Knowledge Transfer

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Abstract

Controversy regarding the nature and frequency of knowledge transfer has received significant attention for more than a century, and this debate has sparked advances in our theoretical understanding of transfer as well as educational practices designed to promote it. We review the classical cognitive approach to studying transfer and highlight several important critiques of that approach regarding issues of context, assessment, and individual differences. These critiques have pushed research to improve understanding of the learning processes that facilitate transfer, the application processes that enact it, and the measurement of it. Research investigating the relationship between achievement goals and transfer serves as an example of the ways issues of context and individual differences are being integrated into the study of transfer. Future work on transfer should continue to refine and clarify how we define, assess, and promote it.

INTRODUCTION

One of the most important functions of the human mind is the ability to use prior knowledge and experience to solve novel problems. The learning and cognitive sciences have called this the ability to *transfer*. Transfer appears evident in our day-to-day lives, from figuring out how to send an e-mail on a new mobile device to finding one's way in a foreign city to solving a problem on an examination without having seen that problem before in class or on a homework assignment. For each situation, transfer consists of some learning or training experience (sending e-mail, interpreting maps, or solving homework problems) followed by a novel task in which some target knowledge or skill acquired from learning is applied to that task. Understanding this ability is critical for both psychology and education.

The importance of transfer for psychology is well illustrated with the following quote from Singley and Anderson's seminal book, *The Transfer of a Cognitive Skill*:

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> "To understand transfer, one must have detailed theories of both learning and performance … In short, the study of transfer is a stringent but necessary test for all comprehensive theories of cognition."
>
> (*Singley & Anderson, 1989*)

Theories of transfer bring together research on learning, memory, and problem solving to predict how and when we use prior knowledge to solve new problems. Understanding transfer is also of critical importance for education. This point is well illustrated by a quote from learning scientist Joanne Lobato:

> "A central and enduring goal of education is to provide learning experiences that are useful beyond the specific conditions of initial learning."
>
> *(Lobato, 2006)*

Transfer is not only a central goal of education, it is also an implicit guiding assumption for the design and construction of curricula, lectures, class activities, and tests. Educators frequently assume (sometimes to our great disappointment) that students will transfer what they know from one activity, lecture, class, or grade to the next. Given the importance of transfer to these disciplines, it should not be surprising that there have been over 100 years of interest, research, and controversy on the topic.

CONTROVERSY

There were differing views at the beginning of the twentieth century concerning whether or not transfer was likely to occur, and evidence supporting both sides of the debate has continued to accumulate well into the twenty-first century. In one view, transfer rarely occurs (Detterman, 1993; Thorndike & Woodworth, 1901) and in the other, transfer is pervasive (Halpern, 1998; Judd, 1908). We believe these different views arise from the complexity of the transfer phenomenon and mixed laboratory results on the topic. Contrary to what the persistence of this debate might suggest, we argue that much progress has been made in the psychological understanding of transfer, and this progress has been driven in part by mixed and sometimes unexpected empirical results, as well as by differing theoretical perspectives.

In this paper we identify some key reasons for the varying views of transfer, summarizing the classic cognitive approach and critiques of that approach. We then briefly review what we see as some major advances in understanding transfer and recent emerging trends. We conclude by highlighting what this work suggests for resolving past controversies and charting new paths forward.

Classical View

Much cognitive psychology work on transfer in the 1970s, 1980s, and 1990s can be categorized under this approach. The classical view focused on understanding how different learning tasks affected the encoding of the target knowledge, the nature of the resulting knowledge representation, and factors influencing the subsequent application of that knowledge. A basic laboratory paradigm used in this research consisted of a learning task or problem(s) followed by a test problem(s). As researchers explored this paradigm, they found transfer for some learning and test scenarios, but not for others (for a review see Day & Goldstone, 2012).

A seminal study that illustrated a surprising case of a transfer failure is Gick and Holyoak's (1980) study of analogical problem solving. Participants in this study first read a story about a dictator's fortress that was overtaken by a military general who first separated and then converged his troops simultaneously from multiple directions. The researchers then tested whether participants would apply this convergence principle to Duncker's radiation problem, a case in which a patient's tumor needed to be destroyed by rays without harming the healthy tissue surrounding the tumor. The research showed that contrary to expectations, college students often failed to apply the just-learned convergence principle. This basic result has been replicated many times (Anolli, Antonietti, Crisafulli, & Cantoia, 2001; Catrambone & Holyoak, 1989; Spencer & Weisberg, 1986) and has been shown to occur for other tasks such as solving physics and math problems when the cover story or domain at test was changed but the same concept applied (Bassok & Holyoak, 1989; Bernardo, 2001; Novick, 1988). These transfer failures have pushed research forward in the classical approach, with an aim to determine why students failed in these situations; this led to many advances and refinements in theories of learning and problem solving (some of which we discuss here). At the same time, the failure to observe transfer in the laboratory seemed at odds with the examples of real-world transfer experiences with which we began the paper, and the approach received critique from a number of different sources in the field (Beach, 1999; Guberman & Greenfield, 1991; Lobato, 2006, 2012; Lobato & Siebert, 2002; Pea, 1987). Many foundational critiques were captured by the influential work of Jean Lave and colleagues working from a perspective of cognitive anthropology (Lave, 1988). In the next section we describe three common critiques and illustrate these with the aforementioned Gick and Holyoak (1980) example. In the later sections we review advances in research on transfer and emerging trends that attempt to address some aspects of these critiques.

Critique of Classical View

Three interrelated concerns emerged: the relation between context and knowledge, the breadth of assessment, and the role of individual differences in transfer. The classical view assumes that knowledge is separate (or separable) from context. Explanations of transfer are typically based on the type of features encoded from the learning problems (e.g., surface vs structural) and how those relate to the test problem. Context is typically limited to the learning and test tasks. For example, in Gick and Holyoak's experiment, transfer was analyzed in terms of the relationship between the initial story problem and Duncker's radiation problem. In contrast, critics argue that context should include not only the learning task but also the broader set of meaningful practices and activities in which that task is situated, such as students solving homework problems as one part of a set of interrelated class-based activities (Greeno, 2006; Lave, 1988). Critics also argue that context should include both motivational aspects (e.g., goals and incentives) as well as social aspects (e.g., the other people involved, status of the evaluator), which have implications for how and why the tasks are performed (Lobato, 2012; Pea, 1987).

The second concern is the breadth of measures to assess transfer. Most dependent measures were problem-solving accuracy, solution strategy, or reaction time, which is a relatively narrow band of behavioral measures. For example, Duncker's radiation problem was a single problem and was scored as correct only if participants generated the expected convergence solution. In contrast, critics argued that the acquired knowledge might be helpful for *learning* from other tasks (Bransford & Schwartz, 1999).

The third concern is that this approach had given little attention to individual differences. Although some of the past research examined the effects of expertise on transfer (Novick, 1988, 1992), most did not examine the effects of individual differences, especially with respect to motivation, which may be particularly important in some contexts over others. For example, Gick and Holyoak did not examine individual differences in students' prior knowledge or motivation for the task. Taken together, both the work conducted within the classical paradigm and the critiques of that paradigm have pushed research forward. We now describe three illustrations of this forward progress.

ADVANCES RESULTING FROM THE TRANSFER DEBATE

A Better Understanding of the Learning Processes that Facilitate Transfer

One set of advances resulting from the research in the classical paradigm is a better understanding of what learning processes facilitate transfer. In fact, several of the initial papers reporting transfer failures led to subsequent work examining which types of instruction could better promote transfer in those scenarios. Much progress was made in understanding the role of self-explanation and analogical comparison in facilitating abstraction, understanding, and transfer. Other work has focused on the nature of the learning material, including research on using worked examples (Atkinson, Renkl, & Merrill, 2003; Paas & Van Merriënboer, 1994), the role of variability in practice (Chen, 1999; Nokes & Ohlsson, 2005), and whether the learning content was concrete or idealized (Goldstone & Sakamoto, 2003; Goldstone & Son, 2005; Sloutsky, Kaminiski, & Heckler, 2005). Here, we focus on two illustrations of these advances; see Koedinger, Corbett, and Perfetti (2012) for a broader review.

The first advance is research on self-explanation. Self-explanation is the process of explaining to oneself with the goal of making sense of new information. A number of laboratory studies have shown that self-explanation can promote learning and transfer. Correlational studies have shown that successful students self-explain when learning new information in domains such as biology, physics, and mathematics and then use that knowledge to solve novel problems and answer deep questions (Chi, Bassok, Lewis, Reimann, & Glaser, 1989). Several experiments have also demonstrated a causal relationship, showing that prompting self-explanations during learning tasks promoted transfer to new problems (Atkinson, Renkl, & Merrill, 2003; Chi, de Leeuw, Chiu, & LaVancher, 1994). Self-explanation is hypothesized to work through generating inferences, in which students can connect their prior knowledge to the new topic, and by providing an opportunity to identify and revise misconceptions (Chi, 2000).

The second example of a learning process that facilitates transfer is analogical comparison. Much research has shown that the act of comparing and contrasting cases or examples by aligning similarities across the examples can help students learn the common structure between the two examples (for a review, see Alfieri, Nokes-Malach, & Schunn, 2013). The resulting knowledge is sometimes referred to as an *abstract schema*, as it is hypothesized to store the common structural features between the two examples and discard the nonoverlapping superficial features. The resulting schema can facilitate transfer to problems with different surface features than the learning task but with similar structure (Novick & Holyoak, 1991; Reeves & Weisberg, 1994). Schema theory provides a representational vehicle to explain how the acquired knowledge can support transfer. As two separate cognitive pathways to transfer, self-explanation and analogical comparison are representative of the broader classical effort to identify the instructional conditions and the underlying cognitive processes that support transfer.

A Better Understanding of the Application Processes that Enact Transfer

In the previous section we focused on instruction and learning processes hypothesized to generate knowledge that transfers. In this part we briefly describe research that has identified different types of transfer *application mechanisms*. Each of these mechanisms takes some type of knowledge acquired from the learning task and then applies it to the test. The mechanisms include rule transfer (Singley & Anderson, 1989), analogy (Gentner, 1983; Gick & Holyoak, 1980), knowledge compilation (Anderson, 1987), and constraint violation (Ohlsson, 1996). Each mechanism has been theorized to use a set of qualitatively distinct cognitive processes, require different amounts of computation, and operate on different types of knowledge structures (e.g., analogy uses problem exemplars, whereas constraint violation uses principle constraints). Each mechanism has received independent empirical support for its existence and each has been implemented as a computational model (see Nokes-Malach & Mestre, 2013 for a summary of the mechanisms). However, relatively little work has compared and contrasted these mechanisms to another within the same experimental paradigm.

Recently we compared the predictions of three of the mechanisms (analogy, knowledge compilation, and constraint violation) to one another in a laboratory study on transfer (Nokes, 2009). The results showed that each mechanism was distinct and identifiable and was triggered under different conditions depending on the participants' prior knowledge and the features of the transfer task. This investigation into the boundary conditions of each mechanism has begun to shed some light on the conditions that underlie successful transfer as well as why transfer might fail under some learning and test situations (Nokes & Belenky, 2011; Nokes-Malach & Mestre, 2013).

A Better Understanding of the (Mis)measurement of Transfer

A third major advance is the development of measurement innovations to better understand transfer phenomena. One recent taxonomy of transfer proposed by Barnett & Ceci (2002) aims to better conceptualize the transfer distance as a function of context and content. Context focuses on when and where knowledge is transferred along dimensions of time, modality, function, knowledge domain, physical space, and social setting. Content focuses on what is transferred, from near transfer of executing procedures to intermediate transfer of adapting procedures to far transfer of recognizing and relating concepts or principles to one another and to new problem features. This taxonomy affords both researchers and educators an opportunity to define and identify different types of transfer. No longer should researchers use a single term for describing transfer outcomes, but should instead use specific terms regarding transfer content and context. This may also help in understanding the mixed results in the literature. For example, different types of instructional conditions and learning processes may be better suited to support different types of transfer, and some types may have more support than others. The aforementioned work investigating which types of transfer processes are enacted depending on prior knowledge and features of the transfer problem may lead to further insights as to what types of transfer outcomes each process predicts.

Transfer as Preparation for Future Learning

A second measurement advance is the experimental formalization of the concept of preparation for future learning (PFL) (Bransford & Schwartz, 1999). PFL adds an important middle step to the classical paradigm: After some initial learning experience, the individual is given an additional learning opportunity or resource followed by the novel task. The idea is that the learning task creates some initial knowledge and, although this knowledge does not lead to direct improvement on the transfer problem, it "prepares" the learner for learning from the additional resource. The knowledge acquired from the learning resource then supports transfer. This broadens the definition of transfer and better captures some real-world transfer problem scenarios. For example, instructing students to read an assigned text before a lecture could impact what and how they learn from the lecture (learning resource), which could then affect later test performance. See Figure 1 for an illustration of this paradigm. One line of research using this paradigm has shown that invention activities (e.g., students attempted to discover statistical techniques to account for some observed data) better prepared students to learn from a new learning resource (e.g., a worked example) than more traditional tell-and-practice instruction (Schwartz & Martin, 2004).

Recent Advances in the Investigation of Motivation and Transfer

There has been relatively little prior work relating individual differences (e.g., developmental differences, cognitive factors, and motivation) and transfer. Here, we focus on individual differences in motivation because we believe it connects well to the context critique in that different types of contexts have implications for participants' motivation. Although motivation has been theorized to be an important factor for transfer, there has been little empirical work examining this connection until recently (e.g., Harp & Mayer, 1998). One motivational construct that prior work suggests may

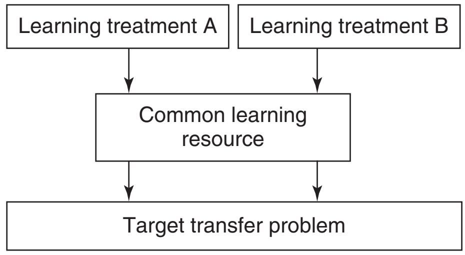

Figure 1 Preparation for future learning research paradigm, in which initial learning experiences prepare students to learn from a new resource, which in turn provides knowledge that can be transferred to a new problem. Adapted from "Inventing to Prepare for Future Learning: The Hidden Efficiency of Encouraging Original Student Production in Statistics Instruction," by D. L. Schwartz and T. Martin, 2004, *Cognition and Instruction*, *22*(2), p. 147. Copyright 2004 by Taylor and Francis Ltd.

be particularly relevant to transfer is students' achievement goals (Pugh & Bergin, 2006).

Achievement goals are the reasons people have for engaging in competence-based achievement activities, similar to those pursued in school (Ames & Archer, 1988; Dweck, 1986; Elliot & McGregor, 2001). One dominant theory of achievement goals is Andrew Elliot's 2×2 conceptual framework that specifies two dimensions of goals based on their definition and valence (Elliot & McGregor, 2001). Definition refers to whether the goal is focused on developing competence in comparison to an intrapersonally defined expectation or prior competence (mastery) or in comparison to others (performance). Valence refers to whether the goals are focused on seeking positive outcomes (approach) or averting negative outcomes (avoidance). Combining these two dimensions results in four types of goals: mastery-approach, mastery-avoidance, performance-approach, and performance-avoidance.

Each goal has been associated with different behaviors, affects, and achievement outcomes. Mastery-approach goals have been associated with positive outcomes such as better self-regulation, deeper cognitive strategies, more effort, and persistence in the face of challenges (Elliot, McGregor, & Gable, 1999). However, these goals only occasionally predict achievement outcomes as measured by grades. Performance-approach goals have been associated with good grades in school (Linnenbrink-Garcia, Tyson, & Patall, 2008), but they are also associated with superficial learning strategies (Elliot, McGregor, & Gable, 1999). Performance-avoidance goals have been associated with uniformly bad outcomes, poor achievement, test anxiety, and reduced interest (Elliot & McGregor, 1999; Elliot & Harackiewicz, 1996). Mastery-avoidance goals have been empirically examined only recently, but there is evidence that they are associated with positive behaviors, such as help-seeking, as well as negative behaviors, such as procrastination (Howell & Watson, 2007; Roussel, Elliot, & Feltman, 2011).

Recently, we have begun to explore the relationship between students' achievement goals, instruction, and transfer (Belenky & Nokes-Malach, 2012, 2013; Nokes & Belenky, 2011; Richey & Nokes-Malach, 2013). In two experiments, Belenky and Nokes-Malach (2012, 2013) found that students who reported high levels of dispositional mastery-approach goal orientation for mathematics were more likely to learn and transfer new statistics concepts than students who reported low levels of mastery-approach orientation. In contrast, none of the other achievement goals were predictive of transfer. Furthermore, we examined whether mastery goals could be promoted with invention activities. We found that students who were given invention activities followed by direct instruction were more likely to adopt state-based mastery goals during learning activities than students who were first given direct instruction followed by practice. Furthermore, this invention activity moderated the effect of students' dispositional mastery-approach orientations on transfer, such that students who entered the experiment low in initial mastery-approach goals were more likely to transfer in the invention condition than in the practice condition. We speculate that mastery-approach goals facilitated constructive cognitive processes such as analogy or self-explanation during learning and thereby created abstract knowledge that transferred. It is also possible that these goals helped during the test by encouraging students to actively seek out and make connections with prior knowledge. By exploring the connections between achievement goals and related cognitive processes, we move closer to developing a more comprehensive model of transfer (Nokes-Malach & Mestre, 2013).

FUTURE DIRECTIONS

In sum, although transfer is clearly a complex and multifaceted phenomenon, much progress has been made. The classical research paradigm has produced many advances in our understanding of the instruction, learning, and application processes that facilitate different types of transfer. We highlighted two learning paths of self-explanation and analogical comparison that have been shown to facilitate the far transfer of content. Future work should analyze what is known about these and other paths in order to construct a more general model of transfer.

We also described research examining the different cognitive mechanisms of knowledge application (e.g., analogy, knowledge compilation, and constraint violation). Recent work has found some initial evidence that these mechanisms are triggered for different types of transfer scenarios (i.e., prior knowledge and task features) and lead to different transfer outcomes (Nokes, 2009). We hope new research continues to test and refine these hypotheses as well as develop computational models of these mechanisms within the same cognitive architecture to further explore the relationships between them.

The field has also made progress in defining transfer. We believe that some of the enduring controversy can be traced to using a single term to refer to an array of different transfer processes and outcomes. Taxonomies such as Barnett and Ceci's can facilitate future progress by providing a shared terminology for researchers to better define and measure transfer phenomena. We also hope that researchers use these definitions to conduct meta-analyses of the existing literature to examine the relationships between learning variables, contexts, and types of outcomes. This taxonomy should be used in future experiments to specify more precisely the transfer outcomes and guide study to underexplored areas. Importantly, recent work has also begun to explore other experimental paradigms such as PFL (Bransford & Schwartz, 1999). The PFL approach has led to a broadening of the definition and measurement of transfer. Other types of transfer scenarios should be developed and explored.

Future work should also further examine individual differences in transfer. This critique prompted us to consider the effect of motivational variables on transfer. We have shown that there are strong relationships between mastery-approach achievement goals and transfer. However, there is much work to be done to test the relationship between these goals and cognitive processes. For example, do mastery-approach goals facilitate spontaneous analogical comparison or self-explanation? A major challenge for future work will be to develop a theory of transfer that connects cognitive factors and mechanisms to the broader instructional, motivational, and social aspects of the transfer context.

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