clothes) that they could map directly into the target passage. (Additional examples are provided by Anderson, Osborn, & Tierney, 1984; Dooling & Lachman, 1971). Helping people "activate previously acquired schemas" is a common practice discussed in the educational literature (e.g. see Anderson, Osborn, & Tierney, 1984). It is noteworthy that the fact that relevant examples and schemas have been learned previously does not guarantee that they will be spontaneously applied in new settings. Work by Gick and Holyoak (1983) provide excellent examples of this type of phenomenon.

3.13 Interpretive Support for New Learning: "Transferring in" cannot always rely on access to previously acquired knowledge schemas, skill sets, or replicative facts that can easily be brought to bear on a new learning situation. To deal with this phenomenon, effective teachers often help students assemble new "platforms for subsequent learning." Excellent examples come from Eagan's *Teaching as Story Telling* (1988). Egan recently provided an example of a "count the soldiers" tale (provided below) that can support students' eventual understanding of place value and bases in arithmetic. It is unlikely that students have already acquired a “count the soldiers” schema that works for the kind of learning Eagan envisions. But, Eagan’s story (personal communication, March 7, 2003) helps them transfer into the instruction by building on a set of concepts that are now integrated into a new, imaginable whole.

> A king wanted to count his army. He had five clueless counselors and one ingenious counselor. Each of the clueless five tried to work out a way of counting the soldiers, but came up with methods that were hopeless. One, for example, tried using tally sticks to make a count, but the soldiers kept moving around, and the count was confused. The ingenious counselor told the king to have the clueless counselors pick up ten pebbles each. He then had them stand behind a table that was set up where the army was to march past. In front of each clueless counselor a bowl was placed. The army then began to march past the end of the table.
>
> As each soldier went by, the first counselor put one pebble into his bowl. Once he had put all ten pebbles into the bowl, he scooped them up and then continued to put one pebble down for each soldier marching by the table. He had a very busy afternoon, putting down his pebbles one by one and then scooping them up when all were in the bowl. Each time he scooped up the ten pebbles, the clueless counselor to his left put one pebble into her bowl [gender equity]. When her ten pebbles were in her bowl, she too scooped them out again, and continued to put one back into the bowl each time the clueless counselor to her right picked his up.

> The clueless counselor to her left had to watch her through the afternoon, and he put one pebble into his bowl each time she picked hers up. And so on for the remaining counselors. At the end of the afternoon, the counselor on the far left had only one pebble in his bowl, the next counselor had two, the next had seven, the next had six and the counselor at the other end of the table, where the soldiers had marched by, had three pebbles in his bowl. So we know that the army had 12,763 soldiers. The king was delighted that his ingenious counselor had counted the whole army with just fifty pebbles.

It is noteworthy that Egan does not assume that his "count the soldiers" story teaches place value and bases; instead it helps set the stage for subsequent learning. Egan encourages teachers to follow up by having the students count the class or some other, more numerous objects using this method and eventually to change the place values from base 10 to other bases. Other educators also argue for the value of designing "meaningful" lessons that help students go beyond what is already schematized to build some kind of conceptual platform that allows them to think. The Cognition and Technology Group at Vanderbilt's (CTGV, 1997) Adventures of Jasper Woodbury provides an example. The visual narratives in the series help students "transfer in" complex real-world knowledge to motivate and anchor the ways they think about new mathematical content. But the videos by themselves are far from being "the instruction." They simply set the stage so that intensive, interactive problem finding and problem solving activities can be orchestrated by teachers and students (e.g. see Barron, 2003;

Crews et al., 1995). As we argue below, however, stories and videos are only a small subset of what may be needed to help students "transfer in."

3.2 Assessing Transfer In with Measures of Transfer Out.

Evaluations of the quality of an educational experience for "transferring in" can be strongly affected by one's measures of "transferring out". For example, educators are often convinced that providing opportunities for students to actively explore situations is important for learning. Terms like "discovery learning", "hands on learning" and "experiential learning" –although typically only loosely defined—represent examples of these kinds of beliefs. From our perspective, the use of SPS measures of transfer out make it difficult to find evidence that these kinds of activities are better than just telling students what they need to learn or letting them practice a set of desired skills. But what if certain kinds of "hands on" or "discovery" activities prepare people to transfer into new learning settings in ways that eventually produce superior learning and "transfer out" in the long run? Tests of this conjecture require a PFL approach to assessing learning and transfer where opportunities for learning are integral components of the transfer assessment. The following sections provide examples of this approach.

3.21 Do Data Analysis Activities Support Theory Learning?

In the first example, we remind readers of an earlier study (Schwartz & Bransford, 1998) which shows how developing students' interpretive knowing "transfers in" to help students learn from an explicit lecture, which in turn, leads to better applicative knowing for a subsequent transfer task. The research arose in the context of teaching cognitive theories of memory. We had developed a model of instruction that we thought would help students "transfer in" to allow them to learn more effectively. We wanted to help undergraduates learn about various memory theories and the types of memory performances they predicted. We realized that standard textbook descriptions of experiments (e.g. studies of memory and schema theory) rarely allowed students to explore raw data. To us as researchers, this kind of experience is important for understanding theories and their predictions. For example, whenever we read about recent psychological theories and their empirical tests, we compare them to our knowledge of data from a variety of studies we have conducted to see if there are matches and mismatches, and whether the findings are plausible. But students who have never seen data cannot do this. Without this level of detail, we feared that students understood only superficially.

Table 1. An example of a task for students in the Data Analysis condition.

In experiment 1, researchers asked six people to recall a list of words learned at 1 sec a piece. Here are the words in the order they were studied:

car, sky, apple, book, cup, lock, coat, light, bush, iron, water, house, tape, file, glass, dog, cloud, hand, chair, bag

Here are the words the subjects recalled in the order they recalled them:
Sbj 1: bag, hand, chair, cloud, sky, light
Sbj 2: bag, chair, hand, car, sky, book, house, bush
Sbj 3: hand, bag, chair, cloud, car, lock, dog
Sbj 4: bag, hand, chair, dog, car, apple, sky, water, glass
Sbj 5: bag, chair, car, iron, apple, cup, water, light

Make a visual representation of the interesting patterns in the data.

As an approach to solving this problem, we asked students to analyze and graph simplified data sets from classic memory experiments to find the "interesting" patterns. Table 1 provides a sample of the data sets the students analyzed. Afterwards, we asked them questions about what they had studied and compared their performance to other students who had not seen the data but had read summaries of the studies. For example, given the true-false question, "Do people tend to remember the first thing they read?"

students who had graphed the data did not do well compared to students who had written a summary of a chapter on memory. Thus, by a standard (replicative) assessment of knowledge, our method of instruction fared poorly.

Nevertheless, we had reasons to believe that our model of instruction would be more effective in the long run; it would prepare students to learn from subsequent direct instruction. In particular, we thought that analyzing the data sets would help the students develop more differentiated knowledge that would guide their subsequent interpretation and learning from a lecture. The perceptual learning literature shows that contrasting cases, like two wines side-by-side, can help learners discern features that make the cases distinctive (e.g., Gibson & Gibson, 1955). By analogy, we asked students to analyze sets of simplified data sets from two different experimental conditions. Combined with actively trying to graph what they found, we assumed that these activities would help prepare the students to recognize the significance of the precise definitions, examples, and explanations that would appear in a formal lesson that they and the non-data analysis students would receive.

To test this hypothesis, students in one condition analyzed the contrasting cases of data. In another condition, students read a modified book chapter that described the same studies and results (in words and graphs), and provided their theoretical significance. This latter group's task was to write a one to two page summary of the important ideas in the chapter. A few days after students completed these tasks, both groups heard a common lecture that explained the experiments, the results, and the theories that were designed to accommodate the results. The question was whether both groups of students had been equally prepared to learn from the lecture. We also included a third group that did not hear the lecture. This group also completed the data analysis activity, but instead of hearing the lecture, they analyzed the data a second time looking for any patterns they may have missed. All told, there were three conditions: Data Analysis + Lecture, Summarize Chapter + Lecture, Double Data Analysis.

To assess whether the students learned from the lecture, we employed two assessments about a week later as part of a class exercise. The first assessment measured transfer by asking students to read the description of a novel experiment. The students' task was to predict as many of the outcomes from the experiment as possible. Eight possible predictions were covered in the previous lessons (e.g., primacy). The second assessment used a recognition test that included factual assertions from the lecture. For example, "When people understand something they have read, they tend to remember it verbatim. True or false?"

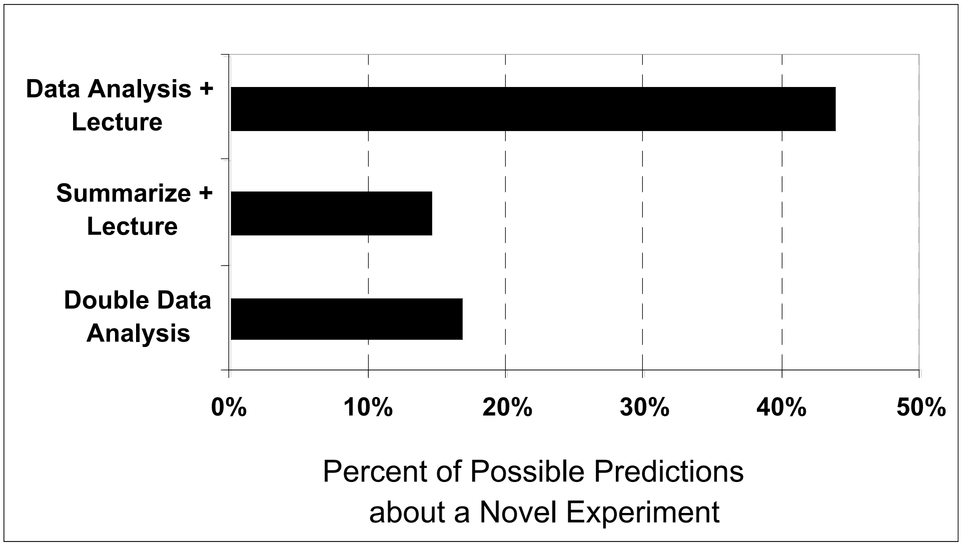


Figure 3. Performance on transfer task of predicting results of a novel experiment. Data analysis activities prepared students to learn from a subsequent lecture and then transfer to a novel problem compared to summarizing a chapter and hearing a lecture or analyzing data for two sessions without a lecture (Schwartz & Bransford, 1998).

On the recognition (true-false) test, the Double Data Analysis condition did poorly, as we had found before. However, given the chance to hear the lecture, the Data Analysis + Lecture group performed as well as the Summarize + Lecture group. More importantly, the prediction task showed the hidden benefit of the data analysis activity. Figure 3 shows that the Double Data Analysis students again performed badly. However, the Summarize + Lecture students performed equally badly. The Data Analysis + Lecture students did quite well, producing over twice as many correct predictions as students in the other conditions. By this result, data analysis was very important for learning from the lecture and transferring this learning to the prediction task. We know the data analysis students learned from the lecture because the Double Data Analysis group that did not hear the lecture performed badly. A variety of control conditions over several studies showed that the effect was not simply due to attention or time on task and that the effects held when the lecture was replaced by a relevant reading.

One lesson from this study is that lectures can be a very effective method of instruction if people are prepared to understand the significance of what the lecture has to offer. Providing students an opportunity to notice distinctions within a set of contrasting cases is a powerful way to prepare people to learn and transfer, at least compared to the common activity of abstracting the key points of a reading into a summary. A second lesson is that transfer assessments that include opportunities for learning can reveal important differences in instruction and ways of knowing. Without opportunities for learning, the data analysis method of instruction appeared ineffective and the students' knowledge was too poorly developed to answer simple factual questions. However, when it was evaluated by how well it prepared students to learn from a lecture and transfer that learning out, it looked very effective.

3.22 Is There a Hidden Efficacy to Original Student Invention?

Another study explores issues of "transferring in" and "transferring out" even more fully (Schwartz & Martin, 2004). It formalizes what we might label the "double transfer" design that was implicit in the preceding study. Figure 4 schematizes the double transfer design. People receive instructional treatment A or B. Afterwards people from both conditions receive equivalent resources for learning key ideas. Then they receive a transfer problem where those ideas apply.

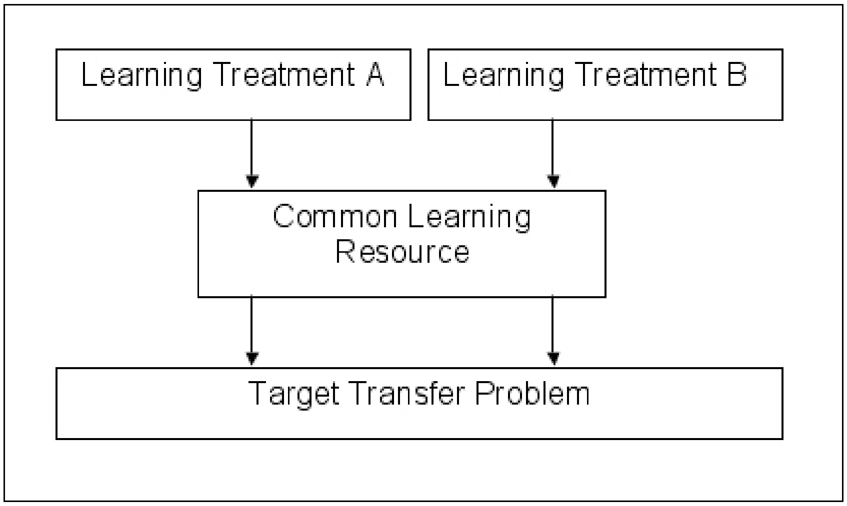


Figure 4. Double transfer methodology that includes "transfer in" and "transfer out" phases. This research design compares how two instructional treatments prepare students to "transfer in" to learn from a resource and then "transfer out" from the resource to solve a problem (Schwartz & Martin, 2004).

In this study, we directly compared the standard transfer design we mentioned earlier and the double transfer design, head-to-head. Figure 5 shows the factorial design. Students learned either with an invention method or a tell-and-practice method. Per the standard transfer design, half of the students in each instructional condition directly tried to solve the transfer problem. Per the double transfer design, the other half of the students received a common learning resource and then completed the transfer problem.

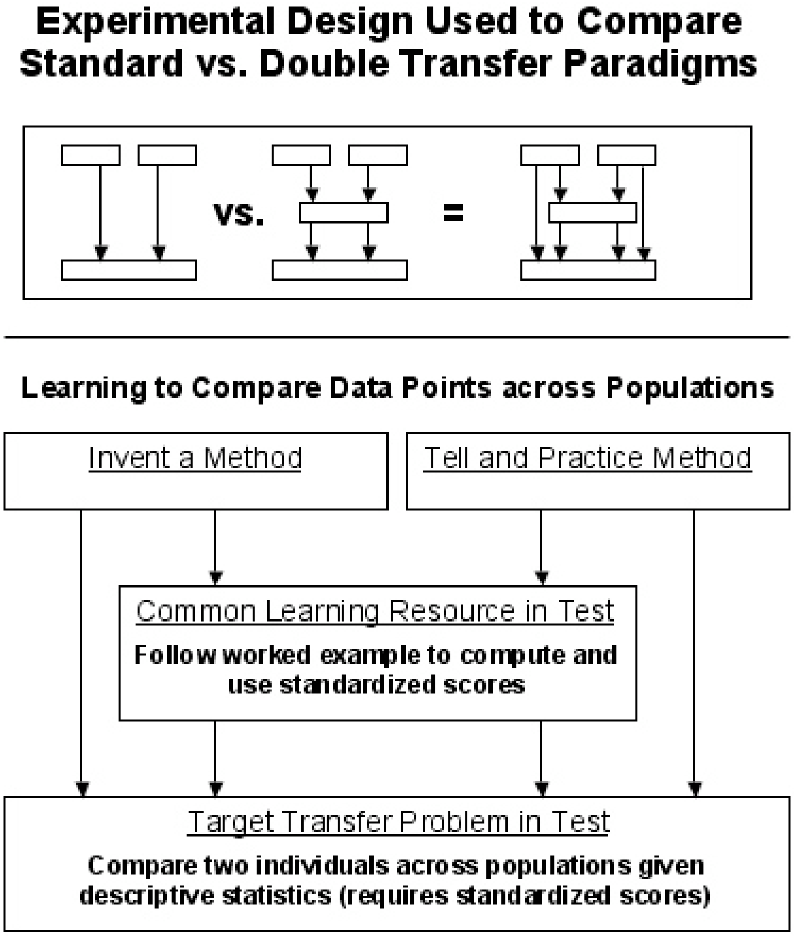


Figure 5. Experimental design to compare the standard and double transfer designs. Participants had to learn to compare scores from two different distributions (e.g., grading on a curve) and transfer this learning to solve a transfer problem (e.g., comparing athletes from different periods in history) (Schwartz & Martin, 2004).

In this study, we were also interested in spontaneous transfer at both transfer in and transfer out (e.g. see Bransford, Franks, Vye, & Sherwood, 1989 for reviews of spontaneous versus prompted transfer). In the earlier study on learning memory concepts, the students did not have to transfer in their knowledge spontaneously to learn from the lecture. It had been made clear to them that the lecture was relevant to the activities they had previously completed, so the study tested the value of preparing students for intentional learning. However, learners often will need to transfer knowledge spontaneously into new situations of learning (e.g., Branford et al., 1989; Gick & Holyoak, 1983). People always "transfer in" some knowledge to make sense of a new situation. The challenge is whether we can prepare them so they spontaneously transfer the "right" knowledge.

The research, which involved 15 classes of 9th-grade students, compared the value of asking students to invent statistical methods versus imitate and practice shown methods. Students in both conditions completed identical activities for the first two weeks. The comparison of the standard and double transfer designs began with the final day of instruction and finished with the posttest. During the final day of instruction, all the students received two scenarios in which they had to compare high scores from two distributions; for example, who broke the world record by a more impressive amount, John in the high jump, or Mike in the javelin throw? They had to decide which score was higher, even though the two distributions had different means and variances. The appropriate solution to this type of problem is to use some form of standardized score. In lay terms, they had to "grade on a curve" and compare where each high score appeared on its respective curve.

Students were divided into two conditions for about 30 minutes. Students from both conditions received the same raw data and histograms. In the *invention* condition, the students had to invent their own solution to the problem of comparing high scores from different distributions. Nobody succeeded in making a general solution, so by many accounts, this would seem inefficient – why not just tell them the method and correct any mistakes as quickly as possible (e.g., Anderson, Conrad, & Corbett, 1989; Lovett &

Greenhouse, 2000; but see Vollmeyer, Burns & Holyoak, 1996; Mantosh & Koedinger, 2003 on the benefits of well-placed delayed feedback). This is what we did for the *tell-and-practice* condition. Students were shown how to solve the problem graphically by first marking deviation regions on a histogram and then comparing the normalized values of the high scores. For this condition, students practiced the method with the data and histograms, and the teachers answered questions or corrected errors when they were found. The question was whether the students from each condition would be equally prepared to transfer this activity to learn during the posttest.

Students completed a posttest that included many statistics problems. Embedded within these problems were two key items that completed the experiment. A worked example item only appeared in half the tests. The worked example constituted the resource from which students could learn. The students who received the resource completed the double-transfer design, whereas the students who did not receive the resource, completed the standard transfer design. The embedded resource provided a worked example for how to compute and compare standardized scores (e.g., is Betty better at assists or steals?). Students followed the steps to complete an analogous problem at the bottom of the page. Nearly all the students who received the worked example followed it correctly, so we know the students were paying attention.

Near the end of the test there was a target "transfer out" problem. The problem included descriptive statistics giving the averages, deviations, and scores of an individual in each of two groups (e.g., which of two students, who were in different biology classes and took different tests, did better on their respective test?). The target transfer problem differed from the instructional activities because it only provided summary measures rather than raw data. This is where the embedded worked-example became important. It showed how to find standardized scores given summary measures. The question was whether students from both instructional conditions would simply interpret the worked example as a "plug and chug" problem on a test, or whether they would transfer in their prior instructional activities to learn what this example was teaching about standardized scores and then apply it to solve the target transfer problem.

Figure 6 shows the percent of students who gave correct solutions to the target transfer problem. Students in the invention condition who received the worked example in the test doubled the performance of the other three groups. The invention students must have learned from the worked example, because invention students who did not receive the example performed poorly. In contrast, the tell-and-practice students performed the same whether or not they received the worked example.

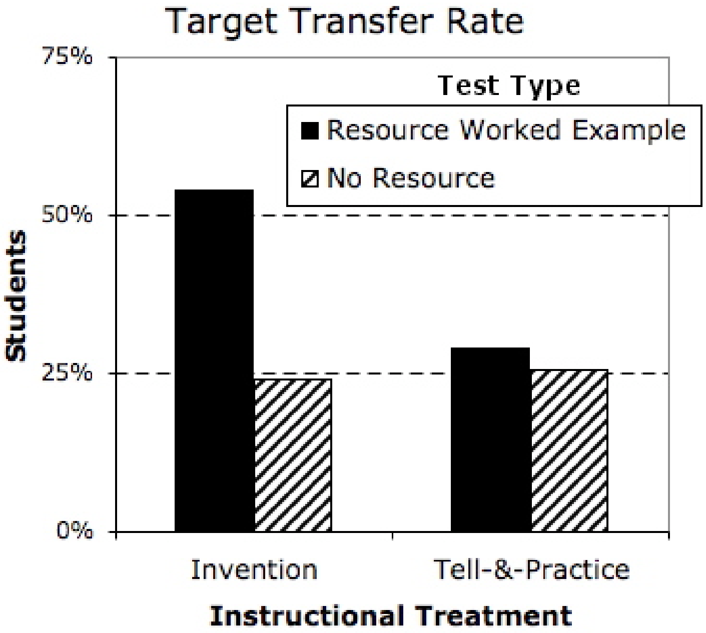


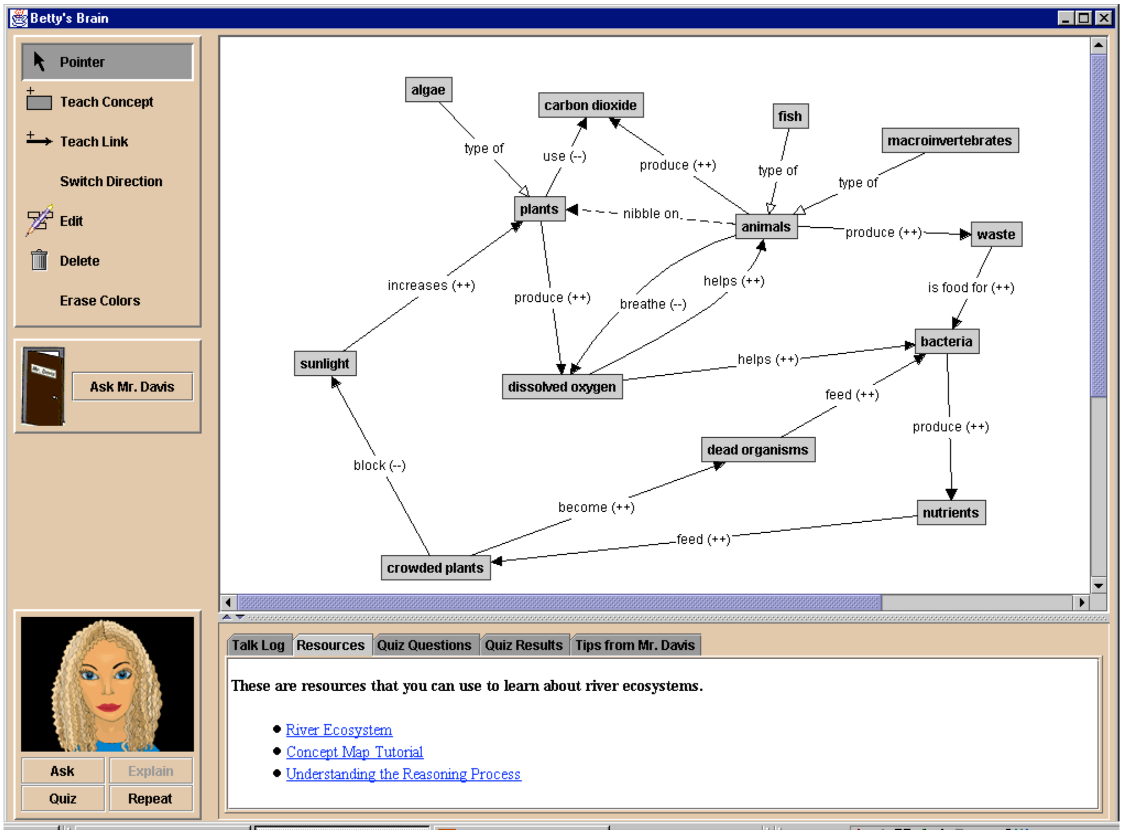
Figure 6: Rate of "transfer out" as a function of instructional method and inclusion of a learning resource (a worked example) embedded in test. Without the opportunity to transfer in to learn at test, the inventing condition did not reveal its value (Schwartz & Martin, 2004).

We believe that there are several important lessons to this study. As before, activities that appear inefficient for direct problem solving (applicative knowing) can still shape people's interpretive knowing and yield measurable benefits for learning. And as before, PFL assessments that examine people's abilities to learn at test can reveal important levels of knowing missed by standard assessments. The results of this experiment also suggest the value of further research into designing assessments that evaluate how well students have been prepared to learn. Besides measuring something that we should care about, it could change the idea of what it means to "teach to the test." For example, if teachers knew that a standardized test required learning during the test, they would have to prepare students to learn from the resources. This seems like a worthwhile use of time, at least compared to teaching specific techniques for solving the narrow classes of problems that are likely to be sampled by a test.

3.23 Are There Differences between Coaching, Teaching, and Tutoring for Student Learning?

The preceding studies examined relatively short-term effects of preparing students to learn – within a week or so after initial instruction. The current study examined whether some forms of instruction can help students learn months later, given complex resources. As in the preceding studies, the use of PFL measures of transfer were crucial for uncovering the potential value of particular strategies for helping students learn.

Biswas et al. (2004) worked with 5th-graders in life science using the teachable agent paradigm (Biswas, Schwartz, Bransford, & TAG-V, 2001). With teachable agents, children teach a computer agent using visual representations that help organize their knowledge. The teachable agent then performs based on this instruction. Students can remediate the agent's knowledge (and their own) based on these performances. For the study, Biswas et al. used a teachable agent named, Betty. Students teach Betty by creating concept maps. In these maps, students specify links that determine whether an increase to one node (e.g., algae) causes an increase or decrease to another (e.g., oxygen), and whether one node is a sub-class of another node (e.g., algae is a type of plant and inherits the properties of plants). Figure 7 shows an example of Betty's interface after she had been taught. Once taught, Betty can answer questions and shows her reasoning by graphically tracing the links and explaining her steps in text and voice. In the current study, Betty could also take quizzes, and students had to teach her so she would pass the quiz.



These are resources that you can use to learn about river ecosystems.

- River Ecosystem
- Concept Map Tutorial
- Understanding the Reasoning Process

Figure 7. A teachable agent. Students teach the agent, Betty, by creating concept maps. Betty answers questions based on how well she has been taught. Betty shows her reasoning by chaining through the links in the concept map.

The study on teachable agents conducted by Leelawong employed three conditions (see Biswas et al., 2004). In each condition, which lasted about six hours, the children had to create the oxygen cycle for a pond ecology. The children did not already know the oxygen cycle, so the software included a number of resources to help the children learn (e.g., web pages). In the Teach condition, the children taught Betty. They could compose questions to see how Betty answered them (based on their teaching), and they could ask Betty to take a quiz. They revised her when she did poorly on the quiz, and there was an "expert agent" who helped them to interpret the incorrect answers. The Tutor condition was similar to the teach condition, except that students did not operate under the guise of teaching Betty. So, instead of asking Betty a question directly, they could ask the tutor questions, and the tutor would explain, "based on what you have done, the answer would be…." The intelligent tutor also showed students the right answer when Betty made a mistake on a quiz question. In the Teach + Coach condition, students taught Betty, but the software also included a coach from whom students could solicit advice. The coach did not directly tell students what to do and provided suggestions only when the students asked for them. These suggestions were not about the oxygen cycle, but rather, they were about ways to teach and evaluate Betty's knowledge and how to learn from resources. Initially, the students in the Teach and Teach + Coach conditions had more difficulty getting Betty to pass the quiz, but eventually they caught up to the Tutor condition. The question was what would happen at transfer.

At transfer, about two months later, all the students had to create a concept map about the nitrogen cycle. The students had not studied the nitrogen cycle, but they had resources from which they could learn during this transfer test. They did not have a tutor or coach and had to learn on their own. Figure 8 shows the number of nodes and causal links that students included in their nitrogen cycles that corresponded to the expert solution (which the students never saw). The Teach condition did better than the Tutor condition. They had been in a teaching role earlier (rather than a "being tutored" role), and hence, they had developed some important competencies (plus confidence) to learn independently. Figure 8 also shows that the Teach + Coach condition did the best at transfer. When learning about the oxygen cycle, these students had received some guidance in how to use resources productively and how to think about the quality of their map. This guidance transferred to learning about the nitrogen cycle. On the transfer test, the Teach+Coach students were even more prepared than the Teach students to use the resources to produce their concept map and improve their learning.

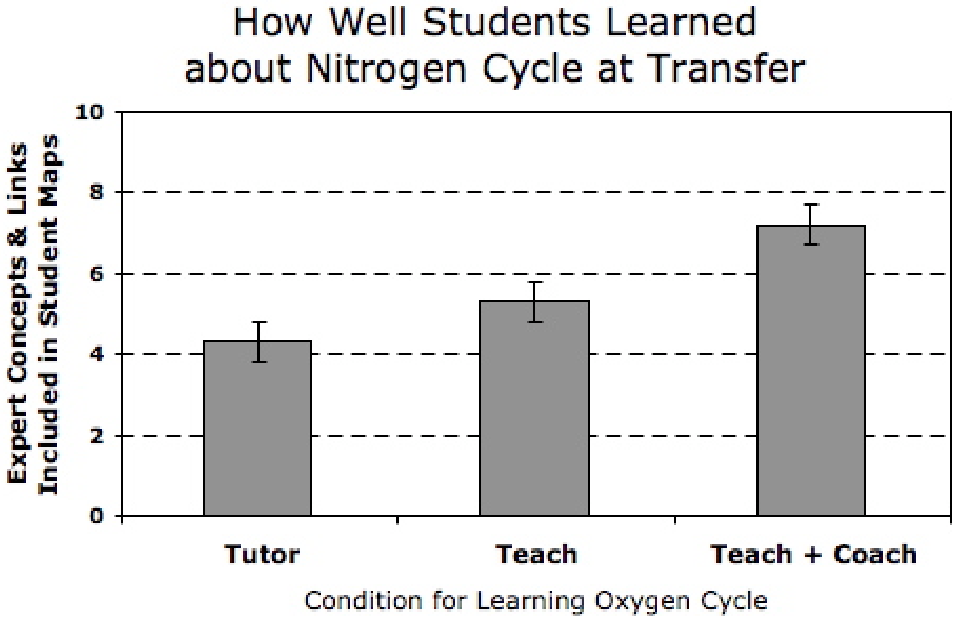


Figure 8. Student performance on a delayed PFL assessment. During initial instruction, the students created a concept map of the Oxygen cycle in one of the three conditions. The question the graph answers is which initial instruction condition best prepared students to learn about the Nitrogen cycle several weeks later without any help. During the initial instruction, the Tutor condition told students if what they entered was right or wrong. In the Teach condition, students asked Betty to answer questions and received feedback on the quality of those answers. In the Teach+Coach condition, there was an intelligent coach that provided suggestions for how to use resources and evaluate Betty's knowledge.

Our interpretation of the Biswas et al. study is not that tutoring is bad for students and learning by teaching with the help of a coach is always superior. There is a wealth of information showing the positive benefits of sophisticated tutoring programs, including the use of real tutors (e.g., Bloom, 1984) and computer tutors (e.g., Koedinger, Anderson, Hadley, & Mark, 1997). Our main point is that a switch from SPS assessments to PFL assessments suggests that some kinds of skills and knowledge may be shortchanged if students' total set of educational experiences involve only "sitting at the feet" of a mentor or tutor.

4.0 Innovation and Efficiency

The preceding examples emphasized initial instructional activities that developed students' interpretive knowledge so they could learn subsequently. That discussion could easily be interpreted to suggest that we place little value on the replicative and applicative aspects of knowing and, instead, mainly encourage the interpretive. However, this is not what we intend to convey. Instead, we believe that educators need to combine the replicative, applicative and interpretive to realize the kinds of outcomes that most educators and parents want students to achieve.

Recently, we have begun to think through the trade-offs and benefits of combining instruction for replicative, applicative, and interpretive knowing. In doing so we realized that we, and perhaps others in the field, had been conflating two dimensions of learning in instruction and assessment. Figure 9 shows these two dimensions. One dimension emphasizes efficiency, the other innovation. Sometimes these two dimensions are characterized as mutually exclusive ends of continuum (e.g., high and low road transfer, Salomon & Perkins, 1989) and as we describe below, they can indeed conflict and this is something that needs to be understood. However, because there are different processes involved, they are not necessarily exclusive of one another. Adaptive experts, for example are presumably high on both dimensions (e.g., Gentner et al., 1997; Hatano, & Inagaki, 1986).

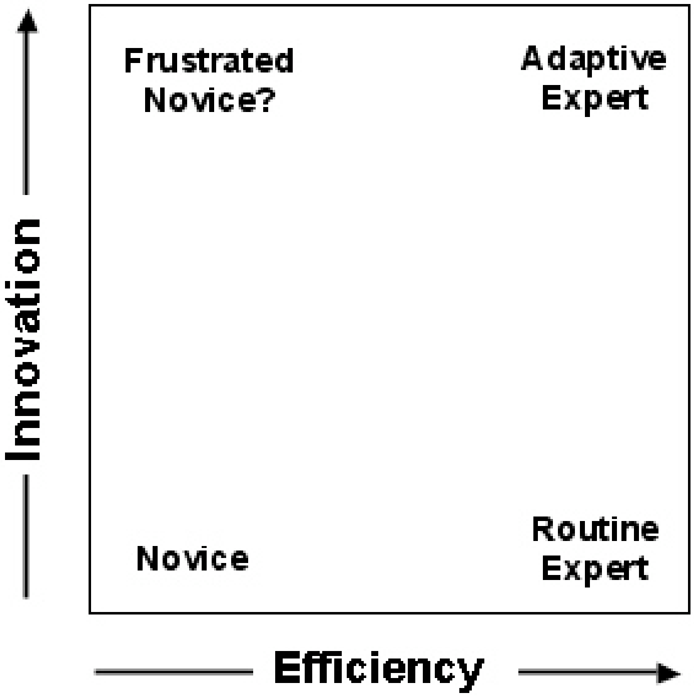


Figure 9. Two dimensions of learning and transfer: Innovation and efficiency.

4.1 Efficiency.

The horizontal dimension is efficiency. People who are high on efficiency can rapidly retrieve and accurately apply appropriate knowledge and skills to solve a problem or understand an explanation. Examples include experts who have a great deal of experience with certain types of problems; for example doctors who have seen many instances of diseases in many different people or who have frequently performed a particular type of surgery. They can diagnose and treat a new patient quickly and effectively. When choosing a surgeon for a particular procedure, many potential patients wisely ask, “How many of these have you successfully performed previously?”

Efficiency seems to be important in all domains. It includes a high degree of consistency (lack of variability) that maximizes success and minimizes failure. Business programs like Six Sigma provide a good example of how efficiency is relevant to organizations as well as to individuals (e.g., Pande, Neuman, & Cavanagh, 2000). Six Sigma consultants attempt to help businesses reduce variability in production processes as much as possible while keeping the mean at a level of “high standards.”

We believe that most of the research in education and training has been focused primarily on efficiency outcomes. This is especially true in America. Piagetian theorists have often expressed amusement when asked what they call the “American question” of “how do we get kids to progress through the developmental stages more rapidly?” This is an efficiency question that fits the American emphasis on pragmatism and “do it now.”

Researchers who study both people and organizations have learned a great deal about promoting efficiency. At a general level, probably the best way to be efficient is to practice at tasks and gain experiences with important classes and components of problems so that they become “routine” and easy to solve later. The best way to ensure transfer is to “teach for it” so that the problems people encounter on a test or in an everyday environment can be solved with high frequency because they are quite close to what has been learned previously. Transfer problems essentially disappear if we teach in contexts where people need to perform, and if we arrange experiences and environments so that the correct behaviors are driven by the environment.

There are ways to practice solving problems that are excellent from an efficiency perspective. Appropriate kinds of practice help people turn non-routine, difficult-to-solve problems into routine problems that can be solved quickly and easily. Phrased another way, efficiency-oriented practice is often about "problem elimination" rather than about in depth, sustained problem solving. A problem is typically defined as a gap or barrier between a goal state and one's present state (e.g. Bransford & Stein, 1993; Hayes, 1989; Newell & Simon, 1972). By preparing people so that the problems they will face in life are essentially routine problems—or at worst very "near transfer" problems—the gap between goal states and present states is either eliminated or made to be very small. This allows people to perform quite effectively.

All of this works well provided the environments for which we are preparing people are "good environments" (e.g. based on strong human values and ideal working conditions) that are stable and do not need improving. As people like Fullan (2001) and Vaill (1991) argue, however, we are living in a "whitewater world" where change is the norm and not the exception. Because efficiency is so emphasized in our time-limited society, it tends to take over as a prime way to assess progress. But, there are also potential downsides of an overemphasis on efficiency. This is where an emphasis on innovation comes into play.

4.2 Innovation.

Experimental studies show that efficiency can often produce "functionally fixed" behaviors (e.g., Luchins, 1942). Similarly, Hatano and Inagaki (1986; Hatano & Oura, 2003) discuss "routine experts" who become very good at solving particular sets of problems but do not continue to learn throughout their lifetimes (except in the sense of becoming even more efficient at their old routines). These potential downsides of an over-emphasis on efficiency (especially in the face of change) make it especially important to attempt to reconceptualize learning and transfer as something more than the ability to apply previously acquired skills and schemas efficiently for routine problem solving.

Our argument is not to eliminate efficiency but to complement it so that people can adapt optimally. In short, we assume that efficiency does not have to be the enemy of innovation and creativity (e.g. Bransford & Stein, 1993). For example, it is well known that efficiency in some processes (e.g. learning to drive a car, learning to decode written words and sentences) frees attentional capacity to do other things (e.g., talking while driving, reading for meaning, Atkinson & Schiffrin, 1968; LaBerge & Samuels, 1974). Similarly, if people, confronted with a new complex problem, have solved aspects of it before, this helps make these sub problems routine and easy to solve. This frees attentional bandwidth and enables people to concentrate on other aspects of the new situation that may require non-routine adaptation. A major theoretical challenge is to understand how efficiency and adaptability can co-exist most effectively. An important step in meeting this challenge is to better understand the dimension of innovation.

People who are optimally adaptive can rearrange their environments and their thinking to handle new types of problem or information (e.g., Hatano & Inagaki, 1986; Hatano & Oura, 2003; Spiro, Feltovich, Jacobson, & Coulson, 1991). As others have argued, innovation and adaptability "favor the prepared mind." From our perspective this means that people need to acquire the kinds of well-organized, fluently-accessible sets of skills and knowledge that are represented on the efficiency dimension. However, we think it is especially important to note that innovation often requires a movement away from what is momentarily most efficient for the individual or the organization.

Wineburg (1998) provides a powerful example of resistance to "efficient over-assimilation" in a study involving history experts and college students. He asked historians who had expertise in a particular domain (e.g. Asian history) to solve history problems that, for them, were non-routine because they came from an unfamiliar domain of American history. The problems involved interpreting some complex decisions made by Abraham Lincoln. The history experts were much more likely than college students to resist making assumptions that readily came to mind based on knowledge of their current culture. The experts realized that these assumptions were indeed coming from their current cultural context rather from the context at the time of Lincoln. They therefore took the time to research these issues to learn what they needed to know to solve the problem. In contrast, the college students went merrily on their way building confidently on a set of very flawed assumptions that came from their current knowledge of the world.

Above, we discussed Burgess's Eagle Challenge and noted that a group of principals thought about a number of possible "wrong" analogies that might help solve the Eagle Challenge (e.g. analogies to releasing wolves into the wild). However, they considered these ideas to be conjectures only, and they realized the need to learn more about the subject by asking relevant questions and searching for information (either through technology or their social networks or both). Lin's (2001) study of a Chinese teacher who carefully and thoughtfully changed her teaching practices to accommodate to a new teaching artifact is also an excellent example of a movement away from efficiency towards adaptation.

The importance of resisting one's initial ideas about a problem or challenge was discussed by Land (1982), inventor of the Polaroid Land camera. With tongue in cheek, he described the processes of innovation (and the insights that precede it) as involving "the sudden cessation of stupidity." The stupidity comes from one's initial framing of problems—framings that contain assumptions that "put people in a box," or more technically, constrained the problem spaces within which they work. (e.g. Bransford & Stein, 1993; Hayes, 1989; Newell & Simon, 1972).

As an illustration, consider an example discussed by Adams (1979). He notes that, many years ago, a group of Engineers tried to design a mechanical tomato picker that was less likely to bruise tomatoes. They did a lot of tinkering but did not make great breakthroughs. Later a group of botanists entered the picture and helped them reframe the problem. Instead of designing a mechanical picker that was less likely to bruise tomatoes, a better strategy might be to design a tomato that was less likely to be bruised. This reframing opened up a number of new possibilities for thinking, and the group eventually engineered a new type of tomato with a thicker, less easily bruised skin.

The importance of inhibiting "off the top of the head" processes is also illustrated by Brown and Kane's (1988) study where they taught young children to look for analogies between instances. Children saw pairs of analogical situations and were guided to notice the analogy so they could use it to solve a subsequent problem (e.g., stack objects on top of each other to be able to reach higher). Rather than simply relying on high frequency "top-of-the-head" reactions to instance pairs, such as temporal associations and obvious causal relations, the children were helped to add a simple "learning by analogy" routine to their cognitive repertoire that allowed them to think about pairs of new instances in a new (for them) manner. To learn to think analogically in this setting, the students had to “move away” from their maximally efficient processing—they had to inhibit saying the first thing that came to mind, and instead, look for more abstract analogies between sets of familiar items that they saw. Feuerstein and colleagues (1979) note that many people have difficulty questioning the first thoughts that come to mind and hence are less likely than others to experience the “sense of disequilibrium” (Piaget, 1953; 1970) that provides an impetus for questioning current assumptions and “letting go” when necessary.

Overcoming the “pull” of efficient access to current knowledge and assumptions is not an easy task, and an over-emphasis on efficiency can be damaging in the long run. For example, the present authors have encountered doctoral students who rushed through their graduate careers. Their quest for efficiency (e.g. “Just tell me what to do for a thesis and I’ll do it”) interfered with their chances for developing novel knowledge for the field and ended up hurting their abilities to generate studies and help their own doctoral students once they became professors. Similarly, business executives who have worked with efficiency programs like Six Sigma have remarked to us that it can hurt the level of innovation in a company if it is applied unthinkingly across the board. A college football coach had the following to say to incoming freshmen players: “We have to make you worse before we can make you better.” Musician friends of ours have talked about their frequent need to break free of well-learned routines so that they can move to a new level of playing ability. As noted earlier, innovation is often preceded by a sense of disequilibrium that signals that certain processes or ways of thinking (e.g., previously learned routines) are not quite working properly. At other times, new ideas may simply emerge from interactions with tools and people without a prior sense that something was wrong or needed to be fixed.

4.3 Balancing Efficiency and Innovation

From the perspective of learning theorists interested in education, Figure 9 becomes especially useful when we ask how we can move people along both of its dimensions. Movement along one dimension alone is unlikely to support the kinds of "preparation for future learning" (PFL) transfer that we and others envision. As already discussed, training dedicated to high efficiency can restrict transfer to highly similar situations. On the other hand, opportunities to engage in general, content free skills of critical thinking or problem solving appear to provide a set of flexible "weak methods" (Newell & Simon, 1972) that are too inefficient for the large problem spaces found in many real-world tasks. If we ask ourselves about the overall effects of K-16 curricula, our reading of the literature suggests that it will not work to give students a set of efficiency oriented, content-filled tasks that follow the horizontal axis of Figure 9, and a separate set of strategy-training tasks that fall along the vertical axis. It is not enough to expose students to content courses and separate thinking courses and then help students integrate them in a "capstone" course at the end of some educational program. This could be somewhat helpful, of course, but the conjecture is that it is far from ideal. In their writings on adaptive expertise, Hatano and colleagues (Hatano & Inagaki, 1986) suggest that the long-term processes by which one is helped to develop expertise are critical for the desired outcome.

We also believe that many people (ourselves included) who have attempted to teach thinking and problem solving have fallen into the efficiency trap of teaching routines for thinking and problem solving. There are a host of useful and sophisticated problem-solving routines (e.g., using fractionation to break away from old habits, using mind maps, etc). Nevertheless, they still are often taught as script-like, mechanical routines—often because this is the only way to show effects when they are assessed through the efficiency-oriented lenses of applicative (SPS) problem solving. As noted earlier, efficiency and applicative problem solving are good things, so there is nothing wrong with thinking skills courses that attempt to help people apply sets of high-level routines efficiently to solve various problems. But this is often accompanied by an under-emphasis on the innovation dimension and what it might mean to help people learn to break free of old routines and discover new ideas on their own.

Assessments of the sorts of "learning innovation" we have in mind differ from "content-lite" tests of creativity or insight problem solving. We assume that innovations relevant to learning arise from useful content knowledge (plus dispositions) that people can transfer in, and therefore PFL assessments of innovation are highly relevant. For example, Schwartz and Martin (2004) asked high school students to innovate their own ways to measure the consistency of different phenomena (e.g., determine the reliability of a baseball-pitching machine). Afterwards, students received a lecture on a standard, efficient method for computing variability. Of particular interest was whether these learning experiences, which took a few hours, would prepare students to innovate solutions to highly novel problems. To find out, a subsequent test included a problem that required working with bi-variate data. During instruction, students had only learned about working with univariate data, so determining co-variance would require innovation. At posttest, 34% of the students invented a way to innovate a measure of covariance.

Though this is far below 100% innovation (it is a difficult task), it is a high level compared to the performance of "top-20" university students who had recently completed a full semester of statistics. Only 12% of the college students created a workable solution. The point here is that it seems unlikely that the high school students had more sophisticated, content-free techniques for innovation than the college students did. Instead, the high school students had developed an understanding and stance towards the topic of variability that prepared them to be innovative.

We suppose that an important way to foster innovation is to provide students with opportunities to be innovative and interactive within a domain. We say, "suppose," because many of the educational efforts at cultivating innovation and inquiry have used efficiency, SPS measures to assess outcomes, so it is difficult to know whether these innovative experiences work. In the studies above on teaching psychology and statistics, students explored data and innovated their own representations, but by themselves, these activities did not provide evidence of learning using SPS assessments. It was only the PFL assessments that included opportunities for subsequent learning that revealed the value of the instruction.

Innovative interactions are different from interactions dedicated to efficiency, where one repeats a behavior to tune speed and accuracy. Innovative interactions involve reaching beyond the immediately known. People often do not know what the final goal state will look like at the outset. Interacting with other people, and with artifacts, is a powerful way to accelerate the development of innovation. For example, Bransford & Stein (1993) note how a number of everyday inventions have evolved as people used them and saw what needed to be changed. If the inventors had never tried to use the initial inventions in their target contexts, the information necessary for new thinking would have been less likely to arise. This, of course, is not to say that innovation cannot also occur in moments of quiet reflection. But even in these cases, there are usually prior experiences that fostered a disequilibrium or curiosity that only got worked out later. Designing environments for innovation requires providing an opportunity for people to test out ideas and let go when necessary, and for providing interactions that can reveal new information and orient learners to notice it.

4.4 Innovation, Efficiency and Adaptive Expertise.

As noted earlier, we believe that it is important to balance efficiency and innovation in instruction. The possibility of achieving this balance is highlighted by Hatano and colleagues' work on adaptive versus routine expertise. Our educational conjecture is that people will benefit most from learning opportunities that balance the two dimensions. For example, children who receive nothing but efficiency-oriented computation training in mathematics may well become efficient, but this kind of experience will lead to limited capabilities in the face of new problems. Balanced instruction would include opportunities to learn with understanding and develop their own mathematical conjectures as well as become efficient at computation. Instruction that balances efficiency and innovation should also include opportunities to experiment with ideas and, in the process, experience the need to change them. We believe that these kinds of experiences often require opportunities to interact actively with artifacts and people. As Vygotsky (1987) pointed out, some forms of knowledge arise only through interaction. However, balancing innovation and efficiency requires special kinds of interactions—not just any kind.

We have found it helpful to disentangle innovation and efficiency to make headway on thinking about their combination. For example, the in situ literature has been particularly interested in interaction, both social and physical. Guitierrez and Rogoff (2003) discuss how in situ theorists think about learning:

> "A central and most distinguishing thesis in this approach is that the structure and development of human psychological processes emerge through participation in culturally mediated, historically developing, practical activity involving cultural practices and tools." p. 21

When in situ theorists have applied this vantage to the topic of transfer, we have found that they are sometimes discussing interactions that facilitate efficiency and at other times interactions that result in innovation—but often these two different dimensions are not as differentiated as they should be. For example, we noted earlier that one argument has been that it is more efficient to build resources into the environment than to expect people to transfer abstract ideas across contextual boundaries. This is an argument that focuses on efficiency. We recall a discussion with a scientist who had worked with the military and concluded that it was cheaper to engineer simpler tasks compared to the expense of training millions of enlistees for complex tasks. Similarly, work on distributed cognition emphasizes how specific environments permit people to offload their cognitive burden to the environment (Kirsch & Maglio, 1994). Work on apprenticeship points to the value of instruction built into the ultimate activity structure. Many cognitive theorists also emphasize efficiency. For example, Barnett and Ceci (2002; this volume) point to six dimensions of similarity that increase the efficiency with which people will transfer across contexts, and Anderson, Reder, and Simon (1997) argue for the value of developing component skills that are likely to resemble the skills needed in the ultimate application context.

A second argument from in situ theorists has concerned innovation, particularly in situations of intellectual repair (e.g., Hutchins, 1995; Winograd & Flores, 1984). Suchman (1987), for example, argued that no amount of planning or pre-existing knowledge can anticipate the breakdowns that always arise during interactions, and therefore, it is important to understand how people construct new meanings in situations of breakdown. Similarly, Carraher and Schliemann (2002) argue that children are able to learn new concepts that could not have arisen from the direct application of prior knowledge.

These are compelling counter-arguments against an "efficiency-only," direct application approach. However, being counter-arguments, they have not typically considered how to prepare people to learn through innovation. We concur that efficiency, in the form of knowledge that can be readily and repeatedly applied, is insufficient for innovation, but it is nevertheless an important ingredient. A world of constant change—with no invariant procedures, norms, or routines that can be directly applied to living and problem solving—is probably a world in which no humans could survive.

Ball and Cohen (1999) make a valuable innovation argument in their discussions of teaching:

> “This perspective views teachers’ capacity not as a fixed storehouse of facts and ideas but as a source and creator of knowledge and skills needed for instruction.” p. 6

Similarly, Sawyer (2003) distinguishes "scripted teaching" from teaching as "disciplined improvisation". In both of these accounts of teaching, there is implicit acknowledgement that being appropriately innovative requires the development of automatized schemas and routines that provide enough background efficiency to keep teachers from becoming overwhelmed and losing site of important goals. However, if teachers have simply learned these automatized routines "by rote" (e.g., in a scripted manner) they will not be prepared to be the kinds of adaptive experts who will continue to meet the needs of students and learn and improve over time. (e.g. CTGV, 2000; Judd, 1908).

Thelen and Smith (1994), in their advocacy of viewing child development within a dynamic systems framework, make a strong case for innovation:

> “Remember that the premier developmental question is how organic form is created—the emergence of *novelty and complexity* in structure and function. Invoking any prior plan *within* the organism leads to an infinite regress.” p. xv

We too believe that prior plans, whether learned or built into the system, are insufficient to account for innovation or novel learning. People need to interact with resources for learning and innovation, even if that innovation occurs later in a quiet moment of reflection. At the same time, efficient prior knowledge (regardless of the specific theoretical formalism used to characterize it) is important for seeding the sparks of innovation. We believe that a major challenge for the field is to balance our accounts of learning and transfer by considering both efficient and innovative processes.

A study by Martin and Schwartz (2004) provides an illustration of the need to focus on balance. They asked 9-10 year-old children to solve fraction equivalence problems. For example, children had to indicate 1/4 of 8 of pieces. In one condition, the children saw pictures of pieces, and they had to circle the correct number of pieces to show the answer. In this condition, children typically transferred in a whole quantity interpretation instead of a ratio interpretation; for example, they circled one piece to indicate one-fourth. The children applied the interpretation that had been highly efficient for their many prior experiences of counting, adding and so forth. But in this case, it was maladaptive. In the interactive condition, the same children received pieces that they physically manipulated. In this condition, the children managed to reinterpret the pieces. By collecting the pieces into piles and pushing them around, they began to see the pieces as groups that could be counted in their own right. For example, they came to reinterpret two pieces as one group, which enabled them to eventually count out four groups and solve the problem of finding 1/4. When the children moved pieces physically, they were correct nearly three times as often as when they could not, regardless of condition order. Interestingly, when the pieces were pre-grouped for the children (e.g., four groups of two pieces), they still did better when they could move the pieces around compared to just looking at them.

The interactive experience of moving the pieces seemed to help the children let go of old efficient interpretations and see new structures. But, it would be a mistake to assume they did not also apply other efficient schemas to help discover the new structures. When the children moved the pieces around, their schemas enabled them to repeatedly count pieces and groups, and to interpret groups of equivalent size as better than groups of different sizes (which led them to make four groups of equal size).

4. 5 A Hypothetical OAC (Optimal Adaptability Corridor).

The preceding discussion leads us to believe that the modified illustration in Figure 10 may be helpful for thinking about the kinds of educational experiences that fit the goals of the superintendents discussed at the beginning of this paper. This figure shows a hypothetical optimal adaptability corridor, or OAC, for the development of adaptive expertise. Its function is to help insure that innovation and efficiency develop together. For example, in the preceding studies on teaching psychology and statistics, the most successful combinations included both opportunities for innovation (e.g., inventing statistics to solve problems) and opportunities for learning efficient solutions invented by experts.

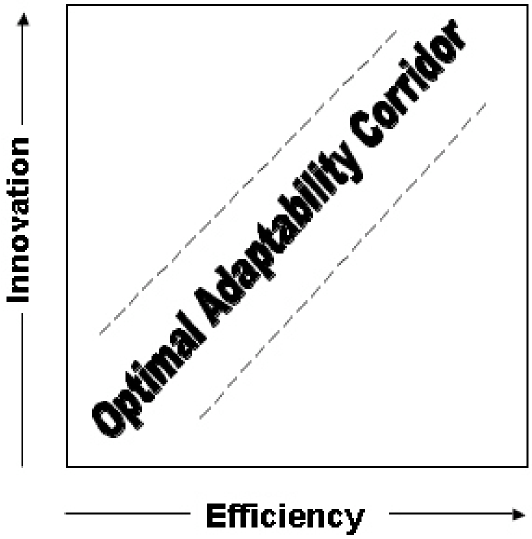


Figure 10: Balancing efficiency and innovation in learning. Is the development of adaptive expertise cultivated by instruction that stays within the Optimal Adaptability Corridor (OAC)?

The presumed outcomes of keeping educational experiences within the OAC involves what Hatano and Inagaki (1986) called "adaptive expertise." Within their base domains, both routine experts (who at the extreme would be trained only along the efficiency dimension) and adaptive experts (whose experiences would tend to fit within the corridor) are highly efficient at solving a number of problems that have become routine for them. However, given a highly novel problem within their domain, or a problem within a new domain, only the adaptive experts can utilize their existing knowledge and practices to learn with the resources at hand. We noted earlier that Wineburg's (1998) studies of historians who were asked to solve problems about areas of history where they were not experts provides an excellent illustration of this kind of performance. Notably, Wineburg used what we call PFL assessments because he provided the historians with resources for new learning. This kind of assessment was necessary to reveal their adaptive expertise.

If we think of the OAC as extending developmentally over a range of ages, young children will typically fall at the low/low end of the vertical and horizontal dimension (we do not, however, assume that young learners are "blank slates" – see NRC,2000). If we assume that both efficiency and innovation are important, the question is how to balance the two. A study by Martin and Schwartz (2004) provides an example of research that looks at different trajectories through the corridor and their effects on transfer. In this study, children learned to manipulate pieces to help solve fraction addition problems over three days. One group of children learned with pie pieces (half pieces in pink, quarter pieces in yellow, and so on). The other group learned with simple tiles of equal size. Both groups received feedback and models of solutions when needed.

Overall the children in each condition learned at the same rate. However, Martin and Schwartz thought the pie pieces might have some detrimental effects for subsequent learning. When looking at pie wedges put together, it is easy to interpret them as part of a whole (e.g., as in a pizza missing one slice). The interpretation of "wholeness" is built into the environment, given people's natural perceptual proclivities. In contrast, when looking at several tiles, it is harder to interpret them as part of a whole. To learn to work with the tiles, children had to innovate new interpretations of the pieces so they were no longer just units; they were also parts of a whole. Thus, the tile students would have a leg-up on the innovation dimension, whereas the pie students would have a leg-up on the efficiency dimension.

To determine whether these different initial experiences had an effect on their learning trajectory at transfer, students in each condition solved problems using new materials at the end of each day. For example, they had to solve problems with beans, which are analogs of tiles. And, they had to solve problems with bars, which are analogs of pies (they come in different lengths colored to indicate whether they are one-fourth, one-half, and so on). The problems the children had to solve were of the same type they had successfully solved earlier in the day when working with the tiles or pies. Thus, the study made sure that the transfer problems were types the students had already learned to solve with their base materials.

Figure 11 schematizes the resulting trajectories through the innovation by efficiency space. For each transfer problem, there were two types of correct performance. One performance was whether children gave the correct verbal answer to a problem. This is an efficient response, because it is the right answer. The other correct performance occurred when children created a correct physical arrangement of the pieces. This is an innovative response, because the children were adapting the physical environment in new ways to help solve the problem. Children could give an efficient verbal response without arranging the pieces correctly, and they could arrange the pieces correctly without knowing how to interpret them verbally. The figure schematizes the changing proportions of correct innovative and efficient responses over the three days. One may see that the tile students accelerated along the innovation dimension at first and then increased in efficiency. The pie students accelerated along the efficiency dimension at first. Thus, the manipulation of asking the students to learn with tiles or pies affected movement through the space.

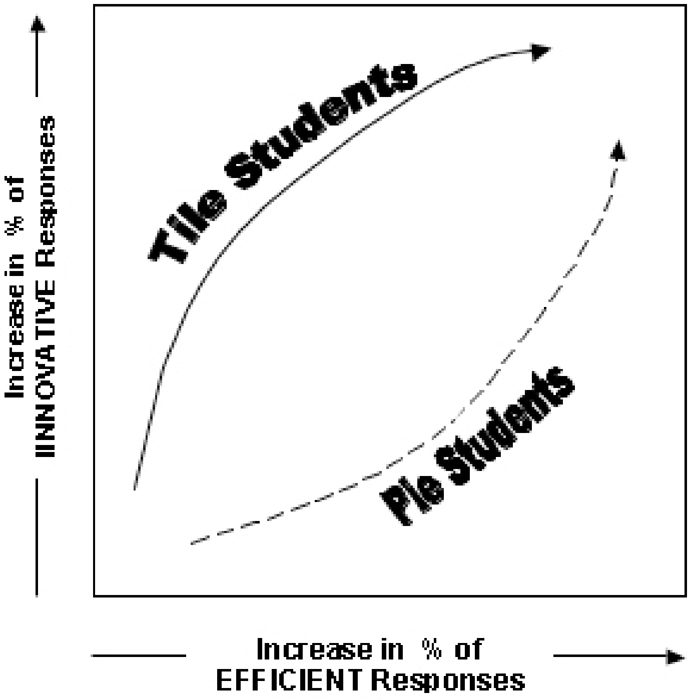


Figure 11. Trajectories of learning at transfer for students who initially learned fraction addition using pie wedges or tile pieces. At transfer, students had to solve fraction problems using new materials (e.g., beans or bars). Correct innovative responses adapted the new materials into useful configurations. Correct efficient responses gave the right verbal answer. Over time, the students who initially learned with tiles exhibited a better ability to adapt the novel materials, showed more stable progress, and ultimately became more efficient than students who initially learned with pies and were more efficient at first (Martin & Schwartz, 2004).

The important finding was that the pie students who exhibited more efficiency at first were actually on a much less stable trajectory. They often got stuck in the space and did not progress, and even when they made progress, they often regressed on the next day. For example, over 50% of the time a pie child reached the upper-right quadrant of "adaptive expertise," he or she regressed on the next day making both incorrect physical arrangements and incorrect verbal answers. In contrast, the tile students demonstrated a very stable trajectory. They rarely got stuck and tended to do better on each successive day. Moreover, they did not regress. For example, when students reached the upper-right quadrant, less than 15% regressed by making an error the next day. Based on this initial study, it appears that early innovation yields better adaptability in the short run and better efficiency in the long run in transfer situations. Needless to say, there is much more research to do on the concept of the OAC.

5. Summary and Future Directions

We began this chapter by describing a common goal among several superintendents. They want graduates from their schools to be in a position to learn and make their own decisions. Having some expertise in the topic of transfer, it was disappointing to us that the transfer literature could not be more helpful in explaining whether this is possible or how to encourage it. The problem is not simply that there is a shortage of experimental research on transfer, or even a shortage of field research that examines transitions from school to work and life. Multiple researchers have looked at the effects of schooling on transfer to everyday situations, often with gloomy results. The problem is that transfer research has not developed a set of constructs or methods suited to addressing the superintendents' concerns. Most of the research on transfer has examined sequestered problem solving in contexts that require the ability to directly apply old knowledge to solve new instances of problems. This is very different from asking if people have been prepared to learn to solve novel problems and engage in other kinds of productive activities. Thus, most transfer-inspired methodologies cannot detect whether school prepares people to learn more effectively than if they had not had school experiences, and hence cannot address the concern of the superintendents.

To develop our ideas, we divided the chapter into four sections that focused on the following goals:

1. Rethink the classic definition of transfer and show how it tends to produce assessments that make people "look dumb" rather than "look smart" (e.g. Norman, 1993). We used Burgess's Eagle Challenge to illustrate how 5th-graders, college students and experienced principals appeared to have very different sets of competencies when we began to move from SPS assessments to those that approached PFL.

2. Differentiate "transferring in" to situations from "transferring out" of them. Failure to clearly differentiate these two examples of transfer can help clarify why some people think that transfer is ubiquitous (their focus is on "transfer in" for learning) whereas others find it to be rare (their focus is on "transfer out" to SPS problem solving). We also noted that Broudy's analysis of three kinds of knowing (replicative, applicative and interpretive) have important implications for thinking about the kinds of "transfer in" that can affect "transfer out."

3. Discuss studies which show that new ways to think about transferring "in" to and "out" can reveal advantages of a variety of interactive instructional techniques that

remain hidden when we use more traditional measures. We discussed three different studies where we were able to control the kinds of learning experiences available to participants. Measures of PFL transfer were critical for revealing the impact of these experiences.

4. Propose a tentative learning and performance "space" that differentiates two dimensions of transfer – innovation and efficiency – and argue for the possibility of an OAC (Optimal Adapatibility Corridor) that balances innovation and efficiency and produces trajectories towards the kinds of adaptive expertise that have been discussed by Hatano and Inagaki (1986). We also provided an example of what research might look like that explores optimal trajectories of learning and development through the innovation-efficiency space. And, we noted that the concept of OAC has just begun to be explored.

We believe that it will be especially useful for the field to explore the separation between activities that support efficient problem solving versus those that support novel learning and innovation. Most of the transfer research has examined efficiency, or how quickly and accurately people can remember and apply appropriate knowledge in a new context. We acknowledged that this is a very important dimension of learning and transfer. At the same time, efficiency is not the only thing that the superintendents were after. They wanted their students to adapt to new situations, learn, and make reasoned decisions. We pointed to the literature on adaptive expertise as an example of instances where people are both efficient and innovative. This literature distinguishes (a) experts who can solve routine tasks efficiently, often using specialized tools, and (b) experts who can adapt to novel situations and learn. This ability to adapt has a number of features that separate it from efficiency. For example, it often requires “letting go” or “holding lightly” solutions and interpretations that are efficient in other contexts. And, it often involves actively interacting with people, tools and environments to discover gaps and misalignments in one’s knowledge that need to be reconciled, as well as gaining access to new structures, interpretations, and forms of interaction. But, adaptive expertise involves efficiency too.

We proposed an optimal adaptability corridor (OAC) that combines innovation and efficiency. We doubt that instruction that emphasizes one or the other will be optimal, and we doubt that separate courses of instruction in each will work well either. Instead, we hypothesized that it is important to interleave activities that promote innovation and efficiency. We further offered the tentative claim that for early learners (novices), innovative experiences may be particularly important. Among other things, they help learners develop new interpretations instead of assimilating new experiences to old ways of thinking. We provided some initial evidence showing that trajectories that favor early innovation lead to superior transfer and ultimate efficiency when working with new situations.

We suspect there are very many mechanisms that come into play during innovative, interactive experiences that can prepare people to learn. For example, some forms of information, like joint attention to new situations, only arise in interaction (e.g., Barron, 2003), and therefore, cannot be adequately experienced without interactions. The choice of people with whom one interacts to solve problems (e.g., people with diverse sets of ideas and experiences versus “like-minded” individuals) will also affect opportunities for innovation. Similarly, collaborative tasks that emphasize design and invention may pull for the sharing of ideas compared to "right answer" tasks that lead to a partitioning of labor. We are not in position to enumerate or empirically defend the many possibilities. Rather we suggest the potential value of thinking about a corridor that combines innovation and efficiency during learning. We also believe that distinctions between innovation and efficiency might help clarify many confusing debates in the literature. For example, some arguments between in situ theorists and "standard" cognitive theorists focus primarily on efficiency. This includes arguments that teaching in context is good because it removes the need for transfer. Other arguments between in situ theorists and "standard" cognitive theorists involve the nature of knowing and how new ideas are discovered in the context of interactions with tools, data and others. By separating efficiency arguments from innovation arguments, these two fields might make better progress in exploring their similarities and differences in understanding how people learn—including how we can help people become better prepared for future learning.

We end by discussing an issue that seems particularly important for further investigation and builds on our repeated observation that standard methods of assessment miss important forms of knowing and transfer that educators should care about. The issue stems from the fact that most high stakes assessments of student learning are sequestered problem solving assessments that tap the replicative and applicative aspects of knowing. We have argued that these assessments can be valid indicators of certain kinds of efficiencies, for example, basic reading and literacy abilities. But, they may vastly underestimate the abilities that people may have to <u>learn</u> about new areas of inquiry or to innovate. Elsewhere (Bransford & Schwartz, 1999), we discuss Feuerstein

(1979) and colleagues' work on dynamic assessments (a form of PFL assessments) and note that one can get very different pictures of people's competencies given dynamic rather than static assessments. New technologies make it possible to conduct large scale assessments of people's abilities to learn to solve new problems (dynamic assessments) rather than simply assess what they can do given SPS tests.

To help start a discussion of PFL "high stakes" assessments, we have been working towards models of dynamic assessment that can serve both formative and summative goals, that can tap both efficiency and innovation, and that can work on either small or large scales. We call them "working smart" assessments. Students learn about the general goal of efficiently solving a future set of recurrent problems. In preparation for this meeting this goal, they are encouraged to innovate "smart tools" that can help. Graphs, charts, spreadsheets, computer simulations, social networks, norms for distributed expertise, and a host of other resources are candidates for "working smart" (e.g., Pea, 1993). Working smart assessments combine the dimensions of innovation and efficiency shown in Figure 9.

The original impetus for having learners create tools for working smart arose in the context of an implementation study in which schools from nine different states were using the Jasper Adventure Series (e.g. CTGV, 1997). Jasper Adventures are video-based narratives that create a story context for anchoring sustained mathematical problem solving. Although it is hard for us to believe in retrospect, the Internet was not in the public consciousness at this time. Therefore, we used video satellite connections to create a "Challenge Series" where classes and schools from different states would try to solve problems posed over the television. The problems were “what if” analogs that varied specific quantities and constraints of the original Jasper problems they had solved.

The Jasper Challenges were exciting for students, teachers, parents and community members, but we kept running into a nagging problem. The goal of the Jasper series was to encourage deep and innovative thinking (there is lots of room for innovation under constraint when solving Jasper problems). However, our satellite challenges were time limited and required fast, efficient thinking. This was a mismatch that bothered us for some time.

Eventually we came up with the idea of Working Smart Jasper. For this to work, we modified the task context surrounding the Jasper Adventures. For example, in one Adventure called, Rescue at Boone’s Meadow (CTGV, 1997), students had to help Emily rescue a wounded eagle by working out flying time, weight, and gas consumption for an ultra-light plane. We modified the task context to help students learn to “work smart.” Students had to help Emily run a rescue and delivery service that involved three ultra-light planes that could carry different payloads, flew at different speeds, and had different degrees of fuel consumption. The students had to help clients of Emily’s company figure out travel times to and from specific regions, costs, and so on. In the context of their imaginary job, students confronted sets of what we call “quasi repetitive activity structures” (QRACS). In the case of Emily’s company, the QRACS involved answering sets of distance/rate/time and fuel consumption problems that recurred frequently. Solving each problem anew (even with a calculator) is inefficient and error-prone. Ultimately, students learned to develop tools such as graphs and spread sheets that allowed them to work smart and perform much better at answering “clients’ questions” than groups who stuck only with their calculators. Examples are discussed in much more detail elsewhere (e.g., Bransford et al., 1996, 2000; Vye et al., 1998; Zech et al., 1998).

As we wrote this chapter, we became aware that "working smart" assessments represented an excellent way to keep instruction within the OAC and combine emphases on both innovation and efficiency. With the Internet, working smart assessments could become a new model for broad-scale standardized testing, where the goal is to foster students' abilities to innovate and learn to solve significant challenges delivered on-line. For example, individuals, classes, or even random samples from a region could receive a challenge on-line, receive several days to prepare, confront the challenge, revise as needed, complete the challenge again, and so on, with the number of cycles to proficiency being one measure of interest. Additionally, each cycle could use increasingly difficult challenges to gauge student gains throughout the year.

Currently, most high stakes assessments are almost totally efficiency oriented, and we believe that this gives only a partial and often misleading picture of students' capabilities and the value of particular kinds of educational experiences. There is, of course, a great deal of work that needs to be conducted to make working smart and other PFL assessments work effectively. For example, we have focused mostly on the validity of our knowledge assessments, and high stakes testing raises many issues concerning reliability. Nevertheless, we believe that new ways of thinking about transfer suggest new ways of thinking about assessment, and that working smart assessments are one example of a different paradigm that could have major effects on education and accountability.

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