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Teaching basic science to optimize transfer

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Abstract

Background: Basic science teachers share the concern that much of what they teach is soon forgotten. Although some evidence suggests that relatively little basic science is forgotten, it may not appear so, as students commonly have difficulty using these concepts to solve or explain clinical problems: This phenomenon, using a concept learned in one context to solve a problem in a different context, is known to cognitive psychologists as *transfer*.

The psychology literature shows that transfer is difficult; typically, even though students may know a concept, fewer than 30% will be able to use it to solve new problems. However a number of strategies to improve transfer can be adopted at the time of initial teaching of the concept, in the use of exemplars to illustrate the concept, and in practice with additional problems.

Aim: In this article, we review the literature in psychology to identify practical strategies to improve transfer.

Methods: Critical review of psychology literature to identify factors that enhance or impede transfer.

Results: There are a number of strategies available to teachers to facilitate transfer. These include active problem-solving at the time of initial learning, imbedding the concept in a problem context, using everyday analogies, and critically, practice with multiple dissimilar problems. Further, mixed practice, where problems illustrating different concepts are mixed together, and distributed practice, spread out over time, can result in significant and large gains.

Conclusion: Transfer is difficult, but specific teaching strategies can enhance this skill by factors of two or three.

Since the time of Flexner, medical education worldwide has consisted of 2 or more years of preclinical education followed by an equivalent time of clinical training. Such an arrangement legitimizes Flexner's concerns about linking the practice of medicine to the scientific underpinnings in biology, psychology, and other disciplines. Yet this universal approach rests on a century old perspective on the nature of learning; the notion that there are "foundational" subjects that can be taught early, and will inculcate general "mental faculties" related to the subject matter. Until the 1950s, educators who ascribed to this philosophy took the position that Latin was the underlying foundation of all Western languages, and philosophy was the basis of science, so inflicted courses in Latin and logic on public school students. Sadly, although the notion of "general mental facilities" fostered by such practices was disproved by Thorndike (1913), the practice survived for at least another 50 years.

However, paralleling this historical view in education, psychology in the last century was dominated by behaviorism, whose fundamental premise is that all learning amount to stimulus – response links, with no generalization. From this theoretical framework, generalization to novel situations was simply not possible, since all responses are conditioned to specific stimuli.

A more moderate view of the phenomenon of generalization and transfer has emerged with the revolution in cognitive psychology beginning in the 1960s. Cognitive psychology was initially based on a computer metaphor, with concepts like "long-term memory", "working memory", and "sensory input systems". Although much subsequent research has shown how the mind is dissimilar to the computer, nevertheless the basic notion of movement of elements in and out of memory survives. In particular, in the cognitive view, learning amounts to changes in long-term memory – no more and no less, and much of the research addresses questions about factors that may facilitate or impede processes involving access to memory.

To many educators, the cognitive view of memory and learning may seem reductionist and incompatible with broader

Practice points

Basic science teachers can adopt a number of strategies to improve transfer. These include:

- Initial teaching

  Explicitly use analogy to common concepts
  Imbed the concept in a problem (PBL)
  Combine text and diagrams as appropriate

- Examples

  Use multiple teaching examples
  Get students to explicitly compare examples to reveal similar concepts

- Practice

  Mix examples of different types (mixed practice)
  Spread practice out over several sessions

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views of the nature and richness of human learning. It clearly excludes considerations of social factors in learning, or emotional influences such as motivation, nor does it typically examine individual differences in aptitude that may influence learning, such as intelligence or spatial ability. Nevertheless, the cognitive perspective has had considerable success in explaining many aspects of learning, thinking, and reasoning.

One recurring research theme in cognitive psychology is the idea of "transfer" – using knowledge acquired in one context to solve a new dissimilar problem in another context. A consistent finding from studies to date is that transfer is, in fact, more difficult that we might think. Typically, students who have learned a concept in one problem context will only have a 10–30% success rate in applying the concept to solve a new problem.

Medical educators have certainly recognized the issue. Stories of medical students who have learned the basic science, passed the examinations, but were then unable to apply this knowledge to solve or explain problems, are commonplace. Typically, this dissociation is viewed as an issue of learning out of context, and proposed solutions attempt to integrate the basic science better with the clinical problems. The two most significant innovations of the past 50 years, the organ system approach of Case Western Reserve University in the 1950s and problem-based learning (PBL), pioneered by McMaster in the late 1960s were both directed to integrating basic science and clinical learning. Despite the significant dissemination of these two innovations, there is little evidence that they have actually succeeded in improving the integration of basic and clinical science. In part this reflects an absence of evidence – few studies have specifically addressed whether students from a PBL curriculum are better able to apply basic science to solving clinical problems. One study that did investigate transfer in an experimental setting concluded that PBL students actually did worse than students from a conventional curriculum (Patel et al. 1991). More typically, curriculum-level comparisons show small or no differences; it is safe to say that no dramatic advantages in performance have emerged from learning in context.

Interestingly, several authors have argued that PBL may actually impede transfer. Bransford et al. (1999) has argued that when students learn a concept in one problem context, the concept is so tightly bound to the context that it may be less available for transfer than if it were learned out of context. Ross (1987) has demonstrated evidence of this, as we will see. His view is that:

> . . . during early learning, the principle is only understood in terms of the earlier example . . . the principle and example are bound together. Even if learners are given the principle or formula, they would use the details of the earlier problem in figuring out how to apply that principle to the current problem
>
> (Ross 1987)

Of course, as has been argued elsewhere (Norman 2003), PBL is not a single intervention, but rather is a whole series of instructional strategies, implemented in different degrees in different institutions. As we will see, many of the strategies that may facilitate transfer are compatible with both PBL and conventional curricula.

In this position article, I will begin with a simple model of how concepts are taught and learned. I will then examine the literature on transfer to illustrate effective strategies to facilitate transfer at each step of the way.

A model of concept learning

In order to explore the effect of various strategies on learning, we will begin with a deliberately simplified example of concept learning. This not intended as exemplary; rather it is simply a way to identify classes of strategies available to the teacher. For simplicity, we assume a linear flow.

First, the learner is introduced to the concept. This may be as text, or text with accompanying picture, a lecture, an e-learning module, or anything in between. But the essential element is the content – the to-be-learned concept.

Second, the learner may well see an example of the concept – how the concept arises "in the real world". In contrast to the original concept, which may involve symbols and is abstract, in this phase, the concept is deliberately imbedded in a prototypical example. In this stage, the basic element is the illustrative example containing both concept and contextual information.

Finally, the learner may be encouraged to engage in practice problems. These may all be illustrations of the same principle just learned (blocked practice), or may deliberately contain confusable examples illustrating other related concepts (mixed practice). But the essential element is multiple practice problems.

Obviously each element of the learning may or may not be present, and may be implemented in various ways. In particular, the order may vary: PBL, for example, introduces the example problem first, and the concept emerges from discussion and reflection on the problem. For the moment, this is not relevant. Our goal is simply to separate the three phases in order to examine various strategies to optimize learning at each.

To provide a brief overview of the nature of the problem of transfer and the effectiveness of strategies, if only the principle is taught, likelihood of transfer to new problems is about 5% (Quilici & Mayer 1996). If the principle is illustrated with a single prototypical example, transfer may go to about 25%. If the principle is illustrated with multiple examples, transfer can be as high as 47% (Catrambone & Holyoak 1989; Lowenstein et al. 2003). This illustrates briefly the potential gain in transfer performance by appropriate instruction. Let me now examine each phase in more detail.

Why is it so difficult?

The results shown in the previous paragraph may come as a surprise. Why is it so difficult to retrieve a learned concept to solve a new problem? The difficulty lies in the mental representation. In order to use a concept such as, for the sake of argument, conservation of momentum, the solver must recognize that the problem is one amenable to a "conservation of momentum" solution. While sometimes the nature of the problem context may give some clues (e.g. it has been shown that many problems in vector addition are framed as boat crossing rivers (Blessing & Ross 1996)), more frequently, what makes the problem difficult is that it does not, on the surface, look analogous to other examples. Indeed, if one can find the correct analogy, that essentially solves the problem, but this appears more difficult than one might think.

Why is it so difficult? Simply, because in order to identify the analogy, the similarity must be identified at the level of the deep (conceptual) structure. As it turns out, this is a characteristic of experts, not learners. As one example (Chi et al. 1981) expert physicists will literally "see" a problem differently from novices – novices may describe it as a "ball rolling down a plane" problem; experts as a "conservation of energy" problem.

And why is it so difficult to see the deep structure of a problem? One theory in cognitive psychology posits that there are two fundamentally different ways of thinking. System 1 is rapid, unconscious, concrete, and contextual, associated with identification of physical objects. System 2 is slow, deliberative, and conceptual, and associated with abstractions. These two processes have been shown to occur in different areas of the brain. It is tempting to hypothesize that novices, who only have concrete examples available in an abstract field such as mechanics, represent problems by surface structure. Experts, by contrast, have numerous examples of abstract problems to draw on, so can see the problem as an underlying principle, using a more refined System 1 thinking. Certainly, we have ample evidence in medicine that expert diagnosis is dominated by System 1, non-analytic reasoning (Norman et al. 2007b).

Facilitating factors

Initial concept learning

Although much early work in transfer used problems where no prior learning was required (Insight problems), more recent work has critically examined aspects of initial learning in areas such as statistics and probability learning. From these studies, a number of critical elements have emerged.

Use of analogy. The cognitive perspective of learning proposes that learning amounts to interpreting new knowledge in light of what we already know. To that end, instruction that explicitly links the new concept to something known (e.g. "a pulsar star actually is emitting streams of light in two opposite directions. As it rotates, it appears to pulsate, just like a lighthouse would") has been shown to facilitate learning. (Donnelly & McDaniel 1993; Norman et al. 2007a). In the Donnelly study, two groups of students learned 12 concepts, then were tested with multiple choice questions directed at basic recall of the explanations and inference (transfer). One group had an everyday analogy; the other did not. The analogy group did worse on recall (80% vs. 86%) but better on inference (83% vs. 77%). Norman (2003) taught undergraduate students three physiological concepts (Starling law, Laplace law, and right heart strain) and then tested students with short clinical cases. One group had a biological explanation; the other had a mechanical analogy, e.g. weight on a horizontal string for Laplace law). Performance of the dual group was 46% vs. 17% for the biological explanation only.

Impact or not of multimedia learning. Mayer (1997) reviewed literature on multimedia learning, distinguishing between effects of the *medium* (e.g. television vs. paper), multi vs. single media (e.g. narration and animation vs. narration, text and illustration vs. text) and contiguity (proximity) effects. Over a series of studies, there was no demonstrable effect of the medium – a computer animation had no advantage over a presentation on paper with drawings – with a mean of 7.5 for computer and 7.3 for book. By contrast, he showed dramatic effects of combined instruction (text and illustration) against a text explanation alone. Average effect was 100% gain with narration and animation, and 67% gain with text and illustration vs. text. Of course, the concepts were mechanical (an air pump) so lent themselves to a diagrammatic explanation; the results may not generalize to concepts like probability equations. Finally, Mayer has shown surprisingly large effects from simply providing text and picture together vs. apart (contiguity); an average gain of 62%.

These investigators also showed consistent interactions with individual differences. Students with high prior knowledge consistently showed smaller gains than students with low prior knowledge. The opposite was true for spatial ability – students with high spatial ability showed larger gains from contiguity than low ability students. In passing, this is *not* the same as visual vs. verbal learners; Massa and Mayer (2006) showed a relation between measured spatial ability and performance with visual and verbal instructional materials, but *no* relation between reported learning preference (visual vs. verbal) and the materials.

Relation between problem context and concept. The essence of PBL is the idea of imbedding the concept to be learned in a problem context. The purported advantages have been described in various ways: improving problem-solving skills, learning in context, "situated cognition", "learning how to learn", etc. However, as we indicated, there may be accompanying disadvantages, related to the use of a single problem. What then is the evidence that PBL-like manipulations can facilitate or impede transfer?

Ross and Kilbane (1997) showed that by imbedding the principle in the example problem, subjects were less likely to make "reversal" errors, not noticing that a cause-effect relation was reversed; however there was only a small increase in overall accuracy (76% vs. 72%). Needham and Begg (1991) contrasted one group that had to attempt to actively solve a problem, and were then provided an answer, with a second group who were given the solution and explanation. The active group had an accuracy on transfer problems of 90% vs. 67% for the passive group.

To the extent that these manipulations capture the effect of PBL, we might conclude that there is a potential small benefit for imbedding principles on problems. However, the mechanism remains somewhat unclear.

For teaching examples

Historically, most of the research on transfer has been conducted using concepts that were known to participants, and so no teaching was required. In these situations, the primary question was the impact of teaching examples, particularly multiple vs. single examples. For example, Lowenstein et al. (2003) contrasted two interventions; two examples vs. an explicit principle and an example, and successive vs. contiguous presentation (similar to Mayer's contiguity). When students were taught a principle and given a single example (common practice) performance on a transfer task was 19%. If they had to explain the example, performance was 44%. Providing two examples with an implicit principle yielded a transfer accuracy of 38%. But two cases, with an explicit comparison, yielded an accuracy of 61%, nearly three times as great. Catrambone and Holyoak (1989) did a similar study, comparing two examples vs. two unrelated examples, and active contrast vs. no contrast. Scores ranged from 25% for the "No compare" groups to 47% for the two examples, active comparison group. The study was replicated by Kurtz and Lowenstein (2007), showing accuracy of 41% when two problems were used during training vs. 15% with one problem.

Thus, the evidence is quite clear. Substantial gains can be achieved by engaging students in multiple teaching examples, even where multiple is two. Additional gain results from getting students to actively compare and contrast to identify the deep structural similarities between examples that appear very different.

For practice

What about the role of practice? For decades, these were the "problems at the end of the chapter" to be handed in weekly. The underlying assumption of these exercises was, presumably, that practice with solving a problem, just like practice with a golf club, will yield improvement in transfer. The problem is that, if the essential skill is recognition of what kind of problem it is, then the "problems at the end of the chapter" has two serious deficits. First, we already know what kind of problem it is. Problems at the end of the "*t*-test" chapter are always *t*-test problems. Second, the practice takes place while the knowledge is fresh, but are not repeated after the knowledge has had time to decay.

The first issue is captured in the notion of "blocked" vs. "mixed" practice. Doing a series of *t*-test problems this week, then some ANOVA problems next week, is "blocked" practice. Mixing them up, so the learner must try to work out what kind of problem it is (mixed practice) can lead to substantial gains in transfer.

At least two studies have demonstrated this. Rohrer and Taylor (2007) had students learn four kinds of geometry problems and practice with 16 additional problems, then were tested on eight new problems. The practice was either blocked or mixed. Students with blocked practice did better in practice (89% vs. 60%), but on transfer with new problems, students who had mixed practice outperformed the blocked group (60% vs. 23%). Hatala et al. (2003) did a similar intervention with three categories of ECGs, where they practiced with 12 examples, four per category, in mixed or blocked practice. Performance on new problems was 47% for mixed, 30% for blocked practice.

The other practice manipulation common in the literature is "massed" vs. "distributed" practice, where the practice is all done in a single session or is distributed over several sessions. Most of this work has been done in motor learning. A review by Lee and Wishart (2005) showed, for example, that two 2-hour sessions per day resulted in about one-third as much performance gain per hour as daily, 1-hour sessions (Baddeley & Longman 1978). However several studies have showed that subjects learning via blocked practice have greater confidence in their abilities than those learning in distributed or random learning conditions (Simon & Bjork 2001), leading to the unfortunate circumstance of greater confidence associate with lower competence. There have been relatively fewer studies of distributed practice in knowledge acquisition when the time interval is measured in days, not seconds, although some very old studies appear to confirm that substantial benefits can result (Pile 1913; Murphy 1916).

Conclusions

Transfer of learned concepts to new problems is far more difficult than teacher may think. Nevertheless, teachers can adopt a number of strategies to facilitate transfer. These include strategies to improve the understanding of the concept at time of initial presentation, use of multiple example problems to identify common deep structure, and use of mixed practice with multiple examples to focus on identifying when a concept applies.

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