Resources, framing, and transfer

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Abstract

As researchers studying student reasoning in introductory physics, and as instructors teaching courses, we often focus on whether and how students apply what they know in one context to their reasoning in another. But we do not speak in terms of "transfer." The term connotes to us a unitary view of knowledge as a thing that is acquired in one context and carried (or not) to another. We speak, rather, in terms of *activating resources*, a language with an explicitly manifold view of cognitive structure. In this chapter, we describe this view and argue that it provides a more firm and generative basis for research.

In particular, our resources-based perspective accounts for why it is difficult, and perhaps unnecessary, to draw a boundary around the notion of "transfer"; provides an analytical framework for exploring the differences between active transfer involving metacognition and passive transfer that "just happens"; helps to explain many results in the transfer literature, such as the rarity of certain kinds of transfer and the ubiquity of others; and provides an ontological underpinning for new views of transfer such as Bransford, Schwartz, and Sears' (this issue) "preparation for future learning."

Introduction

As researchers studying student reasoning in introductory physics, we often focus on whether and how students apply what they know in one context to their reasoning in another. For example, we try to understand and facilitate the conditions under which students use their common-sense about physical phenomena as part of their reasoning in class; e.g., we study why knowledge that students display while answering qualitative questions often seems to evaporate when they address quantitative problems. Although many researchers would say we are studying *transfer*, the term and concept do not figure prominently in our work. Rather, we take *activation* as the central construct. We view students' everyday thinking as involving a myriad of cognitive resources, and we frame our questions in terms of when and how students activate those resources.

This chapter presents our resources-based framework of cognitive structure and discusses how it relates to research on transfer. We argue that the difference between "transfer" and "activation of resources" has substantive and generative implications for research and instruction.

What is transfer?

The term "transfer" does not figure in our work largely because we have difficulty drawing even a rough boundary around what it means. The following example from one of our recent classes illustrates the problem.

In a graduate course for pre-service elementary school teachers, students were working on the question *How big a mirror do you need to see your whole body?* "Sherry"

voiced what many thought was the obvious answer: You need a mirror the same size as your body, because your whole body has to be able to fit in it. Other students in her group used ideas about reflection to argue that the mirror would need to be half that size, but Sherry defended her reasoning. The next week she told her group about a discovery at home: She owns a mirror roughly half her height, and it shows a reflection of her whole body. She had known the answer to the question all along—she saw it every day.

How should we think about this episode, with respect to the notion of transfer? If Sherry had remembered her bedroom mirror during the classroom discussion, she would have known a half-height mirror is sufficient. On a traditional account, however, this would not have been an example of successful transfer, only of simple recall, since the classroom question precisely matched her daily experience.

As it was, Sherry's reasoning during that discussion drew on something other than her experience with mirrors. Perhaps it was her experience with *doors*; a life-sized door is required to fit her whole body. Perhaps it was her experience with *pictures*, printed on surfaces, that a life-sized image of her body would require a life-sized surface. Perhaps it was effectively both of these and other experiences abstracted into a generalization about objects and containers. Whatever knowledge she was using, however, it was not her direct experience with mirrors. Instead, Sherry was applying knowledge gained in some other contexts to a question about mirrors. If transfer is "the ability to extend what has been learned in one context to new contexts" (Bransford, Brown, & Cocking, 1999), then Sherry's erroneous reasoning qualifies. Transfer in this moment was not only easy; it took precedence over simple recall.

That episode illustrates theoretical difficulties discussed within the transfer literature (Barnett & Ceci, 2002; Bransford & Schwartz, 1999; Brown & Campione, 1984). To follow one vein of critique, Sherry's not using her experience from home to answer a question at school is analogous to subjects' not using everyday mathematical abilities at school (Carraher, Carraher, & Schliemann, 1985; Lave, 1988). But these accounts of cognition as situated or distributed conflict with the traditional, "cognitivist" framing of the transfer question, posed in terms of knowledge or abilities acquired in one context transferring (or not) to another (Greeno, 1997). From a cognitivist perspective, the view that Sherry initially failed to "transfer" her everyday knowledge to the classroom leads in the direction of considering all acts of cognition as transfer, including recall.[1]

Unitary and manifold ontologies of cognitive structure

The literature on transfer seems mostly phenomenological, exploring questions of whether and when transfer takes place and how to recognize it. For instance, in their excellent review, Barnett and Ceci (2002) have developed a taxonomy, listing phenomenological aspects of *where* and *when* to look for transfer, such as the knowledge

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[1] We could try to define transfer as occurring only when knowledge from one context is *appropriately* used in another context, or as involving school-taught (as opposed to everyday) knowledge only. But these escape routes are dead ends. It's implausible that the cognitive mechanisms by which knowledge is transferred/activated *inappropriately* differ from the cognitive mechanisms by which knowledge is transferred/activated *correctly*. Similarly, it's hard to imagine a distinction at the level of cognitive structure between school-taught and other knowledge, especially given the generally-held view that new knowledge is built from prior knowledge.

domain, the physical setting, and the time. Their taxonomy also distinguishes what kinds of knowledge might be transferred (procedures, representations, or principles) along with observable features of performance (speed, accuracy, approach).

In the transfer literature, discussions of cognitive structures and mechanism have focused on (1) the nature of the knowledge or skill hoped to be transferred and (2) the role of metacognition or metacognitive scaffolding in supporting transfer. Evidence suggests, for example, that deep principles are more likely to transfer than superficial information (Brown & Kane, 1988) and that transfer is associated with sophisticated metacognition, either self-directed or scaffolded by an instructor (Brown & Campione, 1984). However, the standard references cited in the literature pay little direct attention to the ontology of cognitive structure. What elements of cognitive structure do researchers attribute to the knowledge or ability they are investigating, to see whether it transfers? The tacit, default stance, as Greeno (1997) identified, is to think of the knowledge or ability as a *thing* that an individual acquires in one context and may or may not bring to another. We describe this as a *unitary ontology* (Hammer, 2004b), thinking of the particular piece of knowledge as an intact cognitive unit, in close correspondence with the observable idea or behavior, be it a principle, fact, or procedure. For instance, much of the conceptual change literature is consistent with a unitary ontology; researchers generally think of student (mis)conceptions as robust, intact elements of cognitive structure.

However, the cognitive objects we attribute to minds need not align closely with the ideas and behaviors we hope students to transfer: Ontology need not recapitulate phenomenology! For instance, what we observe as a student's "concept" of *force* need not correspond to a single, intact unit of cognitive structure. Our approach is founded on a manifold ontology of mind, of knowledge and reasoning abilities as comprised of many fine-grained resources that may be activated or not in any particular context. Cognitive science research has been pursuing an assortment of particular models (diSessa, 1993; Minsky, 1986; Thagard, 1989). Here we proceed from the most general assumptions about manifold structure and use the generic term "resources" to refer to components in that structure. Section 1 discusses our ontology in more detail.

To be clear: Our framework ascribes cognitive objects to individual minds, but at a finer grain-size than concepts or abilities as people experience them. In this view, knowledge and experience are emergent, analogous to other emergent phenomena in complex systems, in which the "things" we see—traffic jams, birds flocking, and so on—emerge from many small agents acting in local concert. In other words, we need to be alert to the tendency to "thingify" experience (Minsky, 1986; Wilensky & Resnick, 1999).

Like Greeno, we are skeptical of treating knowledge or abilities as things one acquires and manipulates as intact units. Following earlier work, however, our approach is cognitivist in the sense that we are concerned with the structure of an individual's mind: What are the parts from which we should build a model of an individual's reasoning? We are motivated by similar considerations raised by research on situated cognition, and we contend that a manifold ontology of mind supports views of knowledge and reasoning as situated.[2]

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[2] To preview what we argue below, the activation of finer-grained cognitive resources should often depend on the social and physical environment such that the resulting knowledge can coherently be attributed to the overall system (people + environment). In this way, a resources framework provides a mechanism by which elements of an

In a resources-based framework, we can view learning an idea not as the acquisition or formation of a cognitive object, but rather as a cognitive *state* the learner enters or forms at the moment, involving the activation of multiple resources. "Transfer" would then be understood in terms of the learner entering or forming a similar state later in a different context. In other words, rather than conceiving a unit of knowledge as *transferring* (moving) intact from one context to another, this view of mind centers on *activation* as the central theoretical construct.

For example, we think of Sherry (during class discussion) as activating resources for thinking about physical objects, to reason about the size of a mirror question, resources that could contribute to thinking about how large a doorway or canvas would need to be to contain an object or picture. By contrast, standing in front of her bedroom mirror activates different resources, perhaps the same ones she uses for understanding apertures; if looking at yourself "through" a mirror is like looking at a tree through a window, then it's obvious that you don't need a person-sized mirror, any more than you need a tree-sized window. Over the course of her inquiries, Sherry became aware of these two ways of thinking about mirrors, each "obvious" in its own setting but in conflict when held up for comparison. A crucial aspect of her learning was gaining knowledge about cognitive resources she already had — i.e., knowledge about her knowledge. In this way, a resources-based framework and the notion of activation provide a language for analyzing Sherry's cognition without needing to define whether "transfer" plays a role.

Outline of this chapter

In our view, the difficulties of drawing boundaries around the concept of transfer stem from an ontology of cognitive structure that is both tacit and unitary. In this chapter, we argue for the value of taking an explicitly ontological, mechanistic approach to describing transfer phenomena. Specifically, we argue that a manifold, resources-based ontology avoids the difficulties with the notion of transfer but allows discussion of the same phenomena.

The remainder of this chapter consists of two sections. In the first, we describe the beginnings of a theoretical framework of *resources* and *framing*. We start with a review of this manifold ontology of mind, contrasting the notion of conceptual and epistemological *resources* with unitary views of *(mis)conceptions* and epistemological *beliefs*. We then review research from linguistics and cognitive science on *framing*, which provides a complimentary perspective to research on transfer in that the core phenomena it describes are the context-dependent coherences of individual's interpretations of social or natural phenomena. In our ontology of cognitive structure, framing corresponds to locally coherent activations of resources. Using two examples of *epistemological framing* in college physics students, we illustrate these ideas and examine how they compare with accounts of transfer.

In the second section, we revisit familiar issues from the transfer literature, including the rarity or ubiquity of transfer; passive and active mechanisms of transfer and the role of metacognition; and "sequestered problem solving" versus "preparation for future learning" (Schwartz, Bransford, & Sears, this volume). Discussing these issues from a resources perspective, we argue that

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individual's mind interact with elements of the social and physical environment to create knowledge that's situated or even distributed.

- the core phenomena of transfer are special cases of more general cognitive mechanisms;
- a view of manifold resources provides a more generative basis than unitary views for further research on these and related phenomena; and
- a view of manifold resources provides a more generative basis for curriculum and instruction focused on student knowledge and reasoning.

Section 1: Resources and framing

Here we (i) present a manifold, resources-based view of cognitive structure, (ii) review the notions of *frames* and *framing* and integrate those ideas into our resources-based ontology, and (iii) illustrate these ideas with two brief case studies.

A manifold, resources-based view of cognitive structure

In this section, we outline the resources perspective on cognitive structure, starting with students' intuitive conceptions, then moving to students' intuitive epistemologies.

Resources vs. conceptions

Research on misconceptions posits *conceptions* as cognitive units. Studying student reasoning about mirrors, for example, a researcher might attribute as a misconception the view that images are formed on mirror surfaces or that images travel as intact objects. Either of these conceptions could be responsible for the idea that you need a full-length mirror to see your whole body reflected.[3] The conception is the basic unit of cognitive structure, and an incorrect conception impedes progress toward expert understanding. In some cases, attributing robust conceptions is appropriate, but resources-based accounts afford the alternative of understanding the conception as a local or momentary activation of another sort of cognitive structure. diSessa's accounts of "phenomenological primitives" (diSessa, 1993) and "coordination classes" (diSessa & Sherin, 1998), for example, attribute cognitive structures at other levels, as mini-generalizations from experience whose activation depends sensitively on context. We could understand a student's thinking that full-length mirrors are needed for full-length images in terms of the activation and coordination of resources appropriate for thinking about physical objects. In another context, where those resources are not activated (e.g., Sherry standing in front of her bedroom mirror), the student would not have that idea.

Notice a key difference between these two theoretical frameworks. In the conceptions view, the students' explanation is assumed to stem from "pre-compiled" knowledge that is simply wrong, a robust conception about mirror images. In contrast, according to our resources-based interpretation, the student compiles her explanation in real time from conceptual resources that are neither right nor wrong. Although applied incorrectly here, the resources and coordinations for thinking about physical objects are clearly useful in other contexts.

An example from diSessa (1993) illustrates the explanatory power of this perspective. When asked about the forces acting on a ball that was thrown straight up, many students initially reason in a way that is consistent with the *motion requires force* misconception. Specifically, they say the ball feels a downward force from gravity and also an upward force that decreases as the ball loses speed. Students rarely say something as precise as "the upward force is proportional to the upward velocity," but

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[3] Some might suppose the incorrect answer itself is the misconception.

their reasoning strongly implies that the upward force will approach zero as the ball comes to rest. However, when these same students consider the moment at which the ball comes to rest at its peak, many of them say the ball feels equally strong upward and downward forces. This response contradicts their earlier reasoning that the upward force should approach zero as the ball comes to a stop.

In a conceptions framework, it is difficult to account for why students would so quickly and easily drop a robust conception. In contrast, a resources framework readily explains — and even predicts — these kinds of shifts. Thinking about the rising ball, students are likely to activate *maintaining agency*, the idea that effort must be continued in order to maintain the effect ("if you stop pushing, it'll stop moving"). *Maintaining agency* causes students to think that a continued upward "influence" must act on the ball to keep it moving upward. Asked about forces, students unconsciously map "influence" onto "force," leading to an explanation that's consistent with the *motion requires force* misconception. Thinking about the motionless peak of the trajectory, however, students' intuitive sense of *balancing* turns on; an upward something seems to be balancing a downward something. Asked again about forces, students map that "something" onto force and say the forces balance. This example illustrates how a resources framework naturally accommodates the observed context dependence of students' reasoning.

We have been most influenced in our work by diSessa's accounts (diSessa, 1993; diSessa & Sherin, 1998), but there have been others in the literature, including Minsky's (1986) notion of a mind comprised of a "society" of "agents" and Thagard's (1989) model of "explanatory coherence" among "propositions." Here we proceed from the most general attributes of a manifold cognitive structure and use the term "resources" to refer to cognitive elements in that structure.

All of these views include mechanisms for primitive structures to combine into larger ones. DiSessa and Sherin (1998) discuss coordination classes as internally coherent networks of primitives and "readout strategies." Minsky (1986) posits "k-lines" as patterns of association among agents, and "frames" as structures of agents that organize expectations, drawing on earlier work by Schank (1982).. Thagard (1989) models locally coherent networks of propositions.   Again, we are trying to draw general features of a resources-based approach, taking from these efforts the generic notion of locally coherent sets of resource activations that may, over time, become established as resources in their own right. We say more about frames and framing below. Here, we note that we use the term "frame" generically to refer to a locally coherent set of activations, without attributing the more specific properties in Schank's and Minsky's usage.

In this way, a resources-based ontology can accommodate the formation of concepts such as *Force* in an expert physicist's understanding, as well as some novice misconceptions. For instance, although the above example shows that students don't apply *motion requires force* with theory-like consistency, they *do* behave consistently with that misconception over a broad range of circumstances. In the resources framework, however, even a fully-compiled conception is assumed to be built from finer-grained knowledge elements that have become tightly linked. For example, *motion requires force* might be built from *more effort* → *more result* (with force mapped onto "effort" and velocity mapped onto "result"), *maintaining agency* (with force as the agency needed to maintain velocity), and other conceptual resources.

Epistemological resources

To see how the distinction between the conceptions and resources framework plays out in interpreting student epistemologies (their views about the nature of knowledge and learning), consider a hypothetical physics student named Dan. Even when a reform-minded physics lesson tries to elicit his intuitive ideas, Dan answers in terms of remembered facts and equations. Why? According to the conceptions-based framework adopted by most epistemology researchers, Dan's behavior probably stems from the epistemological *belief* that physics knowledge comes from authority, or that physics knowledge consists largely of facts and formulas. In that case, changing Dan's behavior would likely involve an attempt to confront and replace his epistemological "misconceptions" with more productive beliefs.

The resources framework provides an alternative interpretation and instructional strategy. Dan's focus on facts and formulas probably arises not from a stable, unitary belief, but from the context-sensitive activation of finer-grained *epistemological resources*. Dan has a variety of resources, just as young children have a variety of ways of understanding knowledge and how it may arise. For instance, when asked how she knows what's for dinner, the child might respond "Daddy told me," reflecting the activation of the resource *knowledge as transmitted stuff*; the child views knowledge as a thing that can be passed from one person to another. The same child, when asked how she knows mommy got her a present, might reply, "I figured it out, 'cause it's my birthday and I saw you hiding something." This answer reflects the activation of the resource *knowledge as fabricated stuff*, corresponding to the view that knowledge is built up from "raw materials" such as prior knowledge about birthdays and observations of sneaky parental behavior. So, the same child has multiple epistemological resources for understanding the source of knowledge, and these different resources get activated in different contexts. Along the same lines, we can explain Dan's behavior as stemming from the inappropriate activation of resources such as *knowledge as transmitted stuff* and the underactivation of resources such as *knowledge as fabricated stuff*.

According to this framework, we can help Dan change his approach to reform-minded physics instruction by helping him activate epistemological resources he already possesses and applies in other contexts. For instance, Dan may rely on his common-sense ideas when thinking about wave phenomena he sees at the beach, or when discussing Hamlet's motivations in literature class. As instructors, we would try to help Dan "find" those resources and activate them in physics class.

In a framework currently under development (Hammer & Elby, 2002; Redish, 2004), we posit the existence of numerous metacognitive and epistemological resources, including ones for understanding the source of knowledge (*Knowledge as transmitted stuff*, *Knowledge as fabricated stuff*, *Knowledge as free creation*, and others); forms of knowledge (*Story*, *Rule*, *Fact*, *Game*, and others); knowledge-related activities (*Accumulation*, *Formation*, *Checking*, and others); and stances toward knowledge (*Acceptance*, *Understanding*, *Puzzlement*, and others).[4] Preliminary empirical work suggests that, perhaps to a greater extent than conceptual resources, epistemological resources tend to become activated in locally coherent sets, the nature of which we discuss further below.

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[4] Our theoretical framework incorporates a distinction we've glossed over here because it's not important in what follows, the distinction between *metacognitive* resources for building and manipulating knowledge and *epistemological* resources for understanding the nature of knowledge and knowledge-building (Kitchener, 1983).

Frames and framing

The shift in ontology from unitary concepts or beliefs to manifold resources is motivated by observations of flexibility and variability in student reasoning: Thinking in terms of manifold cognitive elements allows models of mind that can respond differently in different moments. But the variability is not haphazard; resources do not activate and deactivate randomly. The variation we hope to understand is better characterized as among multiple coherences.

There is a rich phenomenology of multiple coherences in linguistic and anthropological research on *frames* and *framing*, where a frame is an individual's interpretation of "What is it that's going on here?" and the gerund form emphasizes interpretation as an ongoing process (MacLachlan & Reid, 1994). To frame an event, utterance, or situation in a particular way is to interpret it in terms of structures of expectations based on similar events. Framing is typically tacit, but is all the more powerful for its implicitness. For example, monkeys engaged in biting each other are skilled at quickly and tacitly "deciding" whether the biting is aggression or play (Bateson, 1972). An employee may frame a gift from her supervisor as kind attention or as unwelcome charity. A student may frame a physics problem as an opportunity for sense making, or an occasion for rote use of formulas.
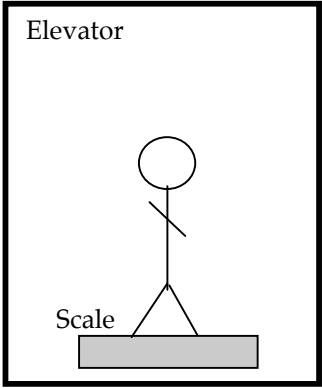
The term "frame" is used in a variety of ways in the sociolinguistics literature (MacLachlan & Reid, 1994; Tannen, 1993). Our use of the term is mainly after linguist Tannen (1993) , anthropologist Goffman (1986), and the discourse analysts reviewed by McLachlan and Reid (1994). Along with Tannen, we seek evidence of framing mainly in speech and other communicative acts. By a "frame" we mean, phenomenologically, a set of expectations an individual has about the situation in which she finds herself that affect what she notices and how she thinks to act. An individual's or group's framing of a situation that can have many aspects, including social ("Whom do I expect to interact with here and how?"), affective ("How do I expect to feel about it?"), epistemological ("What do I expect to use to answer questions and build new knowledge?"), and others. For instance, two students in a large lecture class might frame the situation in the same way socially, expecting to sit still and speak only when called upon, but frame it in different ways epistemologically: One may expect to deliberate over what the professor says, while the other may expect to record information.

Turning back to ontology, we take framing as the activation of a locally coherent set of resources, where by "locally coherent" we mean that in the moment at hand the activations are mutually consistent and reinforcing. For instance, each of the students sitting in lecture has activated a locally coherent set of epistemological and other resources for framing the activity epistemologically, and also a locally coherent set of resources for framing the activity socially. The phenomenology of framing corresponds, in this model, to a distributed encoding—the interpretation is distributed across a network of cognitive elements rather than located in any particular one. We mentioned some specific models of distributed encodings above, including coordination classes (diSessa & Sherin, 1998) and cognitive "frames"(Minsky, 1986; Schank, 1982). Again, we are taking a more generic approach, trying for the most general assumptions: Resources activate in sets, and a set that activates again and again may eventually become established sufficiently to act as a cognitive unit itself.

Example 1: Negotiating a frame for a physics problem

Frames are most visible when they are called into question. The examples of framing in this chapter are mostly occasions for *frame negotiation* – moments when the participants challenge each others' understanding of "what's going on here." Consider the following excerpt from a discussion among three students who met regularly to do homework for their algebra-based introductory physics course at the University of Maryland.[5] We draw this example from Jonathan Tuminaro's dissertation (Tuminaro, in preparation).

       "Tracy," "Sandy," and "Leslie" are working on a problem in which a person is standing on a scale in an elevator (Figure 1). The students have already drawn correct free-body diagrams for the person and for the scale (that is, they have correctly indicated the number and direction of forces on each of those objects, and identified the object that exerts each force – see Figure 2). Initially, the elevator is moving downward at constant speed. The students have correctly ranked the magnitudes of the forces for that case. In the excerpt, the students are starting to consider the question of which forces, if any, would change magnitude if the elevator begins to accelerate downward.

A person stands on a scale in an elevator as shown at the left.

A.   At first, the elevator is moving downward at constant speed. Draw free-body diagrams for (a) the person and (b) the scale. For each force on your diagrams, indicate the object that exerts the force and the object on which the force is exerted. Rank the magnitudes of all the forces from largest to smallest.

B.   Later, the elevator accelerates, increasing its downward speed by 8 m/s in 6 s. Which of the forces on your free-body diagrams, if any, change magnitude while the elevator is accelerating? Do they increase or decrease?

Figure 1: The elevator problem.

       Tracy initially seems to be framing the problem as a quantitative one, an occasion to apply physics formalism, laying out all the numerical quantities in the problem, apparently expecting some algebraic manipulations to answer the question. Sandy, on the other hand, seems to have a different expectation, asking whether they "even need to do all that calculation" and doubting that "they're asking for it [calculation]." Viewing the question as an occasion for intuitive sense-making (rather than calculation), Sandy proceeds to construct a narrative of the physical mechanism by which the so-called "normal" force changes magnitude. Sandy's narrative is informal and significantly aided by gestures, which we note in the transcript between slashes (/like this/). Algebra is conspicuously absent. The other students give indications that

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[5] We videotaped the students in a room that we provided for their use. The room is staffed by at teaching assistant who is available to help the students if they need it, but the TA is not present for the exchange shown here.

they understand Sandy's argument, and the group frames the next several questions that arise in terms of this informally mechanistic, almost kinesthetic analysis.
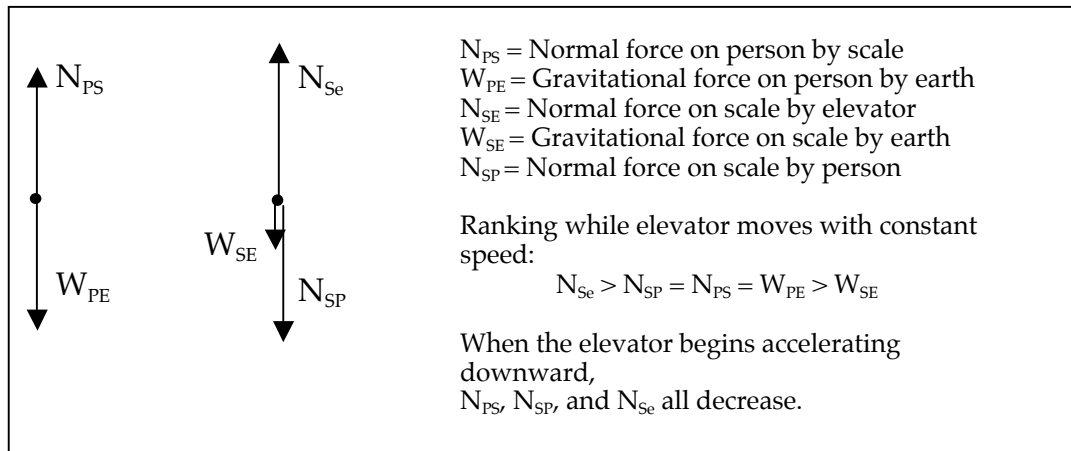

Figure 2: Free-body diagrams for (a) the person and (b) the scale in the elevator problem. The notation is the same as the students'.

The contrast between Tracy's and Sandy's initial frames is indicated by linguistic markers described by Tannen (1993), including change of register (falling vs. rising intonations), switch from turn-taking to overlapping speech, and the introduction of gestures. Word choices further indicate the presence of contrasting expectations; for example, when Sandy says "Do we even need to do all that calculation?" it communicates a sense that Tracy's approach is excessive ("even," "all that") and possibly uncalled for ("do we need to?").

Tracy: Okay, so we know… they gave us the weights, so we know that the person is eighty kilograms and the scale is seven. And, we determined the acceleration.

Sandy: Do we even need to do all that calculation?

Tracy: I don't know.

Sandy: I don't know if they're asking for it.

Tracy: They don't want numbers, but we couldn't really figure it out so we thought maybe numbers would help.

Sandy: Yeah. Well, does um… let's see the… [points to diagram] N_{PS} would—wouldn't you think that'd decrease? At—initially? ⌉
|
Leslie: ⌊When we're accelerating downward.

Sandy: Right when the⌉
|
Leslie: ⌊ The force of the ⌉

|
Sandy: ⌊Like the, it's almost like /palm up/,
   you can look at it and exaggerate it like the elevator pulls away from the person
   first /palm flips down/ and the person has to

Tracy: Oh,

Sandy: catch up to it.

Tracy: That makes sense. And that's why the person would weigh less.

Sandy: Right. [Leslie nodding]

Tracy: Which is what I remember from high school physics.

Sandy's question marks a bid to define the problem as an occasion for kinesthetic sense making rather than quantitative analysis. The group's definition of the problem type will dramatically affect their next steps; the choice is between one set of resource activations and another, each set including epistemological resources for understanding what sorts of knowledge are relevant, metacognitive resources for forming and manipulating those kinds of knowledge, and of course conceptual resources for understanding motion and forces in elevators. *Framing*, then, is (i) the forming of this set, and then, once it is formed, (ii) the use of those resources to interpret utterances, sensory inputs, and so on. For instance, Sandy frames the activity as intuitive sense-making, corresponding to definition (i). Soon afterwards, everyone frames Sandy's reference to "N_{PS}" not as an algebraic symbol to be manipulated but as a *push* of the person against the scale to be reasoned about intuitively, corresponding to definition (ii). That is, these two senses of framing refer to (i) forming and then (ii) applying a locally coherent set of resources, both of which can happen either beneath conscious awareness or in response to explicit frame negotiation.

Frames can often shift easily, as seems to happen here: The students have no difficulty making the transition from one kind of conversation to another. Nor will they have any difficulty making the transition back; in fact, Tuminaro (in preparation) documents such shifts occurring with and without explicit comments, by students or instructors, apparently with and without students' explicit awareness. In other instances, however, frames are "sticky," resistant to shifts even when challenged (see below).

Referring to the formal calculation and intuitive sense-making frames exhibited above, we use the term *epistemological frames*, because those frames answer the question, "how should I approach knowledge?"

In our theoretical perspective, framing generally involves the activation of numerous low-inertia cognitive resources rather than a single, high-inertia cognitive unit. Therefore, the resulting cognitive and behavioral stabilities are local to the moment. However, as we noted, when the same locally coherent set of resources becomes activated again and again, it can eventually become sufficiently established to act as a unit. The next example suggests the role of more established epistemological frames.

Example 2: A lasting shift of frame
The frame shift presented above was probably local to the moment; students were monitoring and shifting their approach to a particular problem, but not necessarily their general approach to learning physics. Working on subsequent problems, the students fall back on old ways, failing to apply physical intuition to support formal problem solving. As physics instructors, we are interested in students taking productive approaches to learning, and there are two sorts of strategies we use to facilitate that.

One is to manipulate the context — the wording and representation of questions, the social setting and structure of lectures and recitation section, and so on — to try to tip students into the desired frame. Over time, we hope, students develop a habit of working in these ways, making the students easier to tip. And in the long run, we hope that tipping becomes unnecessary, as the desired frame crystallizes into sophisticated beliefs and approaches toward learning physics in general.

With some of our students, this appears to happen. But of course, by the time they reach us, students have older, more ingrained habits for approaching classroom science, including some well-established epistemological frames that are undesirable from our standpoint.   For this reason, we do not rely entirely on "passive" reframing, in which contextual cues cause reframing to just happen in our students. We also appeal to active reframing, encouraging students to monitor actively their approach to learning. In other words, we try to get students to take an intentional stance toward epistemological framing. The following is a (sadly atypical!) example of how this can happen.

"Louis" was taking the second semester of one of our reform-oriented introductory physics courses, after taking his first semester in a conventionally taught section. On the first midterm exam, he got one of the lowest scores 36% out of the class of 120 students. A week and a half later on the make-up exam[6], his score jumped to 84%, the highest score on the make-up and near the top of the original distribution, by far the highest gain out of the 42 students who took the make-up. In an interview with Rachel Scherr, on the assurance that she would not leak anything to the instructor until the course was over and grades submitted, Louis gave his understanding of what had happened.

> Louis: I studied a lot for the first test. I studied every word of those homework solutions. And I studied a lot more for the first test than I did for the retest. And um then so I went into the first test thinking I would do really well.

After he had done so poorly on the exam, he went to see the instructor to ask, not about physics content, but about his approach to learning in the course.

> Louis: I said I was looking at the homework solutions and I was, I was memorizing the book too, the Cutnell and Johnson book (Cutnell & Johnson, 2001)? And um the advice that he gave me he said, 'When you study, try to explain it, try to explain it to a ten-year-old.' So I said okay. [But] I still was confident I knew the stuff and then he goes, 'okay then what's voltage?' I was like 'voltage, V=IR?' I gave him a formula he's like, 'okay what's voltage?' I was like 'I don't know [laughs].'

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[6] Our practice in these courses is to give students the opportunity to take a make-up exam, and we average the scores obtained on the original and make-up exams. As much as we can manage, the original and make-up exams are of equivalent difficulty.

Louis noted that the instructor had given this sort of advice before, but Louis hadn't believed it.

> Louis: He was saying in the beginning before the first test, [the instructor] was saying, "think of an analogy." Exactly what I did before the retest. But when he was saying it the first time, he said it and I was like, "whatever." Because in all, especially in my like chemistry classes, the way I did well on the exam is like flash cards of different reactions and memorize it and the better I memorized it the better I did on those exams.

Now he decided to try it.

> Louis: I went back and I actually wrote down, I wrote down like an explanation to a ten-year-old. I used an analogy, I used like dump trucks? And the dump trucks were the voltage carrying across the highway the little line you draw in the circuit, and uh the a resistor was like a traffic accident. Like a resistor would like stop sign so it'd be harder to get through. And […] if the circuits are parallel it'd be like the highway is splitting. So more current would get through.[…] Then I went back to the homework solutions again but instead of like memorizing them I would try and relate my analogy with the dump trucks to the answers in the solutions. The dump truck analogy was like common sense to me. If there's a traffic accident less traffic's going to get through it.

The "dump truck" analogy was his own. Explaining it during the interview, he confused current with voltage; it would make more sense if dump trucks were units of charge. Indeed, the evidence does not show he had formed a fully expert conceptual understanding. His later performance on exams, however, shows that he made great progress. He ended up in the top quarter of the class with an overall grade of B+.

Six months later (without any intervening contact with researchers or the instructor) he left a note under the instructor's door:

> Hi. This is Louis Schuster [pseudonym] from LAST SEMESTER physics…. I just wanted to stop by and say hi. I also wanted to tell you that since I've taken your class, I have a 4.0 GPA, compared to a much lower GPA before your class. I think this increase in GPA has a lot to do with the things I learned in your class — not about physics, but about learning in general….

In a brief e-mail exchange after he left his note, Louis noted that he did, in fact, have experience working with children, both as a camp counselor and as an older brother. He had also worked as a tutor in the campus writing center and informally for his roommate in Calculus, which he said he mentioned because "I use a similar strategy when tutoring-what I like to do is build on what they already know instead of introducing a totally new concept—kind of the way you would explain something to a 10 year old."

This episode interests us, of course, because we want this sort of thing to happen more often. In particular, to the extent possible from the limited data, we would like to understand (i) why the instructor's brief, one-time intervention, centered on approaches to learning, had such a dramatic effect, and (ii) why similar interventions with other students usually have less dramatic effects.

As instructors, we try in various ways to encourage students to use their everyday knowledge and reasoning to build and check their understanding of the ideas in the course. One of these ways is the suggestion here, that students try to explain the ideas as if they were talking to an intelligent child. In giving this advice, we don't expect that most students actually have experience with children. Rather, we expect that students have productive epistemological resources for understanding the activity

of intuitive sense-making, and we suspect that for some students the advice to "explain it to a child" might help activate those resources. The child, we hope, personifies "everyday thinking"; in another version we suggest students think about "what would your non-scientist roommate say?" In other words, we hope that imagining the context of talking to an everyday thinker might nudge students into an intuitive sense-making epistemological frame.

There are several reasons the intervention might have been so effective with Louis. First, he had done very poorly on the first midterm, and this surprised and concerned him. As he explained in the interview, he was taking the same approach he had used in the first semester course: "I just memorized things. And I did okay in it." Coming to speak with the instructor, Louis was already thinking about his overall approach to learning—he was looking for help at an epistemological level.

Moreover, from his experiences as a tutor and, perhaps, from working with children, Louis appears to have established a locally coherent set of epistemological resources—an epistemological frame — for understanding learning as building on prior knowledge. Although he had yet to activate this set of resources in his role as a physics student, they were part of his thinking about contexts of teaching. On this view, Louis's success was analogous to Sherry's, in the opening example of the chapter, activating something he had "known all along" about learning, just as Sherry discovered something she had known all along about mirrors. By contrast, although students have resources for forming Louis's epistemological frame (or so we assume), few may have established it as a resource available for conscious activation and monitoring.

These are two examples of epistemological framing and the possibility of transitions between frames. We have been studying transitions of various kinds (Hammer, 2004a), both student-generated and instructor-prompted. Louca, Elby, Hammer, and Kagey (in press) discuss how a third grade teacher successfully uses an epistemological prompt in guiding her students to talk about proximal mechanism rather than teleology when discussing why autumn leaves change colors. Rosenberg, Hammer and Phelan (Under review) discuss the effect of an eighth grade teacher's prompting students to "start from what you know, not from what the sheets say," in devising a model of the rock cycle. Their analysis includes a "toy model" of the internal coherences of the students' different approaches. Lising & Elby (Under review) discuss shifts in a college student's epistemology prompted by different settings, an introductory physics course or clinical interview in the education building.

In some of these cases, we might speak in terms of transfer, for example, to describe Louis as transferring epistemological knowledge that he developed from his experience as a tutor. That description works well when we are talking about a well-formed cognitive structure developed in one context being activated in another. To the extent that Louis had previously established an epistemological frame that he came to activate *as a cognitive unit*, a description in terms of transfer and our description in terms of resource activations may be equivalent. Thinking in terms of resource activations, however, not only allows us to consider a wider range of possibilities, but also has other advantages, which we review in the next section.

Section 2: Transfer

The core question of transfer research seems to be this: *If students are taught X in some context, what affects whether and how they use X in some other context?* X has varied in the literature from general intellectual ability (by some accounts the original motivation of transfer research was to understand the value of studying Latin in 'training the mind') to particular ideas and strategies. The literature raises a number of concerns about that question (Barnett & Ceci, 2002; Bransford et al., 1999; Bransford & Schwartz, 1999; Mestre, 2003).

First, while educators (including ourselves) naturally focus on whether students learn and use what we teach, what students actually learn may be quite different from that. Students, of course, learn much that instructors do not intend, in and out of class. As a psychological construct, the process of transfer of correct, intended ideas should not differ from the process of transfer of incorrect, unintended ones. Focusing on student knowledge and reasoning, rather than on instructional objectives, evidence of transfer can seem pervasive. Indeed, the phenomenon of misconceptions so often discussed in science education could be interpreted as persistent but undesirable transfer, often termed "negative transfer" (Bransford et al., 1999).

This, in fact, may be one way to understand the evidence that transfer is rare: If students constantly transfer from all parts of their knowledge and experience, it may be difficult to induce them to favor the particular knowledge, X, probed by a particular study. Nonetheless, understanding when and how students transfer knowledge from one context to another could provide instructors guidance for helping students transfer X.

A further difficulty with the core question of transfer research, as Barnett and Ceci (2002) have discussed, is that it begs the issue of what is a context. What, in principle, distinguishes using X again within the same context and transferring X to another? Barnett and Ceci (2002) lay out a taxonomy of different ways contexts can vary, but the question remains of where along any of these dimensions to demark one context from another.

Finally, there is the difficulty of what behaviors instructors should reasonably expect to see in students, having taught them X. As Schwartz, Bransford & Sears (this volume) review in their discussion of "sequestered problem solving" versus "preparation for future learning," students who do not immediately apply X in a new context may still be better prepared to re-learn X in that context. From our perspective, this distinction is difficult to discuss if X is an intact cognitive object. That is, we see much of the confusion in the transfer literature as deriving from tacitly unitary views of knowledge, the view of X as a cognitive unit, whether X is a general intellectual ability or a particular idea. The term "transfer" itself promotes the metaphor of knowledge as a *thing* acquired in one context and brought (or not) to another. When explicitly considering this issue, many researchers would reject this metaphor. But in the transfer literature, there has been little direct attention to the ontology of cognitive structure.

Our purpose in this section is to compare and contrast the theoretical framework we reviewed in Section 1 with the concept of transfer. We argue that a resources-based ontology provides a firmer, more generative basis for progress. First, we discuss mechanisms of activation and stability, within the resources ontology, and how this ontology might contribute to discussions about the role of metacognition. We then revisit instances from this chapter and from the transfer literature.

Passive and deliberate mechanisms of stability

From a unitary perspective, learning a new idea or ability entails *acquiring* it as a thing — it's *in there*, and the question is whether the learner uses it in another context. From a manifold view, by contrast, learning the idea or ability in any context corresponds to activating a set of resources, each generally at a finer grain size than the idea or ability itself. The phenomenon of transfer then corresponds to a similar set of activations occurring later. The set of activations does not necessarily exist as a unit; it is an event, and the question is whether that event recurs. In this section, we discuss three mechanisms by which a set of resource activations becomes stable, that is, reliably mutually activated and locally coherent within a given context.

One mechanism is *structural:* If resources have become compiled into a unit, their mutual activation and coherence are built into the cognitive structure itself. We defined a frame as a set of locally coherent activations, and a frame can become established as a kind of cognitive object (and so, a kind of resource itself) if it recurs often. We draw an analogy to neuroscientists' models of synaptic connections becoming reinforced with repeated use.[7] For instance, the arrival of *object permanence* in early childhood might be understood in terms of a locally coherent set of resources, for understanding causal mechanism and for sensorimotor input and actions, that activate as a set again and again until the pattern becomes established and permanent as a cognitive unit in its own right. diSessa and Sherin (1998) and diSessa and Wagner (this volume) discuss such a unit as a "coordination class."

A set of resource activations can also be locally coherent for non-structural reasons. Mestre and his collaborators (Mestre, Thaden-Koch, Dufresne, & Gerace, 2004; Thaden-Koch, Mestre, Dufresne, Gerace, & Leonard, this volume) discuss coordinations as well, in their account of subjects' perceptions and reasoning with respect to a standard introductory physics demonstration showing two balls racing on differently shaped tracks. Mestre and his colleagues simulated the motions and presented different possibilities to students, asking them which motions appeared most realistic. They found that a certain motion, when viewed by itself, was rejected by many subjects as absurd; but the very same motion, when viewed in the context of a race between the two balls, was rated "highly realistic" by those same students.[8] The students are systematically inconsistent: subjects' reasoning is reproducible and locally coherent, but sensitive to the difference in context between the two situations. In this case, we suggest, there are two sets of locally coherent activations, coordinating "readout strategies" and elements of causal mechanism, one corresponding to "absolute velocity," the other to "relative velocity," as Thaden-Koch *et al.* (this volume) and diSessa and Wagner (this volume) suggest. But there is no reason to treat both sets of activations as structurally stable cognitive units. Their stability remains tied to features of the context.

Consider one further example, now to model a student's reasoning about the Newtonian concept of *force.* For experts, this might be an established coordination class,

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[7] We defer consideration of whether this is more than an analogy.

[8] As Thaden-Koch *et al.* (this volume) discuss, students viewing the motion in isolation attended to its absolute motion, while students viewing the race attended to the relative motion of the two balls. As a result, many students who expected the race to end in a tie rated the "absurd" motion as realistic in the context of the race, since that motion kept the two balls next to each other.

and hence, structurally stable; but we contend that coherence among resources that make up the concept of force cannot take place spontaneously from experience. Everyday experience alone would not provide a context for activation and reactivation of this set. (Evidence for this comes from thirty years of survey and interview data showing that people's reasoning about forces and motion are not generally consistent with Newton's laws.) Because a deep understanding of those laws involves careful reconciling of initially-counterintuitive ideas with everyday experiences and common-sense ideas, the expert *force coordination class* can come into being only in conjunction with epistemological resources activated for understanding consistency and for understanding the value of combining formal and informal knowledge. That is, the learner must actively monitor her thinking to ensure that her resource activations are globally coherent, rather than relying on features of the context to "enforce" that stability.

We have distinguished two sorts of resources, conceptual and epistemological/metacognitive, the former for understanding physical phenomena, and the latter for understanding cognitive phenomena. We expect that an adequate description of mind would include a much larger assortment; this dichotomy is a convenient simplification for our purposes here. In particular, we use it to distinguish *passive* activation, which we take to involve only cognitive resources, from *deliberate* activations in which metacognitive resources play a role.

Thus we are identifying three mechanisms for stability in a set of resources. One is *contextual*, a passive activation based on the situation, where by "passive" we mean that the pattern forms and persists without metacognitive resources playing any role. For instance, the infant need not have any resources for thinking about her knowledge in order to activate a local coherence that corresponds to experiencing something as an object. Research on older children has shown that knowledge and abilities can form without any resources for reflecting on those abilities (Karmiloff-Smith, 1992; Siegler & Stern, 1998). Similarly, the students in the balls-rolling-on-tracks studies (Mestre et al., 2004; Thaden-Koch et al., this volume) were locally coherent in each context, but not because they were attending to their reasoning. The coherence derived from how their cognitive resources responded to the situation, what Greeno (1997) describes as an "attunement to constraints." As the learner activates the same set of resources again and again, it can become cued more easily, leading over short intervals of time to the classic phenomenon of "einstellung" (Luchins, 1942). Over time, the pattern may develop its own integrity and become less dependent on the contextual cues, leading to structural stability as discussed below.

A second mechanism is *deliberate,* meaning that it involves epistemological / metacognitive resources. To reason in a manner consistent with the Newtonian definition of force, a learner generally needs to monitor what conceptual resources she is activating and how. We say "generally" because it is possible to contrive a context in which that coherence results from passive attunement; students working in a Newtonian microworld, for example, may activate resources accordingly. In most situations, however, deliberate attention is needed to maintain coherent activations corresponding to the concept of *force* (Sinatra & Pintrich, 2002). Over time, the pattern can become established: Just as a teacher can let scaffolding fade over time when helping students learn a problem-solving approach, an individual can become less mindful of her own reasoning. In other words, a pattern of activations maintained by active monitoring can become automated with repeated use, reducing the importance of active monitoring.

The third mechanism for stability, again, is structural. With reuse, a set of activations can become established to the point that it becomes a kind of cognitive unit, and so a kind of resource in its own right. For instance, an infant comes to think about "objects" in a fairly consistent way across a wide range of situations. The cognitive unit can have its own activation conditions, passive or deliberate. But once activated, the internal coherence in the resource activations is automatic. The coordination classes of *object* and of *force* (diSessa & Sherin, 1998) both eventually form an integrity such that the concept can be understood as corresponding to an essentially fixed cognitive structure. Its *activation* continues to depend on context, like any other resource, but its stability does not.

Defining "context" and "transfer"

Barnett and Ceci's (2002) taxonomy outlines ways in which a context may vary. Some ambiguity remains, however, about when and how along these dimensions to draw lines between contexts. To consider the example at the opening of this chapter, for instance, it would be reasonable to expect that "looking in a mirror" would be sufficient to define a context for thinking about mirror images and reflection. In general, we think a context is always with respect to some area of experience. For example, for most people a library determines a context with respect to general comportment but not with respect to topic of study. Finally, contexts need not align among different people. If you met your true love in that particular library, it would be a different context for you than for most others, at least with respect to the topic of romance. Steele (1997) has documented how the same outward circumstances of a mathematics exam may constitute different contexts for minorities and women than for white men, with respect to mathematical reasoning.

In light of the different mechanisms for stability discussed above, we propose an approach to defining "context," if not a complete definition: By "context," for an individual with respect to a set of resources, we mean *the circumstances for passive but reliable activation*. On this definition, for Sherry, looking in a mirror at home was evidently a different context from looking in a mirror at school, because for her the two situations activated different resources. By contrast, with respect to resources for understanding objects as having size and location, for most people parking a car is not a different context from sliding a chair. On this line of reasoning, we would not say Sherry "transfers" from experiences with doors or paintings to her thinking about mirrors. Instead, we would say that, for Sherry, the mirror question is part of the context for activating resources about objects.

But what is "transfer"? In our framework, if "learning X" in some context means that students reliably show that knowledge or ability in that context, there is no reason to expect that X *exists* other than as a pattern of activation in that context. If its activation and stability as a set depend on features of that context, as is the case in "passive" activation, then the "knowledge" is not well attributed to the individual; it is distributed across the individual and the context, and therefore cannot be viewed as a "thing" the subject could move (transfer) from one context to another.

The metaphor of knowledge as a thing is applicable when X develops its own integrity as an established local coherence that comes to activate (or not) as a unit, as we expect happens with the coordination classes of object and force. In other words, a locally coherent set of resources can be viewed as a transferable "thing" when the mechanism for its stability is structural rather than contextual or deliberate. We noted

this would be a plausible account of what happened to Louis, and we briefly revisit his case.

Louis revisited as a case of transfer

Louis was the student who decided to try a different approach to learning, after the instructor's advice to "explain it to a ten year old," such as by developing his dump truck analogy for understanding electricity. While we described this in terms of epistemological framing, we could also describe it in terms of transfer.

Working as a tutor and as a camp counselor, Louis developed strategic knowledge about teaching; he would try to "build on what they already know instead of introducing a totally new concept." Learning physics had been a different context for him, reliably activating a different set of resources, including strategies for taking in and remembering information but not strategies for assessing and building upon his own prior knowledge. His experience in that physics course, particularly the instructor's advice during office hours, prompted him to transfer the well-formed pattern (frame) he had established as a teacher to his own learning of physics (and subsequently, by his account, to his learning more generally). This transfer of epistemology led to further transfer at the level of conceptual understanding. To approach learning in his new way, Louis needed to look for conceptual resources from everyday experience (dump trucks) to think about electricity. At both the epistemological and conceptual levels, the transfer would be described as active: By his description, Louis consciously chose to try a different approach to learning, to write "like an explanation for a ten year old," leading to a deliberate search for conceptual knowledge from his everyday experiences.

That account fits the classic transfer archetype for two reasons. First, it supposes the knowledge had become effectively unitary, established as a pattern within the original contexts of his experiences as a teacher, for the epistemology, and of his experiences with vehicles on roads, for the conceptual understanding. Second, it characterizes the knowledge as originally tied to those contexts.

We see other plausible accounts of Louis's success. Louis may never have formed a stable, coherent epistemology in the context of teaching. Rather, his experience in the physics course may have helped him recognize aspects of his teaching strategies and consolidate them. That is, Louis may not have simply drawn upon those resources; he may also have done substantial cognitive work in combining them into a coherent, consciously-examined, broadly-applied frame. From a phenomenological or a unitary point of view, this second story sounds more like epistemological learning than epistemological transfer.

That is, with respect to both the level of intactness of the knowledge and the extent to which it was tied to a particular context, there is a continuum of possibilities. The theoretical construct of transfer, with its tacit metaphor of *knowledge as stuff,* is useful only for cases at the ends of the spectra: intact (structurally stable) patterns of activations that arise only in particular circumstances. The manifold view of resources, activations, and frames subsumes those conditions as special cases, while gaining us a language and framework for thinking about cases where the relevant knowledge is less intact or less tied to specific contexts.

Such cases, we expect, are especially relevant to instruction, where the knowledge of interest is delineated by course objectives. Teaching students a difficult new idea or ability over a few days or weeks would rarely result in their forming a new,

intact cognitive unit. This has been a theme of some new approaches to understanding and studying transfer, to which we now turn.

An ontological basis for new views of transfer

Reviewing previous research on transfer, Bransford and Schwartz (1999) and Bransford, Schwartz, and Sears (this volume) argue that most researchers have taken a "sequestered problem solving" (SPS) approach, testing if an idea or ability learned in one context is immediately applied to another. They advocate a different approach, viewing transfer as "preparation for future learning" (PFL), which entails looking for evidence that knowledge learned in one context facilitates the (re)learning of that knowledge or related knowledge in another context.

Singley and Anderson (1989), for example, found that learning text editor A did not immediately help subjects learn text editor B; on their first day with the new editor, subjects did no better than new recruits who had never seen editor A. On their second day with the editor B, however, subjects who had learned editor A did much better than subjects who hadn't. Schwartz, Bransford and Sears (this volume) note that transfer experiments often fail to look for these kinds of delayed effects that pop up in the context of later learning.

The authors also cite a striking classroom-based experiment of their own (Schwartz & Bransford, 1998) of college students studying psychology, motivated in part by their previous difficulties helping students learn and apply the theories of memory used to explain classic memory experiments. A control group read the relevant textbook chapter, wrote a one- to two-page summary of it, and attended a lecture intended to synthesize the main results. The two treatment groups did not use the textbook, but instead worked through simplified data sets from classic memory experiments, trying to discover the patterns on their own. The activity design was informed by the "contrasting cases" methods used by perceptual learning theorists, according to whom learning to "see" a given pattern involves seeing how it contrasts with other patterns.

After completing this activity, one of the treatment groups attended the same lecture as the control group did, while the other treatment group skipped lecture entirely, spending that time slot with the data sets, looking for patterns they may have missed previously. All subjects then took an exam in which they read about a new memory experiment and predicted likely outcomes. The treatment group that looked for data patterns and then heard the lecture did much better than either the control group (textbook summary + lecture) or the other treatment group (data set activity + data set activity). In fact, the latter treatment group scored just as badly on the exam as the control group did.

Schwartz, Bransford, and Sears (this volume) showcase this as an example in which the treatment activity didn't teach the target concepts (as probed by the sequestered problem solving approach), but instead prepared students for future learning in the lecture.[9] Specifically, they claim, the treatment activity helped students

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[9] As Bransford *et al*. (this volume) note, a variety of control conditions over several studies suggests that the effect is not simply due to attention or time on task. Also, the effects hold when lecture is replaced by a relevant reading. Furthermore, an independent but structurally similar experiment, involving 9th graders learning basic statistics concepts, yielded similar results.

learn to "see" the contrasting data patterns that the lecture then helped them explain. We claim that our resources framework —unlike a unitary framework — provides a mechanistic underpinning for their interpretation.

According to the unitary ontology, a given concept is a cognitive unit that a student either does or does not possess. The poor exam results indicate that neither summarizing a textbook chapter *nor* looking for patterns in the data enables students to acquire that cognitive unit. Why does looking for patterns (but not summarizing a chapter) enable students to then acquire that unit in a lecture? In other words, if students didn't learn memory concepts by looking at data patterns, why are those students "better off" in the long term? A framework in which concepts are the cognitive atoms has no tools for answering that question. (Researchers who adopt a unitary ontology may have tools for addressing this issue; our point is that those tools come from outside the unitary framework.) Applied more generally, this line of reasoning shows why a unitary ontology is poorly equipped for buttressing a view of transfer as preparation for future learning.

A resources-based ontology provides a mechanistic underpinning for a PFL approach to understanding transfer: Learning a new idea is not an all-or-nothing acquisition but involves an activation of existing resources in new combinations, and this may facilitate subsequent reactivation in one of two ways. In a passive mechanism, reuse raises the probability of the pattern activating again. In a deliberate mechanism, the learner is aware of and choosing to maintain the pattern. Either mechanism would be consistent with the beneficial incremental effect of prior learning, consistent as well with findings in the literature that transfer is more likely when students have seen the given idea in at least two separate contexts *or* when they receive metacognitive scaffolding (Bransford et al., 1999).

We note that diSessa's and Sherin's (1998) and diSessa and Wagner's (this volume) notion of coordination and coordination class may be particularly appropriate to Bransford & Schwartz's (1999) findings. In the network of resources constituting a coordination class, a key component is the *read-out strategies*, i.e., the sets of resources affecting perception, or what patterns are perceived. diSessa & Sherin argue that teaching a concept such as *force* is partly a matter helping students learn to "see" in a way consistent with that concept. That's exactly what Bransford & Schwartz's "contrasting cases" activity seems to have accomplished. Working through the activity, students started to form a network of resources enabling them to see the patterns in memory data that are consistent with the intended memory concepts. Those readout strategies are an essential part, but only a part, of the overall cognitive structure corresponding to a memory concept.[10] The lecture helped students build up other parts of the cognitive structure and connect them to the perceptual part. In this way, the resources framework explains why the pattern-finding activity was an essential but not sufficient component of students' learning.

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[10] diSessa and Wagner might argue that the memory concepts and theories relevant to Schwartz & Branford's (1998) experiment are not coordination classes, the primary function of which (they claim) is information gathering. We are assuming that, whatever cognitive structure describes those memory concepts, it involves readout strategies.

Implications for physics instruction

In the physics education research community of which we are a part, substantial and successful effort has gone into developing instructional materials that help students overcome common misconceptions, as measured by standardized assessments such as the Force Concept Inventory (Hestenes, Wells, & Swackhamer, 1992). Most of these materials, including many developed by our group, promote cognitive conflict and intuition-building to help students overcome their difficulties as efficiently as possible. As Schwartz, Bransford and Sears (this volume) point out, however, instruction that maximizes students' success on sequestered problem solving assessments might differ from instruction that best prepares students for future learning. In other words, in our attempts to show quick, easily-measured results, we might be shortchanging our students in the long run.

Some research appears to bear this out. For instance Redish, Saul & Steinberg. (1997) showed that, even when students "learn" Newton's 3rd law as measured by items probing that concept in isolation, they are not prepared to integrate that concept into their future learning about multi-body problem-solving.

If structurally similar studies yield similar results, the implications are profound, for both instruction and assessment. When testing instructional materials, we should systematically include both SPS (sequestered problem solving) and PFL (preparation for future learning) assessments, so that instructors can weigh any trade-offs that are revealed between "good" PFL but "bad" SPS results (or vice versa). And if we choose to favor PFL goals over SPS goals in a given set of materials, we must take into account the metacognition/epistemology literature and the emerging PFL-based transfer literature, to gain insight into what fosters preparation for future learning. Insights specifically relevant to physics instruction might include the value of letting students invent their own data-analysis methods and representations (see section 3.22 of Schwartz, Bransford & Sears, this volume), and the importance of helping students become deliberative and reflective about their own learning processes.

Closing remarks

We do not speak in terms of transfer in our research. In this chapter, we have argued that it would not gain us anything to start: The language of resource activations subsumes "transfer" as a special case. At the same time, we have argued that this language, with its attention to ontology and mechanism, has advantages over the language of transfer. An account of resources, activations, and framing is a productive alternative to the traditional notion of knowledge transfer, productive in the sense of its promise for theoretical coherence and generativity. A unitary framework, by contrast, does a poorer job of accounting for some examples of transfer phenomena and fails to address many difficulties highlighted in the transfer literature.

Bransford and Schwartz (1999) noted that the distinction they describe between SPS and PFL is not new. Despite literature challenging the traditional view of transfer in favor of preparation for future learning, the former continues to hold sway over educational thought. The problem, we propose, may be in the tacit ontology that comes with the metaphor of transfer. Like students, instructors and researchers have a variety of ways of thinking about knowledge and learning. The notion of transfer connotes some *thing* that transfers, a metaphor of *knowledge as stuff*, an epistemological resource that is useful for thinking about how information may exist in and move between locations. By the same token, however, this metaphor calls to mind teaching as

providing and learning as *acquiring*. It generates questions focused on knowledge as teachers provide it—the "new" knowledge or skills we might hope to *impart*. A resources-based ontology, by contrast, highlights the students' existing knowledge, and the metaphor of *knowledge as activations* generates questions that focus attention back again on the students, on what resources they have available and how those resources are organized and re-organizable.

Acknowledgements

References

Barnett, S. M., & Ceci, S. J. (2002). When and where do we apply what we learn? A taxonomy for far transfer. *Psychological Bulletin, 128*(4), 612-637.

Bateson, G. (1972). A Theory of Play and Fantasy (Originally published 1954). In G. Bateson (Ed.), *Steps to an ecology of mind; collected essays in anthropology, psychiatry, evolution, and epistemology* (pp. xxviii, 545 p.). San Francisco,: Chandler Pub. Co.

Bransford, J. D., Brown, A. L., & Cocking, R. R. (1999). *How People Learn: Brain, Mind, Experience, and School*. Washington DC: National Academy Press.

Bransford, J. D., & Schwartz, D. L. (1999). Rethinking transfer: A simple proposal with multiple implications. In *Review of Research in Education, 24 1999* (Vol. 24, pp. 61-100).

Brown, A. L., & Campione, J. C. (1984). Three faces of transfer: Implications for early competence, individual differences and instruction. In M. E. Lamb & B. Rogoff (Eds.), *Advances in Developmental Psychology* (Vol. 3, pp. 143-192). Hillsdale, NY: Erlbaum.

Brown, A. L., & Kane, M. J. (1988). Preschool children can learn to transfer: Learning to learn and learning from examples. *Cognitive Psychology, 20*, 493-523.

Carraher, T. N., Carraher, D. W., & Schliemann, A. D. (1985). Mathematics in the street and in school. *British Journal of Developmental Psychology, 3*, 21-29.

Cutnell, J., & Johnson, K. (2001). *Physics* (5th ed.). New York: Wiley.

diSessa, A. (1993). Towards an epistemology of physics. *Cognition and Instruction, 10*(2-3), 105-225.

diSessa, A. A., & Sherin, B. L. (1998). What changes in conceptual change? *International Journal of Science Education, 20*(10), 1155-1191.

diSessa, A. A., & Wagner, J. (this volume). What coordination has to say about transfer. In J. Mestre (Ed.), *Transfer of Learning: Research and Perspectives*. Greenwich, CT: Information Age Publishing.

Goffman, E. (1986). *Frame analysis : an essay on the organization of experience* (Northeastern University Press ed.). Boston: Northeastern University Press.

Greeno, J. (1997). On claims that answer the wrong questions. *Educational Researcher, 26*(1), 5-17.

Hammer, D. (2004a). The variability of student reasoning, lecture 2: Transitions. In E. Redish, C. Tarsitani & M. Vicentini (Eds.), *Proceedings of the Enrico Fermi Summer School, Course CLVI*: Italian Physical Society.

Hammer, D. (2004b). The variability of student reasoning, lecture 3: Manifold cognitive resources. In E. Redish, C. Tarsitani & M. Vicentini (Eds.), *Proceedings of the Enrico Fermi Summer School, Course CLVI*: Italian Physical Society.

Hammer, D., & Elby, A. (2002). On the form of a personal epistemology. In B. K. Hofer & P. R. Pintrich (Eds.), *Personal Epistemology: The Psychology of Beliefs about Knowledge and Knowing* (pp. 169-190). Mahwah, N.J.: Lawrence Erlbaum.

Hestenes, D., Wells, M., & Swackhamer, G. (1992). Force Concept Inventory. *The Physics Teacher, 30*(3), 141-158.

Karmiloff-Smith, A. (1992). *Beyond Modularity*. Cambridge, MA: MIT Press.

Kitchener, K. S. (1983). Cognition, Metacognition, and Epistemic Cognition - a 3-Level Model of Cognitive Processing. *Human Development, 26*(4), 222-232.

Lave, J. (1988). *Cognition in practice: Mind, mathematics and culture in everyday life*. Cambridge: Cambridge University Press.

Lising, L., & Elby, A. (Under review). The impact of epistemology on learning: a case study from introductory physics.

Louca, L., Elby, A., Hammer, D., & Kagey, T. (in press). Epistemological resources: Applying a new epistemological framework to science instruction. *Educational Psychologist*.

Luchins, A. S. (1942). Mechanization in problem solving: the effect of Einstellung. *Psychological Monographs, 54 (whole number 248)*.

MacLachlan, G. L., & Reid, I. (1994). *Framing and interpretation*. Carlton, Vic. Portland, Or.: Melbourne University Press.

Mestre, J. (2003). *Transfer of Learning: Issues and Research Agenda*: Report of a Workshop at the National Science Foundation.

Mestre, J., Thaden-Koch, T., Dufresne, R., & Gerace, W. (2004). The dependence of knowledge deployment on context among physics novices. In E. Redish & M. Vicentini (Eds.), *Proceedings of the Enrico Fermi Summer School, Course CLVI*: Italian Physical Society.

Minsky, M. L. (1986). *Society of Mind*. New York: Simon and Schuster.

Redish, E. F. (2004). A theoretical framework for physics education research: Modeling student thinking. In E. Redish, C. Tarsitani & M. Vicentini (Eds.), *Proceedings of the Enrico Fermi Summer School, Course CLVI*: Italian Physical Society.

Redish, E. F., Saul, J. M., & Steinberg, R. N. (1997). On the effectiveness of active-engagement microcomputer-based laboratories. *Amercian Journal of Physics, 65*(January), 45-54.

Rosenberg, S. A., Hammer, D., & Phelan, J. (Under review). Multiple epistemological coherences in an eighth-grade discussion of the rock cycle.

Schank, R. C. (1982). *Dynamic memory : a theory of reminding and learning in computers and people*. Cambridge [Cambridgeshire] New York: Cambridge University Press.

Schwartz, D. L., Bransford, J. D., & Sears, D. (this volume). Efficiency and innovation in transfer. In J. Mestre (Ed.), *Transfer of Learning: Research and Perspectives*. Greenwich, CT: Information Age Publishing.

Siegler, R. S., & Stern, E. (1998). Conscious and unconscious strategy discoveries: A microgenetic analysis. *Journal of Experimental Psychology-General, 127*(4), 377-397.

Sinatra, G. M., & Pintrich, P. R. (2002). The role of intentions in conceptual change. In G. M. Sinatra & P. R. Pintrich (Eds.), *Intentional Conceptual Change* (pp. 1-18). Mahwah, NJ: Erlbaum.

Singley, M. K., & Anderson, J. R. (1989). *The transfer of cognitive skill*. Cambridge, Mass.: Harvard University press.

Steele, C. M. (1997). A threat in the air: How stereotypes shape intellectual identity and performance. *American Psychologist, 52*(6), 613-629.

Tannen, D. (1993). *Framing in discourse*. New York: Oxford University Press.

Thaden-Koch, T., Mestre, J., Dufresne, R., Gerace, W., & Leonard, W. (this volume). When transfer fails: Effect of knowledge, expectations, and observations on transfer in physics. In J. Mestre (Ed.), *Transfer of Learning: Research and Perspectives*. Greenwich, CT: Information Age Publishing.

Thagard, P. (1989). Explanatory Coherence. *Behavioral and Brain Sciences, 12*(3), 435-466.

Tuminaro, J. (in preparation). *A framework for understanding the role of mathematics in physics [working title]*. Unpublished Doctoral, University of Maryland.

Wilensky, U., & Resnick, M. (1999). Thinking in levels: A dynamic systems perspective to making sense of the world. *Journal of Science Education and Technology, 8*(1), 3-19.