Knowledge Base and Transfer: On the Usefulness of Useless Knowledge

Learning often cannot be translated into a generic form until there has been enough mastery of the specifics of the situation to permit the discovery of lower order regularities which can then be recombined into higher-order, more generic coding systems.

—Jerome Bruner, Going beyond the Information Given

In recent years, acquiring a large knowledge base has been basically ignored in education, replaced by a focus on programs that teach learning strategies, heuristics, and general thinking skills, with a minimal knowledge base required. In short, the focus is on short-cuts to learning. The problem is there are no short-cuts.

Many learning theories are based on laboratory research designed to be either concerned with areas that students are unfamiliar with or, for purposes of research convenience, that ignore knowledge base. But to talk of knowledge base is to talk of transfer, for transfer depends on knowledge base. This is as true for young children as it is for adults. To say that students must acquire a large store of knowledge to effectively engage in transfer may appear commonsensical and too obvious to mention. Yet, this is what the present chapter is all about. If you ask anyone in—or outside—of education whether they think knowledge base is important, the answer will be, “yes, of course.” But the answer is mostly an automatic one with little specific understanding of the profound implications for transfer. In addition, a closer scrutiny typically reveals that the “yes, of course,” refers to a minimal knowledge base. Like answering questionnaires, there is a discrepancy between answers and actual behaviors.

The past 99 years of research on transfer shows clearly that general transfer does not occur in most educational and work situations. I suggest that this
is largely because we have not paid sufficient attention to the role of knowledge in learning to think. The (a) quantity of knowledge one possesses and (b) the way it is organized. I refer to as knowledge base. I define knowledge base quite broadly, to include knowledge acquired by reading, personal experience, careful listening, and astute observing. A knowledge base also includes thinking, for when you think you add to this base.

Accordingly, it's crucial to understand why and in what way a large knowledge base is important for us to become proficient in transfer. I consider knowledge base the absolute requirement not only for transfer but for thinking and reasoning. As one researcher has concluded, it appears that some of what predicts good everyday reasoning is the breadth and depth of the knowledge base. Contrary to most current educational thinking, I believe the research shows that knowledge base is the primary ingredient and absolute requirement for transfer. And lots of it.

The trend in education has been to gain quick fixes with the use of what are thought to be general problem-solving strategies and thinking techniques. This trend has come from a misunderstanding of the ingredients involved in expert problem solving. Historically, experts have been thought to possess special thinking strategies that novices don't have that allowed the experts to solve problems. They don't. There is virtually no evidence showing that experts have access to general problem-solving techniques that novices lack. For general transfer beyond a specific area, still more knowledge is necessary. For transfer to occur, learning must be transformed into a general or generic form, and for this to happen requires a considerable knowledge base. As Jerome Bruner pointed out years ago.

Learning often cannot be translated into a general form until there has been enough mastery of the specifics of the situation to permit the discovery of lower order regularities which can then be recombined into higher-order, more generic coding systems.

In this chapter I will present the general knowledge-base conditions necessary for optimal transfer to occur and explain its importance. Transfer of learning requires more than quick-fix strategies.

As counterintuitive as it may sound, learners must have a knowledge base in a subject in order to even know enough to ask questions about it. It is generally thought that in the absence of knowledge about a subject, questions would be unending. How many times have teachers asked a new group of students, "what questions do you have, before we start," only to wait patiently before a group of blank stares. This is not just a matter of shyness, as Naomi Miyake and Donald Norman demonstrate in a telling piece entitled, "To Ask a Question, One Must Know Enough to Know What Is Not Known." As they point out, although at first glance, one might expect novices to be filled with questions, there are strong theoretical reasons not to expect this. For example, what significant questions could you ask about the implications of Planck's constant? Thus without a sufficient knowledge base, novices do not have a framework within which to formulate adequate questions.

Possessing a large knowledge base enables a learner to think about the subject in depth. McKeachie notes, "I try to teach my students to use 'deep processing.' But if a student knows nothing about a field, it is not possible to go very deep. The conceptual structures are not there." Making a similar observation about teaching, Carl Bereiter says, "What is typically viewed as a failure of knowledge to transfer is actually a failure to teach the conceptual knowledge in the first place." Voss stresses that, "When learning is viewed as transfer, the primary factor influencing learning is the knowledge the individual brings into and uses in the particular learning situation." Frederiksens remarks that although there are some problems, for example, puzzles, that require only a restricted knowledge base, "there is no substitute for having the requisite knowledge if one is to solve a problem. For some kinds of problems, such as engineering the knowledge base is very large." Indeed.

I have known experts in many fields. The proficient and creative ones have always had an extensive knowledge base. I might note that this knowledge base does not necessarily come from a classroom or other formal learning situation. In reading about great innovators, this becomes clear. Stanford Ovshinsky, the inventor of the amorphous metal semiconductor says.

You must have a knowledge of technical subjects, but that does not necessarily mean a formal education. After all, I worked in the field of medicine, was published in medical journals, and I had nothing but a high school and trade school education. However, I am continually learning and educating myself.

The knowledge that one possesses affects the type of mental models that one can construct as well as the type of problems that can even be recognized, let alone solved.

Jacob Rabinow, the electrical engineer and renowned inventor and holder of many U.S. patents, also noted.

An inventor has to be well trained. You're not going to combine ideas if you have none to start with. An amateur can invent very well, but he will invent old junk because he doesn't know what's new. That is one of the tragedies of these self-styled inventors who come to us at the Bureau of Standards with an idea. They're nice people, but they have no training. It's as if they want to write but have never read a book.

Wilson Greatbatch, also an engineer and renowned inventor says.

I firmly believe that a broad background is helpful when it comes to inventing. I give credit for much of what I've been able to do to Cornell University, where I did my undergraduate work, and to the breadth of coursework they gave me in engineering. I had much more chemistry and physics and math than anyone would ever need in order to do just electrical engineering.

Although the old adage "more is better" doesn't often apply, it does apply to knowledge base.

Meaningful learning, then, is dependent upon a base of relevant prior
Knowledge. Thus, as Christine M. Tan notes, "students who are very low in prior knowledge cannot benefit from cognitive strategy instruction. Students who adopt a surface passive approach probably do not have the critical mass of facts necessary for them to use any cognitive strategies." Not only is transfer directly responsible for physical invention, psychological invention is directly responsible for mental transfer. Knowledge base is not only important in fields like engineering but in the creative arts as well. There are those, however—both students and faculty—who believe they can perform great acts of creativity by sheer force of their intellect. Some even avoid acquiring knowledge, believing that it may spoil the purity of their individual creations. This is nonsense, of course. The overwhelming majority of us mortals don't function on the basis of a disembodied intellect. To think well requires something to think about—and again, lots of it.

At this point, I would like to note that just having a knowledge base is not enough. Information by itself does little; it needs to be entered into a prepared cognitive system (see chapter 7). Knowledge often consists of a mass of rote memorized subject matter that is not understood deeply enough to enable a student to think critically about a subject. There are situations, too, where an extremely knowledgeable person can be so well informed about an area that she or he becomes inflexible and is not able to conceive or to consider alternatives. Thus it should be understood that when I use the term knowledge base, I generally refer to an appropriately prepared system of knowledge. Think about it for a moment: If simply entering knowledge into our mental apparatus was sufficient, people who have photographic memories would be brilliant and creative. They're not. At least not any more than the rest of us. This is a simple but paradigmatic example.

There have been two basic reasons for not requiring students to master an extensive knowledge base. The first is that a large knowledge base is thought to be psychologically overloading. The second is that a large knowledge base often complicates controlled laboratory research. Unfortunately, both reasons are often true. The transfer implications are nevertheless severe. Robert Glaser has observed that in programs emphasizing general thinking skills, an avoidance of the complexity of subject matter information is typical. The practical reason offered is that teachers and students would find it difficult to manage and inhibit the thinking processes that need to be practiced and acquired. The significant aspect is that little direct connection is made with thinking and problem-solving in the course of learning cumulative domains of knowledge.

In a later publication, Glaser laments that developmental psychologists—LA Piaget—have devoted little attention to changes in children's knowledge base. Piaget's stage theory has come under severe criticism in recent years and has been all but abandoned by many developmental psychologists, who now conclude that the young child doesn't think all that differently from adults: they are not as illogical and concrete in their thinking as we once thought.

Piaget's stage theory is increasingly interpreted in alternative ways. For example, it seems that children are simply more like novices as opposed to experts: their cognitive shifts are not due to maturational changes but due to a changing knowledge base. Increasingly recognized is that knowledge of specific content domains isn't only a crucial dimension of cognitive development, but that changes in this knowledge base may be responsible for cognitive shifts previously attributed to acquiring learning strategies and to the natural emergence of Piagetian-type developmental stages. Echoing similar observations, cognitive psychology researchers Gick and Holyoak note only recently has the learner's background knowledge been considered in relationship to transfer of knowledge. Perhaps this neglect is due to researchers' extensive use of artificial materials, for which little prior knowledge was relevant, in both computer-learning and problem-solving tasks. More recent work has made use of more naturalistic materials: accordingly, the role of prior knowledge has become a more central concern.

Without a large and valid knowledge base, the use of isolated transfer strategies is not likely to be transferred to situations outside the instructional context. This is largely the case because without an extensive knowledge base, there is nothing to connect isolated strategies together. As I indicated earlier, although teaching specific strategies is a viable approach for some situations, there are just too many strategies and we don't know when or to what extent or under what conditions any given strategy will work.

Learning strategies and heuristics, or rules and procedures for thinking, have evolved out of an emphasis on process teaching in education, on the one hand, and findings from computer programming technology, on the other hand. To many proponents of process teaching, a teacher doesn't even need to have expertise in the area being taught; all that is required are skills at directing the students to learn on their own. I once taught with a colleague who maintained that he could teach any subject because he had expertise in instructional process. Certainly knowledge of how to teach is important. But knowledge of the subject is even more important. Current research clearly shows that to teach effectively teachers must understand the structure of the discipline or area being taught.

We have modeled learning and instruction on a misconception of how computers work, thinking that algorithmic-type rules, procedures, and heuristic principles are all that's required to do good mental computation (i.e., thinking). What are called artificial intelligence (AI) or expert systems refers to computer-problem-solving systems. For some time now the emphasis on algorithms (i.e., a set of rules or sequence of steps designed for programming a computer to solve a problem) has switched to requiring knowledge base. As Patricia Langley and Herb Simon make clear: During the decade from the mid-60s to the mid-70s, attention in AI turned to professional level performance in complex task domains. It was discovered, or rediscovered, that expert performance requires knowledge—large amounts of it.
Irony that at a time when computer program designers of so-called expert systems have shifted away from a strategies approach to solving problems to a knowledge-based paradigm, education continues to model itself on an outdated AI technology.

There are medical diagnostic computer programs with the expertise of the most highly regarded physicians. Some programs even surpass physician diagnoses. These programs are not distinguished by their procedures, their special heuristics, or their analytical strategies, but by their large stores of knowledge—what they know. Such an AI system exhibits intelligent understanding and action at a high level of competence primarily because of the specific knowledge that it can bring to bear. . . . that the reasoning processes of intelligent systems are generally weak and are not the primary source of power. 20

Knowledge base is further, cognitive “procedures” are increasingly recognized as depending much more on knowledge base than previously thought. For example, John Anderson and his colleagues were forced to revise their computational (AI) view of how mental-procedures are developed by re-emphasizing the central role of knowledge base. 21

Until recently, developmental psychologists focused almost no attention on children’s knowledge base in explaining changes in their thinking and reasoning. As noted above, this was because changes in children’s thinking were viewed as essentially a maturational process that developed in orderly natural stages. For example, it was thought—and still is by many psychologists—that children under about 5 years of age are not proficient at transfer. Indeed, findings from analogy test questions of the sort: A.B.C.D (e.g., light is to dark as day is to night) seem to clearly support the lack of transfer in young children. But the ground-breaking research of Ann Brown and her colleagues has shown that the lack of transfer by young children is not so much due to their developmental stage as to a lack of an appropriate knowledge base. 22 Brown’s research with children can be seen as a model for the importance of knowledge base in general. Her research clearly demonstrates highly competent analogical reasoning in young children as long as they possess the relevant knowledge base required for understanding the relations used in the analogies. 23

Children, like novices or non-experts, have historically been viewed as being “perceptually bound.” Perceptually bound means one is tied to the superficial concrete characteristics of phenomena. As a consequence, it is often thought that children are not able to engage in inference; in short, they are not able to transfer their knowledge. Their knowledge is said to be encapsulated or welded to the specific context or situation in which it was learned. Further, the claim has been that transfer of learning depends largely on the degree of perceptual similarity that exists among objects, ideas, or events. This view dates back at least to the psychologist Edward Thorndike’s very influential theory that transfer depends on identical elements among items. The concept of functional fixedness (discussed in chapter 2), where a rock may not be seen as a hammer when a nail needs to be driven, can be explained as the consequence of being perceptually bound. Brown’s research has repeatedly shown that only when children lack an adequate knowledge base, including theoretical knowledge (see chapter 9) do they rely on the surface features of identical elements and become perceptually bound—indeed, as we adults do.

KINDS OF KNOWLEDGE AND WHAT THEY DO

Typically, cognitive and instructional scientists describe four basic kinds of knowledge: (a) declarative knowledge, (b) procedural knowledge, (c) strategic knowledge, and (d) conditional knowledge. I will add a fifth kind, not typically mentioned: (e) theoretical knowledge. It is my view, knowledge base is defined by all five of these kinds of knowledge. People who possess—to varying degrees—all five kinds of knowledge are proficient at transfer. There are other publications covering procedural, strategic, and—to a lesser extent—conditional knowledge, so I do not discuss them in detail but only briefly define them. Instead, I focus on declarative knowledge. (Theoretical knowledge is discussed in chapter 9.)

Procedural knowledge is how-to knowledge; though we can identify a Buick, we may not know how to drive one. Strategic knowledge is knowledge of our mental processes, such as how we learn and remember; it’s the self-monitoring of our progress in the act of learning. Conditional knowledge is knowledge of when to apply our knowledge in context-appropriate ways; we don’t behave in the same way in all situations. Theoretical knowledge is our understanding of deep level relationships, of cause and effect, and other explanatory connections about phenomena.

Declarative knowledge is knowledge of or about something. We either do or do not know what a Buick is. Though it’s often difficult in practice to separate the five kinds of knowledge, in my view declarative knowledge—knowledge of or about something—is the most crucial for transfer. I say this because (a) declarative knowledge provides us with the preconditions necessary for the other four kinds of knowledge; (b) it often includes or directly generates the other four; (c) declarative knowledge frequently provides a general framework for assimilating more detailed new knowledge; (d) it often facilitates the elaboration of newly acquired knowledge; and (e) it frequently provides useful analogs (or mental models) to help in the understanding of new knowledge.

Singly and Anderson, although known for their cognitive work on procedural knowledge, nevertheless assert, “indeed, one could argue that the defining feature of declarative knowledge is that it serves as the basis for transfer to multiple tasks . . . [and represents] somewhat of an antidote to the
encapsulation of knowledge. Knowledge base also affects our use of strategies in a number of ways. It often contains information that makes the use of a strategy unnecessary. Frequently, material learned by relying on an already existing knowledge base stimulates strategies to incorporate other material that is not congruent with prior knowledge. In fact, many strategies can only be effectively applied by people who possess a considerable declarative knowledge base.

One of the functions of a knowledge base is not just learning what needs to be learned but filtering out what should not be learned. Ann Brown and others have noted that a learner cannot be flexible if he or she has little knowledge available; flexibility requires possessing a considerable amount of knowledge. Students with a moderate level of general knowledge about mathematical procedures are able to effectively "screen out" distracting and irrelevant content- or context-specific details in mathematical word problems. Students who are only trained in procedures cannot. In other words, strategy use and selection is often knowledge driven.

Ceci and Ruiz note that what makes some knowledge easier to transfer than other types is not the abstractness of its conceptual structure but rather the combination of an invitation to transfer that's contained in the original learning, coupled with an elaborated knowledge representation that is sufficiently well developed that most problems are representations of parts of it.

The psychological research also clearly demonstrates that valid intuitive knowledge is made possible by a large knowledge base. This knowledge base is deeply processed on a nonconsciously level and results in the perception of patterns. Declarative knowledge, then, is more likely to produce far transfer than the other kinds of knowledge (with the exception of theoretical knowledge, which in most cases includes or is a kind of declarative knowledge).

Yet another implication of knowledge base is that the similarity of two objects or events is not fixed—contrary to the identical elements theory of transfer—but will change with alterations in our knowledge base. Finally, knowledge base, particularly theoretical knowledge, constrains inappropriate transfer (e.g., seeing a whale as a fish) (see chapter 9). Young children and novices are famous for inappropriate transfer. Without an appropriate knowledge base we can end up with "runaway" transfers.

THE USEFULNESS OF USELESS KNOWLEDGE

Typically, we want only knowledge that's immediately useful. To achieve general transfer, however, often requires much more than immediately useful knowledge. It requires learning that may be considered useless knowledge. I remember as a freshman in college reading in an edited book an essay entitled, On the Usefulness of Useless Knowledge. The essay was written by Abraham Flexner, a physician, well-known educator, and one-time director of the Institute for Advanced Studies at Princeton. In his essay Flexner cited examples of knowledge that appeared to have absolutely no use, but that years later someone saw as something other than what it appeared to be; the person was therefore able to transfer the "useless" knowledge to other areas, which later had major applied importance. For example, the mathematical equations of James Clerk Maxwell (1831–1879), the Scottish physicist who formulated the relationship between magnetism and electricity, were thought to be useless at the time he formulated them. The detection of Maxwell's theoretical "electromagnetic waves" came only much later when they were discovered by Heinrich Hertz (1857–1894), the German physicist.

Moreover, the work of both Maxwell and Hertz was thought to be relatively useless until Guglielmo Marconi (1874–1937), the Italian engineer and inventor, applied this useless knowledge and invented wireless telegraphy. The same can be said of the English scientist Michael Faraday (1791–1867), who, with little formal education, discovered the induction of "electric" current from magnets. Without all of the above "useless" knowledge, I would not be writing these words—as I'm now doing—on my word processor after sunset. Moreover, the essay on useless knowledge has been tacked away in the back of my mind for years. I have never used that chapter in my teaching or writings; until now it was a "useless" piece of information that I had stored away.

Other examples of "useless" knowledge can be cited. Historically, mathematics is perhaps the field that best exemplifies the discovery of what may appear to be useless knowledge. Non-Euclidian geometry, invented by Carl Friedrich Gauss (1777–1855), the German mathematician, physicist, and astronomer, was originally considered useless. In fact Albert Einstein's (1879–1955) relativity theory could not have been formulated without it. Likewise, Group Theory in mathematics was considered useless, but is now the basis of the quantum theory of spectroscopy. Such examples of seemingly useless knowledge are not rare. More recently in mathematics, knot theory was a system for describing and classifying knots. It was thought to be a quite useless kind of mathematical game for theorists to waste away their time; it remained so until someone transferred this theoretical knowledge to another field: Knot theory is currently important in the biochemical analysis of explaining how jumbled strands of DNA in the nuclei of living cells divide without becoming entangled. Someone saw knots as being like jumbled strands of DNA.

When early in his career Abraham Pais, a theoretical physicist, discovered the k-meson particle, it was thought to have no useful application. Today, however, meson particles are used to treat cancer because they can be beamed at cancerous cells without burning the tissue around them. Pais points out that what at first looked like useless knowledge, "turned out in the past to have practical applications. Electronics, transistors, television, radio—all are based on discoveries made by people who are just interested in
conceptual questions. In other words by people not interested in the usefulness of the knowledge.

Stanford Ovshinsky, the renowned inventor, says, “For the most part, my inventions come from seemingly unrelated information.” Wilson Greatbatch, electrical engineer and inventor of the first implantable heart pacemaker, recounts how he came by his idea. While in school, he held many part-time jobs, one of which was at Cornell University’s animal behavior laboratory. While he was working there, two brain surgeons came to perform experimental surgery on animals. The surgeons, like Greatbatch, brought their lunch to work so Greatbatch and the surgeons sat in the sun and talked. During these lunches, he learned about a disease called heart block, the remedy for which he was later to invent: the implantable pacemaker. The technologies, however, were not available for him to invent what he eventually invented. At the time, then, these talks and the information that came from them were useless knowledge. But they remained in his knowledge base until needed. Let me further describe the usefulness of useless knowledge with a telling illustration from the world of fine art.

Possessing an extensive knowledge base does not just apply to science and engineering. As an example of the importance of technology, as an example of the importance of useless knowledge, consider the first graduate student of Dr. James Wyeth, the engineer and inventor of the plastic soda bottle, son of N. C. Wyeth, brother of Andrew, and uncle of Jaime, all famous artists, describes a particular painting that his brother Andrew painted of General Lafayette’s headquarters near Chadds Ford, Pennsylvania, the Wyeth homestead. I would like to quote Nat’s description.

It’s a beautiful, old building, built before the Revolutionary War, and in his picture was a huge sycamore tree coming up from behind the building with all its beautiful branches. You could see part of the trunk coming up over the roof line. When I first saw the painting, he wasn’t quite finished with it. He showed a lot of drawings of the trunk and the gnarled roots going into the ground, and I said, “Gee whiz, where’s that in the picture?” “It’s not in the picture,” he said. And I looked at him. “Nat,” he said, “for me to get the feeling that I want in that tree, the part of that tree that’s showing, I’ve got to understand and know very thoroughly how that tree is anchored to the ground in back of that house.” It never showed in the picture. But he could draw the part of the tree above the house with a lot more authenticity because he knew exactly the way that thing was anchored in the ground. To me, this was all very indicative of what my father trained us in whatever we were doing: to understand what we were doing.

The point here is that all of the apparently useless or irrelevant knowledge of how the tree was anchored into the ground, since this knowledge was not directly used in the painting, was in fact useful. In the same way, says Nat, the engineer must have a very fundamental training and understanding of the laws of physics before he or she can use them. “This is particularly important,” he says, “when you’re using your skills in fields or areas where you’re really exploring for the first time. We have enough to do and enough problems without moving in false directions because we haven’t learned the basics in engineering.” The same holds true for the role of knowledge in transferring our learning.

What we typically view as useful knowledge is knowledge that we consider not only to be relevant but immediately relevant. The question is, however, what is meant by relevance? We might ask this question by framing it in a journalistic format: relevant for “who, what, why, when, and where.” The terms useful and relevance are relative to goals, context, and to time. As we saw above, today’s useless knowledge may be tomorrow’s crucial piece of information. As a society we all too often value only what appears relevant now, the immediate “bottom line” to what we are learning. But deep learning that leads to transfer requires “useless” and “irrelevant” knowledge (relative to a here-and-now context and time frame). This is not only true for the kinds of “big transfers” cited above but for simpler everyday learning as well.

**IRRELEVANT KNOWLEDGE: THE COUNTERINTUITIVE NATURE OF INSTRUCTING FOR TRANSFER**

A subset of what I call useless knowledge is irrelevant knowledge. Unlike useless knowledge, irrelevant knowledge is considered useful, but just not relevant to one’s immediate subject or problem. What is required for achieving transfer, however, is often irrelevant knowledge. What we think is necessary for achieving transfer is often counterintuitive, that is, counter to what intuition or common sense would lead one to expect. Accordingly, some kinds of knowledge are considered irrelevant when in fact they are not. For example, many of us who teach often consider it counterproductive to present incorrect examples of a concept to students. Common sense seems to tell us that if we want a student to learn a concept or action that we should precisely teach the concept or action and not irrelevant or extraneous pieces of knowledge. Frequently, however, irrelevant knowledge is directly relevant to the process of learning and transfer. Irrelevant knowledge can be seen as a variant of useless knowledge. Knowledge viewed as relevant for something may not be seen as relevant for a given transfer situation.

Years ago, an interesting experiment was conducted that illustrates the relevance of irrelevant knowledge. Marvin Herbert and Charles Harsh designed an experiment on modeling in which two groups of cats were to learn the tasks of string pulling and door opening simply by observing the performances of other cats. One group of cats observed only the final errorless performances, whereas the other group observed the early trials of the cats learning. As a consequence, the latter group of cats observed the mistakes that were made during the learning as well as the correct performances. The result was that the observing cats learned to solve the problems more quickly than the cats who learned only from their direct experience, thus clearly illustrating the effects of observational learning. The important finding, however, was that the cats who observed the errors (read: irrelevant knowledge)
made by other cats during learning transferred their learning more readily than those who observed only the correct responses.

The observation of the errorless performances were missing the critical choice points or alternatives during learning. They were missing what is often considered irrelevant knowledge. The observation of a final skilled performance does not provide information needed to choose between concepts. Now, lest we think these findings only pertain to lower animals, other early research with humans has resulted in familiar findings. Another experiment with seventh-grade students from three school districts investigated learning adverb concepts by including and removing negative instances. Results indicated that knowledge of negative instances was a vital part of concept acquisition.

Other researchers have noted the problem of experts modeling their refined skills to students. As in the cat experiment above, students who learn a concept or a principle in the absence of irrelevant cues typically have more difficulty in applying the concept or principle to a similar situation that involves irrelevant cues than does a student who learned the material in the presence of irrelevant cues. Thus, simplified situations, such as verbal presentations or simple diagrams, do not typically involve irrelevant cues and, hence, may provide inefficient teaching situations. Again, we have known this for some time. As another early author observes, a learning situation with all its irrelevant cues is “significantly better in facilitating transfer” than is a situation which has had many of its irrelevant cues removed. Here we have some of the elements that I suggest distinguish training from education: instruction given without “irrelevant” knowledge is best characterized as training, not education.

The implications for transfer in many fields is striking, especially in clinical/vocational fields where students learn by observing experts. For example, in medical and most other clinical education programs it is common practice for students learning a skill such as diagnosing to observe and imitate the highly selective (that is, minus the irrelevant cues) information-processing strategies of the expert physicians whom they accompany on ward rounds. However, the findings presented here suggest that such short-cut learning experiences inhibit the acquisition of the etiological factors underlying the diagnosis by excluding a wide range of original relevant data that were important to the expert physician’s current skill at diagnosing. Further, an item of information that may be irrelevant for diagnosing one case may nevertheless be quite relevant in other diagnoses. The expert physician (who already possesses a rich knowledge base of possible causes of a disease) can afford to consider such immediate information in the interests of diagnostic efficiency. There are other problems, too, for acquiring transfer from professional practice situations (shown in chapters 9 and 10). It seems that knowledge from many apparently diverse situations share similar structures that may summate into generic learning. The more we know, the better.

Later summaries of the literature on experts find “no convincing evidence that experts really differ in their cognitive processes...All the other research did not succeed convincingly in specifying different cognitive strategies and capacities of experts.” It is now well known that expert chess players utilize an enormous amount of knowledge of chess patterns. Chess players must spend thousands of hours in acquiring a large knowledge base, by playing chess, reading books and magazines on chess, and carefully studying thousands of chess positions (see chapter 10).

Now, there are two kinds of expertise. One is routine expertise, the other adaptive expertise. Each kind is based upon the amount of knowledge acquired and how it is used. Routine expertise rests on a restricted knowledge base in a particular area; adaptive expertise, on the other hand, is based on a more extensive knowledge base. Adaptive experts utilize procedures flexibly, can modify them based on feedback demands, and can invent new procedures to deal with novel problems and situations. To use an analogy, someone who implements a recipe quickly and accurately can be called a routine expert, whereas an adaptive expert would be able to substitute ingredients in the recipe if necessary and modify it for different requirements. In general, training leads to routine expertise, whereas knowledge-based deep learning leads to adaptive expertise and to creativity. Accordingly, routine expertise leads to narrow transfer within an area; adaptive expertise leads to broad transfer extending beyond an area. By comparison, children are a kind of routine expert, and adults a kind of adaptive expert.

Competent problem solvers (experts) not only have an appropriate knowledge base available in their long-term memory, they also have the ability to access and use that knowledge. The essential difference between experts and novices is not simply knowledge base but how that knowledge base is organized. Again, Glaser has found that “the evidence indicates that what humans actually do as they learn and acquire experience is to build up an extremely large store of structured knowledge.” This structured knowledge enables
them to “see into” a problem more quickly than a novice. “What differentiates an expert problem solver from a non-expert” says Glaser, “is not the use of different or more powerful heuristics, but an initial representation that allows the expert to succeed in pursuing the better path to solution without considering all the others.” Thus we can see once again that an extensive knowledge base allows the expert to either not be sidetracked by irrelevant aspects linked to a problem, or to see what may be considered irrelevant knowledge as in fact directly relevant. It is perhaps noteworthy to point out that Glaser’s early expertise was as a behavioral psychologist doing research in measurement theory, human performance, and as an advocate of programmed instruction and teaching machines.

Studies indicate that the way we process information is greatly enhanced by experience with new information. Research suggests that experts form immediate representations of problems that systematically cue their knowledge, whereas novices do not have such efficient access to their knowledge. The implication is that when experts look at a complicated situation, they form mental representations composed of a few patterns or chunks and other hierarchically organized mental structures. There are other important differences, too, between those with lots of knowledge and those with little. As I have already pointed out, high-knowledge individuals are able to identify problems and issues more precisely and more quickly than are low-knowledge individuals. Further, this difference enables them to more precisely encode and store information. As a consequence, access to and retrieval of pertinent information is more efficient. High knowledge individuals have a much greater knowledge of contingent, irrelevant, and contextual relationships and are more adept at using or discarding this knowledge. Thus, Glaser concludes, “Our interpretation is that the problem-solving difficulty of novices can be attributed largely to the inadequacies of their knowledge bases and not to limitations in their processing capabilities such as the inability to use problem-solving heuristics.” But other consequences issuing from a large knowledge base have implications for transfer.

A knowledge base develops our ability to perceive patterns in the environment. Years ago, Jerome Bruner recognized that much of what we classify as learning, recognition, and problem solving consists of being able to identify recurrent regularities in the environment. What makes such a task a problem is that the recurrent regularities—be they turns in a maze, elements in a temporal pattern, or a pattern in successive events—may either be masked by factors that are irrelevant to the regularity, or the regularity itself may be of such complexity that it exceeds the memory span that an observer brings to the task. Since Bruner, others have also recognized that “a very important component of the knowledge-base is a fast-action pattern-recognition system ... that greatly reduces processing load ... [and] ... these patterns serve the purpose of retrieval aids for desirable courses of action.” Others also conclude that the expert is not merely an unindexed compendium of facts, however. Instead, large numbers of patterns serve as an index to guide the expert in a fraction of a second to relevant parts of the knowledge store. This knowledge includes sets of rich schemata that can guide a problem’s interpretation and solution and add crucial pieces of information. This capacity to use pattern-indexed schemata is probably a large part of what we call physical intuition.

Finally, people high in knowledge base exhibit superior memory and encoding procedures for retrieval and transfer than do those low in knowledge base. At first glance, the commonsense explanation might be that those with a good memory are able to amass and retain a larger knowledge base than those with poorer memories. But this is not the correct explanation. Somewhat counterintuitively, acquiring a large knowledge base is not the consequence of a superior memory. Rather, superior memory is the consequence of having a large knowledge base. Having a large knowledge base provides more frameworks and related connections, and enables information to be remembered, maintained, and retrieved. For example, studies have shown that master chess players could not remember a randomly generated chess board set-up any better than chess players of lesser ability.

Lauren Resnick, though an advocate of learning strategies, suggests “that learning depends heavily on what people already know poses a fundamental problem for instruction. Without special intervention, the knowledge rich would grow greatly in knowledge, the knowledge poor very little.” It seems that as with monetary capital, intellectual capital feeds on itself: The rich grow richer and the poor grow poorer. Resnick also suggests a remedy for knowledge deficits called “bootstrapping.” She says, “It may be helpful to recast the traditional instructional question of how to convey information as a problem of cognitive bootstrapping—beginning a climb without firmly established prior knowledge, yet behaving as if one had the knowledge.” Learning strategies presumably provide the remedy. As we have seen, however, learning strategies have yet to yield any significant profit. Making believe that one has intellectual capital doesn’t seem to work any more than making believe one has real capital.

CONCLUSION

In the classic, formal-discipline view of education, knowledge base was always considered important, but it was largely an intuitive principle. Now, however, there is considerable hard evidence pointing not only to the importance of knowledge base but to its cognitive advantages as well. The two camps, the knowledge-base camp—sometimes referred to as the Knowledge
Knowledge Base and Transfer: On the Usefulness of Useless Knowledge

Mafia— and the learning/thinking strategy camp—which I refer to as the cookbook camp—remain largely divided.

We still have a way to go to understand all that a knowledge base does. As James Voss noted years ago, "The extent to which knowledge of one domain may be useful in learning new information of another domain is, of course, an open question: we do not know how specific or how general transfer effects are." He goes on to point out that we need to know more about how the vague hypothetical construct "schema" works. More importantly for transfer, he says, "when the schema notion becomes sufficiently unpacked, we may find that we have highly specific transfer which is found frequently with high-knowledge individuals because of their varied experiences." Although we are beginning to unpack the hypothetical construct of "schema," we still need to know more about what knowledge base does we need to know, for example, the differences between the knowledge required for well-structured problems and domains, such as mathematics and physics, as opposed to ill-structured areas, such as literary analysis, psychology, and political theory.

Contrary to popular expectation, despite the importance of knowledge base, for most people there appears to be little if any transfer from one domain to another, quite different domain. We often expect that there should be transfer. This expectation, however, is based on false assumptions about the nature of intelligence; it is also based on what is called the "halo effect." (The halo effect is when some one is regarded. we often tend to consider their opinions in other areas to be valid ones.) For example, we hold physicists and physicians in high regard. But knowledge of medicine or skill in problem solving in physics does not necessarily transfer to moral, philosophical, political, or economic problems. A given individual may, of course, acquire such knowledge across a number of domains.

As addressed in chapters 9 and 10, a knowledge-base crisis exists in many professional fields, and in our schools as well. In many professional fields and programs, practitioners tend neither to engage in nor to read or utilize relevant research-based knowledge about their fields. One final caveat: over the years, I have observed that some people need a large knowledge base to accomplish a little, whereas others need only a little knowledge base to accomplish a lot. What's the difference between these two types? Part of the answer may be motivation (see chapter 7) or a transfer ability that is hardwired into our nervous systems (see chapter 11). But we do not need to be hardwired in an extraordinary sense to engage in transfer.

Notes


References

6German physicist Max Planck (1858–1947) won a Nobel Prize in 1918 for his discoveries in connection with quantum theory. Planck's constant refers to the proportional energy of a photon to the frequency of that photon (a photon is a quantum of electromagnetic energy, generally described as a discrete particle having zero mass, no electric charge, and an indefinitely extended life).
13Ibid., p. 130.
The centrality of analogy in knowledge acquisition in instructional contexts.


The activation and acquisition of knowledge. In S. Vosniadou & A. Anthony (Eds.), Similarity and analogical reasoning (pp. 332–354). New York: Cambridge University Press.


Today's leaders look to tomorrow. Fortune (March 26th), p. 78.


Nonexamples: Why teachers don't use them and why teacher educators should. Mid-Western Educational Researcher, 4, 2–6.


Variation in the amount of irrelevant cues in training and test conditions and the effect upon transfer. Journal of Educational Psychology, 58, 62–68.

Effect of negative instances in concept acquisition using a verbal-learning task. Journal of Educational Psychology, 64(2), 267–268.

New approaches to instruction. Because wisdom can't be told. In S. Vosniadou & A. Anthony (Eds.), Similarity and analogical reasoning (pp. 470–497). New York: Cambridge University Press, p. 484.

See, for example, Overing, R. L. R., & Travers, R. M. W. (1967). Variation in the amount of irrelevant cues in training and test conditions and the effect upon transfer. Journal of Educational Psychology, 58, 62–68, p. 02.


