DYNAMIC TRANSFER:

A PERSPECTIVE FROM PHYSICS EDUCATION RESEARCH

Running head: Dynamic transfer

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ABSTRACT

We contrast previous views of transfer of learning with emerging perspectives in the field. Based on the latter, we have adapted our previously developed analytical framework to characterize transfer as it occurs dynamically in an interview. Our adapted framework is also consistent with a theoretical framework proposed by Redish (in press) that addresses several cognitive and epistemological issues. In light of Redish's framework and contemporary transfer models, we have demonstrated how our analytical framework can help identify and characterize transfer as it occurs in an interview. We describe instances in which students transfer their learning spontaneously in an interview as well as those in which transfer is promoted by scaffolding provided by the interviewer. In connection with the latter, we describe yet another research methodology—the teaching interviews that can allow us to investigate dynamic scaffolded transfer.

OVERVIEW

Transfer of learning is often (e.g. Reed, 1993; Singley & Anderson, 1989) defined as applying what one has learned in one situation to a different situation. Several researchers (e.g. (McKeough, Lupart, & Marini, 1995) have described transfer of learning as the ultimate goal of education. After all, what use is knowledge if it cannot be applied elsewhere? Science education researchers and cognitive psychologists have spent significant time and effort in examining transfer of learning in various situations, identifying the factors that influence it and suggesting strategies and interventions to promote it.

A comprehensive review of transfer literature is beyond the scope of this chapter. Rather, we will broadly describe some of the changing trends in researchers' views about transfer, focusing specifically on some contemporary models of transfer (Bransford & Schwartz, 1999; Greeno, Moore, & Smith, 1993; Lobato, 1996, 2003). These models adopt perspectives that are quite different from previous views of transfer (e.g. Singley & Anderson, 1989). Next, we present a framework that we have used to analyze interview data and discuss how it aligns with contemporary models of transfer, and when used in conjunction with these models, can help identify how students transfer their knowledge and learning dynamically during an interview. Finally, based on our framework and contemporary transfer models, we propose a research methodology – the teaching interview – that has hitherto not been extensively used in physics education research and discuss its promise for researching and promoting dynamic transfer.

CHANGING TRENDS IN TRANSFER RESEARCH

Most of the research on transfer of learning has focused on whether students who had learned a problem solving strategy in a given context were able to apply this strategy to other contexts (e.g. Adams *et al*., 1988; Bassok, 1990; Brown & Kane, 1988; Chen & Daehler, 1989; Lockhart, Lamon, & Gick, 1988; Nisbett, Fong, Lehmann, & Cheng, 1987; Novik & Nussbaum, 1981; Perfetto, Bransford, & Franks, 1983; Reed, Ernst, & Banerji, 1974; Throndike & Woodworth, 1901; Wertheimer, 1959). A typical example is the "jealous spouses vs. cannibal-missionary" problem (Reed *et al*., 1974) or the "fortress vs. tumor" problem (Duncker, 1945; Gick & Holyoak, 1980). Researchers saw deep structural similarities between the two problems in each pair and they hoped that students through analogical transfer would be able to successfully solve the second problem after learning how to solve the first. However, the results of these and other similar transfer studies demonstrate that transfer, when measured this way, is rather rare.

The perspective adopted by transfer researchers typically involves pre-defining the underlying concept that should transfer and then seeking evidence for transfer. Studies based on these traditional views of transfer often show little support for the occurrence of transfer. However, almost all of us know from everyday experience that we seldom invent a procedure or strategy each time in a new situation. Clearly *something* transfers from one situation to another. In fact, we transfer even without consciously thinking about it. Could it be that we researchers are overly focused on what we should find and are ignoring what students in fact do transfer?

To reconcile the apparently contradictory evidence of the simultaneous ubiquity and the lack of transfer, some researchers have reconsidered the ways to characterize transfer (Bransford & Schwartz, 1999; Greeno *et al*., 1993; Lobato, 1996, 2003). The above approach of predetermining what should transfer can be self-limiting. Lobato (1996) points out that students may transfer both productively and unproductively, in ways that the researchers may not have previously considered. She argues that we should not decide a priori what students should transfer but rather adopt a student-centered perspective to find out what students do transfer and investigate the mediating factors. An understanding of these factors can provide us insights into the kinds of interventions that might facilitate productive transfer. Lobato's "Actor-Oriented Model of Transfer" has its origin in the ideas of "perceived similarities" by Hoffding (1892) and "situated cognition" by Lave & Wenger (1991). The model relies on "personal creations of relations of similarity" by the learner, between the learning and transfer contexts, rather than similarities perceived by the researcher.

Lobato's model builds on the socio-cultural aspects of transfer (Greeno *et al.*, 1993) and situated cognition (Lave & Wenger, 1991). These ideas go beyond thinking of transfer as occurring entirely in a student's mind and begin to look at how the external factors such as interactions with the environment, peers or the teacher can affect the transfer of learning. Previous researchers have conceptualized transfer as the process of recognizing similarity of surface features (Throndike, 1906) or deep structure (Judd, 1908) between the two contexts. Other researchers believe that transfer involves building symbolic mental representation or schema in the learning context and then mapping and applying that schema to the transfer context (Anderson & Thompson, 1989; Gentner, 1983; Holyoak & Thagard, 1989). Greeno *et al*. (1993) argue that this process, while possible, is rather rare. Instead, they focus on activities that the learner performs in the learning context. The learner interacts and becomes "attuned to the affordances" of the learning contexts of its "potential states of affairs" and brings the knowledge of these aspects of the learning context into the transfer context.

Another contemporary perspective of transfer is offered by Bransford and Schwartz (Bransford & Schwartz, 1999, Schwartz, Bransford and Sears, this volume). They characterize previous transfer studies as having focused on "sequestered problem solving" in which a learner is required to solve a problem in the transfer context without scaffolding that was available in the learning context. Bransford and Schwartz promote an alternative perspective of transfer as “preparation for future learning.” They believe that undue focus on whether or not students can problem-solve “cold” in the transfer context has led to the lack of evidence of transfer. Rather, they focus on how students *learn* to solve the problem in the transfer context. Transfer is more likely if students are given opportunities to reconstruct their learning in the transfer context in the same way as they did in the learning context.

All of the above perspectives share at least three common themes. First, they look at transfer from the students’ perspective rather than a pre-defined researcher’s perspective, i.e. they ask what similarities the student sees in a given situation. Second, they describe transfer as the dynamic construction of knowledge in the target scenario, rather than applying what they have learned previously. Therefore, transfer must be assessed by whether students can *learn* in the new situation. Finally, the above perspectives go beyond looking at transfer from a purely cognitive perspective and include socio-cultural aspects in their discussion.

In the next section we present an analytical framework that describes students’ sense-making processes in an interview. We choose the interview as a setting in which to examine transfer because it is a widely used tool in educational research and affords us an opportunity to study how students transfer and construct knowledge dynamically—consistent with the current perspectives.

A FRAMEWORK TO MODEL DYNAMIC TRANSFER

Interviews are a useful tool to gauge the dynamics of transfer of learning and provide insights into how students apply and reconstruct knowledge and experiences gained elsewhere as they respond to a question. A researcher's agenda can potentially affect interpretation of interview data (Scherr & Wittmann, 2002). Based on her agenda an interviewer may attend to a particular aspect of a student's response at the expense of others or may unwittingly cue the student. The assumption that student knowledge remains static while it is probed in an interview can also affect the interpretation of interview data because it overlooks situations in which students make up answers to questions they may never have previously considered. Therefore, it ignores the dynamic of *in situ* transfer and construction of knowledge by students. The analytical framework that we have developed addresses both of these assumptions.

Researchers in our group are working on various projects that investigate how students transfer their learning from one context to another. Our goals include investigations on students' transfer of Newtonian ideas (Allbaugh, 2003) or energy concepts (Itza-Ortiz, Lawrence, & Zollman, 2003) from mechanics to electricity or magnetism; transfer from the classroom to the real-world (Engelhardt, Gray, & Rebello, 2004; Engelhardt & Rebello, 2003; Engelhardt, Rebello, & Itza-Ortiz, 2003); transfer from everyday experiences into an interview setting (Hrepic, 2002; Hrepic, Rebello, & Zollman, 2002) and transfer from one problem to another within an interview (Gray, 2004). Our interview participants ranged from non-science majors in conceptually-based classes to engineering and physics majors in calculus-based physics classes. Therefore, our framework has implications that are not specific to a particular level of students or area in physics. The framework and its implication have been discussed elsewhere (Engelhardt *et al*., 2003; Gray *et al*., 2003; Itza-Ortiz *et al*., 2004). Below we describe the role of elements of our framework in transfer of learning.

Elements of the Framework

Our framework emerged by re-analyzing and parsing several interview transcripts to understand the student's reasoning process. This process afforded us the opportunity to observe how students build and transfer knowledge dynamically based on their previous learning and experiences in ways that are consistent with the contemporary models of transfer. A careful analysis of interviews revealed four elements or factors that can play a role in dynamic transfer of knowledge and learning.

External Inputs answer the question: "What prompts transfer?" An external input is information provided by the interviewer via a protocol question, follow-up or clarification questions, as well as other hints or cues. It also includes other materials, e.g. text, pictures, demos, videos, etc. used in the interview. External inputs can play a key role in influencing transfer of knowledge. They can prime the student to focus on certain aspects of a problem situation at the expense of others. They may provide verbal and non-verbal feedback that prompts the student to think in a particular way, thereby facilitating either positive or negative transfer. Taking into consideration the external input is consistent with Greeno *et al*. (1993) and Lobato's (1996, 2003) view that "transfer is distributed across mental, material, social and cultural planes." Interaction with the interviewer is an example of this social interaction which may cue students to access various knowledge elements or tools in their reasoning.

Tools answer the question: "What transfers?" They can be broadly categorized into pre-existing tools or created tools. Pre-existing tools include a student's prior experience or knowledge gained through everyday life or instruction. This internal dormant knowledge includes knowledge structures of grain sizes ranging from phenomenological primitives (diSessa, 1988), resources (Hammer, 2000) or facets (Minstrell, 1992) to mental models (Driver, 1995; Glasersfeld, 1989; Johnson-Laird, 1983; Vosniadou, 1994). Tools enable us to characterize what a student transfers from her/his prior knowledge and experience. Lobato's Actor-Oriented Model focuses on what the student considers the "same" between the learning and transfer scenarios. She points out that "what experts consider a surface feature may be structurally substantive for a learner." Our definition of tools is consistent with Lobato's perspective in that we do not pre-define what the student should transfer but rather seek to find anything that the students transfers regardless of whether it is a surface feature or a deep structural similarity. Tools also include information about the "affordances" or "potential states of affairs" of either the learning or the transfer context as proposed by Greeno *et al*. (1993). The concept of tools is also similar to the notion of "knowing with" invoked by Bransford & Schwartz (1999) who point out that learners often "utilize their previously acquired concepts and experiences," a view based on the idea that a person "… thinks, perceives and judges with everything that [s]he has studied in school although [s]he cannot recall these things on demand," (Broudy, 1977, p. 12). Thus, almost any object or idea, concrete or abstract, real or imaginary, can potentially be a tool.

Tools also include students' epistemic resources (Redish, in press). Hammer & Elby (2002) have described at least two kinds of personal epistemological modes that students use in a learning situation—"knowledge as propagated stuff" and "knowledge as fabricated stuff." A student's personal epistemology or epistemic resources affect the types of cognitive tools that they tend to rely on. For instance, a student who believes that "knowledge is propagated stuff (from authority)" may tend to transfer only those 'facts' acquired from 'authoritative' sources such as a textbook or an instructor, rather than from her personal life experiences or peers. Thus, epistemic resources are “meta-tools” or higher-level tools that control the use of lower-level (cognitive) tools that the student uses.

In contrast to pre-existing tools, created tools are dynamically constructed at an earlier instance in the interview such as knowledge acquired while reasoning through previous questions. Created tools are more likely to be utilized by a student operating in “knowledge is fabricated stuff” epistemic mode. The notion of dynamic construction of tools consistent with the contemporary transfer models is discussed in the context of the workbench.

Workbench includes various mental processes that may utilize external inputs and tools. Workbench processes can be as simple as making connections between various tools or executing a known rule or procedure in a typical workbench process. Workbench processes include that reorganization and restructuring of knowledge such as assimilation and accommodation (Piaget, 1964), conceptual combination (Ward, Smith, & Vaid, 1997) or hybridization (Hrepic, 2002; Hrepic *et al*., 2002). Workbench processes also include analogical, inductive or deductive reasoning as well as decision making. Decision making is often the first step to transfer in that it involves the learner recognizing that the transfer context is similar to a learning context and determines the appropriateness of the tools to be activated in the transfer context. The tools that a learner activates depend upon their epistemic resource meta-tool. Tool activation is referred to by Collins & Ferguson (1993) and later Redish (2003) as an “epistemic game.” According to Redish (2003, p. 45), activation of a tool involves “coherent activity that uses particular kinds of knowledge (i.e. tools) and the processes associated with that knowledge to create [new] knowledge.” Therefore, epistemic games are a workbench process.

The concept of a workbench is consistent with the notion that transfer is a dynamic process in that the relations and similarities are constructed anew in the transfer context and not merely transported from the learning context. Lobato's Actor-Oriented Model asks, "What relations of similarity are created? How are they supported by the environment?" (Lobato, 2003, p. 20). The model of transfer by Greeno *et al* hypothesizes that "a symbolic representation of structure is *generated* in the transfer situation based partly on information about another situation that is retrieved." This process of generation of the symbolic representation (in the transfer situation) is a workbench process. The information about the other (learning) situation that is retrieved is a tool. The concept of a workbench process affords the opportunity for the researcher to investigate the learners' ability "to learn new information and relate their learning to previous experiences," consistent with Bransford and Schwartz's (1999, p. 69) view of "ideal assessment" of transfer as preparation for future learning.

The **answer** marks a 'stopping point' in the reasoning process and not necessarily the final outcome or conclusion. Answers can broadly be categorized into three types: decisive, indecisive and none. A decisive answer is one in which the student arrives at a single conclusion. A correct answer would typically be a performance measure of positive transfer and an incorrect answer would be indicative of negative transfer. However, the correctness of the answer is not important from the perspective of a student-centered model of transfer. An indecisive answer—when a student is unable to choose between two answers or when a student requests more information can be potentially interesting. Bransford & Schwartz (1999) believe that an 'answer' is in fact a question requesting further information that is indicative of their preparation for future learning. Some physics education researchers (e.g. Thornton, 2002) have shown that the open-endedness of students' questions is often an indicator of superior conceptual understanding. Students' questions play an important role in determining the extent to which students may be transferring and constructing new knowledge dynamically. Conversely, a student's response that he/she "does not know" without even venturing a guess can be indicative of a "knowledge as propagated stuff" epistemic mode as per which the learner looks for the 'right' answer and is unwilling to even attempt to construct one on the spot.

Connections with Cognitive Information Processing

The framework above is consistent with cognitive information processing (Driscoll, 2000) and an often used metaphor – the computer. The external input is analogous to human sensory inputs, or computer input devices – e.g. mouse, keyboard, etc. Tools correspond to information stored in long term memory that is retrieved before usage, similar to data on the hard drive that is loaded into a buffer before usage. The workbench corresponds to processes in the short term working memory or in a computer's CPU. Finally, the answer corresponds to the output action or speech by the individual or in the case of the computer, the information displayed on the monitor or printed. These connections demonstrate how contemporary ideas of transfer can be considered in the context of cognitive information processing. Transfer involves retrieval of information from the long term memory followed by its processing in the working memory. The latter step helps emphasize that transfer is more than mere retrieval of stored schema but involves "dynamic production of sameness" (Lobato, 1996, 2003) through associations and control (Redish, 2003) in the short term memory.

Alignment of Framework with Contemporary Models of Transfer

Various elements of our framework align with contemporary models of transfer (see Table 1). The alignment indicates that our framework can serve as a valuable tool to investigate transfer of learning from the perspective of these contemporary models of transfer.

TABLE 1 ABOUT HERE

Modeling Transfer

Redish (2003) describes a two-level framework (Figure 1) based on fundamental neuro-cognitive theories. The lower level includes *associations* between knowledge elements, which are "relations of similarity" in Lobato's (1996, 2003) Actor-Oriented Model. The upper level includes *executive control* that enhances (turns on) or suppresses (turns off) the associations between these knowledge elements based on a learner's epistemologies and expectations.

FIGURE 1 ABOUT HERE

Redish's framework provides an overarching structure for our model of transfer which categorizes various tools and workbench processes as follows:

'Source' Tools are pre-existing knowledge or experiences from a prior context such as a real-life experience (Engelhardt & Rebello, 2003; Engelhardt *et al*., 2003), classroom instruction

(Allbaugh, 2003; Itza-Ortiz *et al*., 2003; Itza-Ortiz, Rebello, & Zollman, 2004), popular media or even previous interview questions (Gray, 2004). Source tools include a learner's dormant knowledge that is activated to make sense of new situations.

'Target' Tools are attributes of the 'target' situation that the learner uses to "know with," (Bransford & Schwartz, 1999; Broudy, 1977). They define the target context in the learner's mind. Target tools are presented via external inputs; however, not all inputs are tools. Rather the learner 'reads-out' part of the input information that she considers relevant, and uses this read-out information as tools (diSessa, 1998). Target tools may include surface features, deep structure, affordances or states of affairs (Greeno *et al*., 1993) that a learner attends to.

'Epistemic Meta-Tools' are epistemic resources ("knowledge is propagated" or "knowledge is fabricated") that a student activates to exercise executive control over workbench processes. Unlike the target tool, the epistemic meta-tool may be activated from a learner's long term memory through priming by the external input.

'**Read-out**' is the process by which a learner recognizes the relevance of certain attributes or transfer tools in the external inputs. A learner may be primed to notice some information at the expense of others, based on the epistemic meta-tools that are activated at that time.

'Activation' is the process by which a learner recalls into working memory, source tools or epistemic meta-tools that are dormant in long term memory.

'**Association'** is the process by which a learner interconnects tools in the working memory. Various types of associations are possible, e.g. inferential, causal, analogical, deductive or inductive. It is often difficult to distinguish between activation of a tool and its association with other tools. Typically when students explicate the associations that they construct, the activation is implied.

'Priming' is a higher order (meta) process by which covert meta-messages influence the way in which a learner frames the situation and activates certain epistemic meta-tools. Evidence of priming is indirectly inferred from the sources of knowledge that the learner refers to in her reasoning.

'Control' is a higher order (meta) process by which a learner enhances or suppresses associations, activations and read-out based on the epistemic meta-tools. 'Epistemic gaming' (Redish, 2003) by which a learner decides the types of knowledge is a controlling process. Like priming, evidence of executive control must be inferred indirectly from a learner's statements (e.g. "I made it up.").

FIGURE 2 ABOUT HERE

Figure 2 demonstrates our framework that builds on the generic structure provided by Redish (Figure 1). We model transfer mechanism in three phases that are often indistinguishable.

Phase 1: The interviewer provides external input describing the problem scenario. Additionally, the interviewer also primes the learner through 'covert messages' to activate epistemic meta-tools.

Phase 2: The activated epistemic meta-tool controls the process by which the learner weighs the relevance and reads-out certain pieces of input information to be used as a target tool in the reasoning process.

Phase 3: The epistemic meta-tool activates source tools from long-term memory. If the 'knowledge is propagated stuff' epistemic meta-tool is activated in phase 2, the learner is more likely to utilize knowledge acquired through formal instruction. If the 'knowledge as fabricated stuff' epistemic meta-tool is activated the learner is more likely to use self-constructed knowledge. The learner establishes associations or relationships between the source and target tools. The association process described here is typically explicated by the student, while the activation process is implicit.

Therefore, in our model, *transfer is a dynamic creation of associations between target tools read out from the external inputs and source tools activated from long term memory. Readout, activation and associations are mediated through higher-order control by epistemic meta-tools which are in turn activated through priming by covert meta-messages in the external input*.

We acknowledge that our model of transfer includes the role of the working memory in ways that may not be consistent with existing knowledge about the limitations of working memory. One such limitation is the maximum number of items that we can attend to simultaneously in our working memory. Another limitation pertains to the maximum duration for which one can hold information in working memory without continuous rehearsal. Our model is silent about these limitations, because we use the term 'working memory' rather loosely. Further research may be needed to refine this model to be more consistent with existing notions of working memory as used in cognitive science.

Phase 4 (not in Figure 2): Two possibilities exist. First, in the short term, the source-target tool association prompts metacognitive reflection and self-regulation (Flavell, 1979, 1987) causing the learner to rethink the problem. Second, if the source-target tool association is strongly established to yield a new tool (comprising the two interlinked tools) that is committed to long term memory. This new tool may be activated as a single cognitive entity in the future, akin to Hammer, Elby, Scherr and Redish's model (this volume) of coherent activation of coordinated resources. A learner's repeated association of the same tools in different contexts creates in her mind a coordination class (diSessa, 1998) that is central to 'Class A' transfer described by diSessa and Wagner (this volume).

We adopt a 'value neutral' stance toward the scientific correctness of the associations described above and focus instead on the underlying factors. This knowledge of the intuitive associations, whether correct or incorrect, can help us design curriculum and instruction that promotes transfer as described later in this chapter.

Commonalities of Our Model with Other Models in this Volume

Our model shares commonalities with other models discussed in this volume. We focus on the perspectives described by Dufresne, *et al*., Hammer *et al,* Schwartz *et al.*, and diSessa and Wagner in their respective chapters.

Dufresne *et al.* (this volume) have described transfer as a "complex dynamical process leading to the activation and application of knowledge in response to context." Transfer is a dynamic process involving coordination of knowledge pieces, which are akin to the source and target tools in our model, albeit in our model we do not comment of the grain size of the tools. Transfer as per Dufresne *et al.* includes two sub-processes. First is the "readout filter" i.e.

noticing relevant information in a situation, which is very similar to the read-out process in our model. Second is the "expectation filter" which includes activating and applying the knowledge pieces to make inferences. This sub-process is analogous to the activation and association processes in our model. Dufresne *et al.* describe transfer as a process through which learners align their readout and expectations to achieve a state of quasi-equilibrium. This description is similar to our notion that the associations (between source and target tools) dynamically created by the learner are not stable in time and are in fact highly context dependent. One minor difference with our model is that the latter attempts to include issues pertaining to social interactions which can affect a learner's epistemic mode albeit we have explored these issues in a rather contrived research context of an interview. Dufresne *et al.* clearly acknowledge the importance of social context in transfer, but focus instead on the cognitive issues pertaining to their research in physics problem solving.

Hammer *et al* (this volume) point out that previous researchers have used a "unitary ontology" of transfer of an "intact cognitive unit." Rather, Hammer *et al* describe transfer as a "manifold ontology" of "locally coherent resources activated or deactivated based on the learner's epistemic "frame" in the context. These resources are mutually associated so that they have a high likelihood of being activated together. Transfer occurs when the learner enters a similar state in a new context and activates the same set of resources. This idea is similar to our notion of dynamic creation of associations between tools activated from a learner's long term memory. However, the long term stability of this association is not a required aspect of what we call transfer, although such long term stability is indeed desirable.

Schwartz *et al* (this volume) extend their previous discussion of transfer as preparation for future learning. They differentiate between "transferring out of" and "transferring into" situations. The former is the conventional and rather rarely observed transfer. The latter is consistent with our view. Transferring in is akin to Broudy's view (1977) of "knowing with," i.e. interpreting your new situation in light of previous experiences. Interpretive associations are rather subtle and are ignored in traditional assessments such as sequestered problem solving, which focus on replicative and applicative associations. The "double transfer" experiment (discussed later) can measure both "transfer in" and "transfer out." Our model of transfer also focuses on associations that learners dynamically construct between the target and source tools; however, it does not distinguish between replicative, applicative and interpretive associations. Schwartz *et al*'s double transfer experiment could be adapted with the teaching interview discussed later in this chapter.

diSessa and Wagner (this volume) categorize transfer based on the grain size of the transferred knowledge, frequency of transfer and need for new learning to facilitate transfer. 'Class A Transfer' is deployment of "well prepared" knowledge – such as a coordination class (diSessa, 1998), which requires little or no new learning, because the expert learner already possesses a coherently organized set of resources and is aware of their realm of applicability ("span") and can recognize the applicability of resources in new contexts. In contrast, during the ubiquitous 'Class C Transfer' novice learners use small grained prior knowledge productively and unproductively in new situations. Our model focuses on Class C that is almost indistinguishable from novice learning, rather than Class A transfer by experts.

Applying Our Model – An Example

We demonstrate our model to analyze data collected by other researchers (Wittmann & Scherr, 2002) who investigated the effect of a student's epistemological mode on her reasoning in an interview about current and conductivity. The student was asked what "category" [conductor or insulator] Styrofoam fell into. She began by stating that it was insulating. When asked why, she stated that she had "memorized it!" When asked to explain the property of Styrofoam that might lead to its insulating behavior, she referred to the "little density thing" and added that she did not "really know" the answer. When prompted that Styrofoam was "not terribly dense" she restated that she did not "really know" but added that "something inhibits the electrons from moving quickly." Asked to explain her reasoning, she talked about electrons bound to the lattice, but when asked to elaborate she stated, "I have no idea! That's organic chemistry!" As the authors point out, the student in this segment appears to rely on the epistemic mode that "knowledge is propagated" from authority (organic chemistry) and must be committed to memory. She appears to read out the 'density' attribute (target tool) of the Styrofoam and associate with her memorized knowledge about electrons (source tool).

In a subsequent interview segment the interviewer specifically asks the student to provide "any explanation" that she can find. The student begins to elaborate her reasoning: "… the electrons are bound to these molecules and it takes certain energies to tear them away." She is asked what tears them away and responds that she "assumes … just the battery…the power supply." As the authors explain, the prompt to provide "any explanation" appears to switch the student into the "knowledge is fabricated stuff" epistemic mode as indicative of the choice of her word "assume." She associates her ideas of electrons being "bound to molecules" and needing "energies to tear them away," both of which are source tools – knowledge acquired previously with the battery or power supply attributes in the target context.

In this episode, the phrasing of the question appears to have primed the student into different epistemic modes. Initially she was asked what category (conductor or insulator)

Styrofoam fell into. We speculate that asking her use pre-constructed categories with scientific sounding labels may have activated her “knowledge is propagated” epistemic meta-tool. Later, asking her to provide “any explanation” she could find activated the “knowledge is fabricated” epistemic meta-tool. That a student’s epistemic mode is not stable is consistent with the idea that transfer exists across multiple planes – intellectual, material and social (Lobato, 1996). Interaction with the interviewer primes the student into an epistemic mode, which in turn controls the activation and association between source and target tools.

IMPLICATIONS FOR TRANSFER STUDIES IN PHYSICS EDUCATION RESEARCH

As demonstrated above, our model has implications for investigating dynamic transfer in an interview, occurring over timescales of a few minutes. In this section we present examples from our research and use the framework to identify transfer processes occurring dynamically in a student’s reasoning path.

Spontaneous Transfer

During an interview, students often spontaneously, without any external hints create associations or “relations of similarity” (Lobato, 1996, 2003) between source tools (e.g. prior knowledge) and the target tools read out from the scenario at hand. Below we discuss several examples of spontaneous transfer occurring in myriad situations.

Spontaneous transfer from the classroom to the real-world

Engelhardt *et al*. (2003) investigated the extent to which students transferred their classroom learning to everyday devices e.g. a bicycle. In the transcript below a bicycle is turned upside down so that the wheels a rotate freely.

Interviewer:	Why doesn't the rear wheel stop moving when you stop pedaling?
Student:	Inertia, because it's already in motion so it tends to just keep going in motion unless a force is applied to stop it.
Interviewer:	What is force?
Student:	Force is for instance if I put my hand and I push down that is me putting a force on the wheel. So I guess force is a …we just covered that definition today. Force is a downward pull on an object.

The student appears to activate the "knowledge as propagated stuff" epistemic resource. She spontaneously associates inertia and Newton's first law (source tools) learned in class with the spinning bike wheel. (target tool) She clarifies the association when asked to explain the term "force" (another source tool) which she associates with the affordances of the target context -- the bike pedal and her kinesthetic feeling. (target tools) As demonstrated in this episode, most students intuitively used force rather than energy to explain the working of a bicycle even when presented with contexts (e.g. cycling uphill vs. downhill) that we believed should prompt them to make associations with energy. The implications for using real-world devices as a pedagogical vehicle to learn physics is that there may be certain concepts that students tend to associate spontaneously with certain devices. To develop effective curricula, we need to be cognizant of these spontaneous associations.

Spontaneous transfer from the real-world to the interview

Hrepic (2002) investigated students' mental models of sound propagation in air and through a wall. Below a student, provided with the diagram in Figure 3, explains her reasoning for why and how sound gets to the other side of a wall.

Interviewer:	If the listener hears the speaker [from the other side of the wall], how does sound get to the other side?
Student:	If the person is loud enough I think it can get to the other side because it's gonna travel through. Sound…is almost more… (pause) sneakier than air would be. Like air can't always get through, but sound can because it can get through the tinier, little areas and tiny as little…I mean as if a door is shut, you obviously are gonna be able to hear [sound from the other side]. It's not as loud. It's not as pointy. It's muffled. But you can still hear. But if there is a fan directly on an open door, it's gonna go right into the room, it's gonna go right into the area that fan is blowing. But if you shut that door, the air is not gonna go through. It's not gonna be able to get through. It's just like that's that – end of barrier. It can't get any there. But the sound can get through.

FIGURE 3 ABOUT HERE

The student contrasts sound with air in that sound is “sneakier” than air, which could not have gotten through unless the door was open. She uses this contrast as a source tool (i.e. air through a door) to accentuate the affordances of the target tool (i.e. sound through the wall).

Spontaneous transfer from one class to another class

Allbaugh (2003) investigated students’ transfer of Newton’s second law from mechanics to electricity and magnetism. Each student was presented a scenario involving a charged particle in an electric field and was asked to predict the path of the particle. Although these students had previously never used Newton’s second law in electrostatics contexts, over half of them appeared to spontaneously recognize the relevance of mass (source tool) in the target context and associate it with Newton’s second law (source tool) learned in the previous semester.

Student A:	Well then the acceleration will be smaller…Because the force on it is going to be the same and if the mass is going to go up, the acceleration is going to have to come down from Newton’s second law.
Student B:	Since it’s mass like it is ‘it’s kq1q2 over r squared [writes equation] also equals ma. So acceleration is going to be less. The mass is bigger so compared to that one this is going to move closer.

Spontaneous transfer between successive interview questions

Gray (2004) investigated the effect of question order on student responses to pairs of Force Concept Inventory (FCI) (Hestenes, Wells, & Swackhammer, 1992) questions. In think aloud interviews students were asked to work though one question followed by another question, the similarities and differences between the two questions and whether the second question would cause them to rethink the previous question. Therefore, the study investigated the extent to which students would spontaneously associate elements of one question with another.

A student incorrectly selects choice 4 for the hockey puck question in Figure 4 (FCI Question # 8). Next, she decides that the spaceship question in Figure 5 (FCI Question # 21) is similar to the hockey question and selects choice 4 for the spaceship question as well. But, while explaining her reasoning in the spaceship question, she realizes that her answer to the hockey puck question is incorrect and now selects choice 1 for the hockey puck question.

Student:	Uh, it looks like the same deal except this is in space and not under forces of gravity, like the hockey puck was. So, I think [choice] 4 is also going to be a good answer for this one. Actually looking at this one I think on the first question [choice] 1 was probably the best answer for that one.
Interviewer:	Okay.
Student:	Yeah, I think I mixed up the reasoning. In space the momentum and inertia are going to carry it at an angle to get to its right angle position.

The above example is 'backward transfer' because the second context (spaceship) prompts the student to change her responses in the first context (hockey puck). She dynamically and spontaneously associates the two contexts and recognizes the differences between them. She recognizes the relevance of the absence of gravity (source tool) in the spaceship context and associates it with the hockey puck question (target tool). However, this association does not enable her to arrive at the correct answer, therefore this case is an example of negative backward transfer. However, in a different situation this type of association could potentially result in positive backward transfer. This activation process did not occur for the reverse question order.

This example also demonstrates the role of backward transfer in metacognitive self-regulation. This learner uses tools from a later experience to reflect on and recognize inconsistencies in her previous reasoning. Although her final answer is incorrect, it is noteworthy that the learner is spontaneously engaging in these productive reasoning processes during an interview.

FIGURE 4 ABOUT HERE

FIGURE 5 ABOUT HERE

Finally, ‘spontaneous’ transfer as described here does not necessarily mean that a learner relies solely on the “knowledge is fabricated stuff” epistemic resource as the controlling meta-tool. In fact, a student could be spontaneous yet tend to rely only on what she has learned from authority such as definitions learned in class.

Scaffolded Transfer

In the examples in the previous section, the learner appeared to create associations spontaneously without any additional external inputs from the interviewer. Minimizing external inputs is desirable if our goal is to avoid, as far as possible, changing student knowledge in the process of investigating it. However, if our goal is to design instructional interventions we must also investigate how students respond to external inputs and attempts to change their ideas. In this section we discuss what we call ‘scaffolded’ transfer that is facilitated by direct and conscious inputs of the interviewer, which would prompt the student to dynamically create associations.

Existence of transfer explicated to the student

Allbaugh (2003) presented students with a sequence of images and descriptions of a problem scenario involving a large sled on ice that held six identical blocks (Figure 6). The student was asked a series of questions asking her/him to predict what would happen if first one block, then two blocks and so on were thrown from the sled at a given velocity every 10 seconds. Finally, each student was then asked if the scenario reminded her/him of anything she/he had encountered before either in or out of class.

FIGURE 6 ABOUT HERE

Initially, with no scaffolding provided five of the 14 students could not think of anything from their past that they could associate with this scenario. Three students (e.g. Student C below) spontaneously associated the target tool (sled problem) with a problem encountered in the past. The remaining six students associated the scenario with tools learned in class: center of mass and internal forces.

Student C:	Like it reminds me of a problem we did in high school. A squirrel is on an icy tin roof and so he's sliding down the roof and he's able to stop sliding because he has nuts in his mouth and so he like spits them out …So I've encountered stuff like this before.

Finally, the scaffolding was introduced. Students were told that physics professors who had been teaching the subject for years found the sled scenario similar to a homework problem on rocket propulsion that had been previously assigned in the course. The students were asked whether or not they agreed with the professors and why.

Thus, students were provided with a specific source tool -- the rocket problem. Epistemological factors are also present because students usually tend to believe in the professors' correctness (e.g. Student A below). By telling students that professors had seen associations, it is likely that students' "knowledge as propagated from authority" epistemic resource may have been activated.

Student A:	I guess [turns paper sideways] Hmm. [laughs] I guess. Yeah. Like, initially at rest, another similarity, a certain mass. Now, you're like burning fuel. Yeah. Yeah. I guess those guys are smart.

All of the students alluded to associations between the two scenarios. Two of these students (e.g. Student A) turned the horizontal image of the sled onto its side before they agreed with the professors. From Greeno *et al.'s* (1993) perspective these students were performing activities (rotating the page) that helped attune them to the affordances of the source tool (rocket problem) presented to them and recognized "potential states of affairs" in the learning context. These students (e.g. Student D below) transferred tools used in the sled scenario to the rocket propulsion scenario.

Student D:	Yeah, I can see how that relates to it. Sending out a mass of fuel in one direction and that propels the rocket forward. It's just this guy, ah, what he's throwing to the left is like the rocket fuel.

In this experiment we do not know whether students would have established associations if they had been presented with two problems and simply asked if they saw similarities between the two scenarios, without being told that professors saw similarities. This fact does not negate the positive implications of the study. That it is possible to have students dynamically construct “relations of similarity” (Lobato, 1996, 2003) with the appropriate prompts and epistemological triggers has important implications for instruction.

Cued transfer between interview questions

Gray's (2004) research on the effect of presenting students with two related questions successively provides an interesting example of scaffolded transfer. Students were specifically asked whether their response to one question was affected by the other question and what similarities they saw between the two questions. Thus, students were cued to focus on similarities and engage in the “dynamic production of sameness” between the two questions (Lobato, 1996, 2003).

The student below was first presented with the ‘airplane question,’ (Figure 7) which is modified (Rebello & Zollman, 2004) Question # 23 on the FCI. The student incorrectly answered this question by choosing path 1, a parabolic path behind the plane. The student was then presented with the cannon question, (Figure 8) which is Question # 12 on the FCI. Here, he incorrectly selects choice 3. The interviewer then asked the student several questions regarding the two scenarios such as, “Did the airplane question influence your answer to the cannon question?” “Do you still agree with your answer to the airplane question?” “Would you have answered the airplane question differently if you had been asked the cannon question first?” and

"Do you see any similarities between these questions?" All of these questions prompted the student to dynamically create similarities between the two scenarios.

FIGURE 7 ABOUT HERE

FIGURE 8 ABOUT HERE

The last of the interviewers' cuing questions makes the student rethink his answer to the airplane question. Initially the student had stated that the two problems were not similar. However, asking the student again whether there were "any" similarities, appears to have triggered him into an epistemic mode in which he was comfortable creating relations of similarity between the two situations. While describing these similarities he realized that his answer to the airplane question was incorrect. He then chose the correct response, answer 5, and described why this was correct.

Interviewer:	Do you think these two problems are similar?
Student:	No, they aren't.
Interviewer:	Do they have any similarities?
Student:	I mean, I can see some similarities because you've got the velocity of the ball by the time it reaches the end of the cannon and you've got, you know, the velocity of the bowling ball being carried inside the plane so when it leaves the plane, I mean they both still have a velocity carrying themselves and I've actually… now I change my mind. If I had this

question [cannon] first, I would have probably answered [choice] 4 differently, er I would have answered 4 on this [airplane] question or [choice] 5.

Interviewer: Okay.

Student: Cause I didn't even think about that. Cause of when the ball comes out, it's still got a velocity going forward, not backwards.

Interviewer: Okay.

Student: The ball would have carried with a forward motion.

Interviewer: Which, [choice] 4 or [choice] 5? Any preference?

Student: I would probably say [choice] 5.

The student recognizes the relevance of the forward velocity of the bowling ball. He associates this target tool with a source tool. (velocity of the cannon ball) These associations were prompted by the interviewer's external input asking the student whether there were "any" similarities between the questions. The line of reasoning shown above was also displayed by other students. All four of the students who were asked the two questions in this order eventually answered the airplane question correctly. Some of them did so after returning to it following the cannon ball question. This experimental design of comparing two questions is a useful way to promote transfer. Students can build a holistic conceptual understanding when they are prompted to generate associations by engaging in "personal constructions of similarities across activities." (Lobato, 1996, 2003) This strategy also appears to invoke metacognitive self regulation, such as in the example above when the student realized that she "didn't even think about" the forward velocity of the bowling ball in the airplane question, until after she was asked the cannon question. Finally, the students were specifically asked to return to the previous (airplane) question and *conjecture* whether they would answer it differently. They did not do so of their own accord. Therefore, we have established that transfer *could* occur spontaneously, not that it *will* occur. Such a possibility of transfer could not be established when the order of questions was reversed.

Scaffolded transfer is consistent with the model of transfer by Greeno *et al*. (1993). Interaction with the interviewer can prime the learner to activate epistemic resources that control associations between source and target tools. A method to promote transfer along the lines described above is described by Redish (2003). Students are presented an 'Elby pair' of questions, both of which involve the same physics concept. One question cues a common misconception while the other cues the correct solution. After students answer both questions, they are asked to reconcile their different approaches, i.e. they are asked to dynamically create associations between the two situations. The airplane and cannonball question, when asked in that order, appear to function similar to an 'Elby pair.'

THE TEACHING INTERVIEW: ANOTHER METHOD TO STUDY TRANSFER

Physics education researchers have often used semi-structured clinical interviews modeled after Piaget (1929). The goal is to explore student conceptual understanding without altering it in the process. Clinical interviews help uncover the ideas that students bring with them from previous experiences to the interview although they tell us little about how students might respond to particular instructional strategies. Knowledge of the latter is important for curriculum development and instruction.

The teaching interview is an adaptation of the teaching experiment technique that has often been used in mathematics education research (Steffe, 1983; Steffe & Thompson, 2000) to investigate how students might respond to certain instructional strategies. A few physics education researchers (Katu, Lunetta, & van den Berg, 1993; Komorek & Duit, in press) have used the teaching experiment methodology. Our adaptation of the teaching interview was developed by Engelhardt, Corpuz, Ozimek and Rebello (2003) who were interested in investigating how student ideas of real-world devices changed with instruction. The teaching interview includes multiple teaching episodes with a group of two or three students. The researcher (interviewer) simultaneously takes on the role of a teacher in a mock instructional setting that utilizes the learning cycle (Karplus, 1974) and Socratic dialog (Hake, 1987), incorporating demonstrations, hands-on experiences and predict-explain-observe-explain sequences. Because it incorporates these instructional elements, the teaching interview can serve as a useful bridge between clinical research and curriculum development.

The teaching interview is also different from action research. The latter is typically performed in a 'real' instructional setting to test curriculum or instruction that has already been developed. Rather, the teaching interview precedes the development of curriculum and instruction, and therefore does not follow a pre-decided strategy. Instead, the teaching interview is semi-structured in that it allows the researcher to attempt different instructional inputs that may change students' models. For instance, if a student is unable to construct a mental model, the researcher can gradually provide increasingly focused prompts (e.g. discrepant events) until the student builds the model. Conversely, if a student already has a coherent model in a given scenario, the researcher can present different situations to 'stress' the student's model to determine its robustness. Alternatively, if a student in the group has a coherent (and correct) model and another one does not, the interviewer can ask each student to convince the other of the correctness of their model as in peer instruction (Mazur, 1997) and observe the ensuing interaction.

Finally, the teaching interview is not a particular research methodology but rather refers to a family of techniques that lie along a continuum ranging from clinical interviews to classroom action research. Several variations in the teaching interview are also possible. For instance, one might conduct teaching interviews with individual students rather than with groups of students. Having a single student eliminates the variables associated with student-student interactions and provides the researcher with greater control in guiding the single student's model construction process.

We believe that the teaching interview can also help investigate transfer from contemporary perspectives. First, it creates an environment that provides a rich repertoire of experiences and tools and provides an opportunity for the dynamic "personal constructions of relations of similarities" (Lobato, 1996, 2003) and associations (Redish, 2003) between tools, maximizing the possibilities of students' attunement to the affordances (Greeno *et al*., 1993) of these tools. Second, the teaching interview allows the researcher to assess student learning *in situ,* consistent with transfer as preparation for future learning (Bransford & Schwartz, 1999). Finally, the teaching interview allows for student-student and student-teacher interactions, allowing the researcher to investigate the socio-cultural dynamics of transfer (Greeno *et al*., 1993; Lobato, 1996, 2003).

The teaching interview provides a level of scaffolding that is greater than a clinical interview. Interactions with other students and hands-on activities also provide inputs to the sense-making process of each student. Therefore, the teaching interview enables students to develop associations and transfer their learning from one scenario to another, and therefore allows one to investigate transfer of learning with maximal scaffolding. It is not our intent here to elevate the teaching interview as the ultimate research methodology to investigate transfer. Indeed, as contemporary perspectives indicate, transfer is almost ubiquitous and unavoidable. Therefore, a clinical interview too provides a useful methodology in which to study the dynamics of spontaneous *in situ* transfer. However, the teaching interview additionally allows us to study scaffolded transfer.

In this volume Schwartz, Bransford and Sears describe a methodology to investigate the effects of a learning treatment on how well it prepares students to learn. Two groups of students used two different teaching methods ("tell and practice" vs. "invent"). Then both groups were provided with a common learning resource followed by a common transfer problem task. Students who used the "invent" method were better able to utilize the learning resource and performed better than the "tell and practice" group on the transfer task. Using this methodology the researchers were able to study both "transfer in" and "transfer out" of the learning resource.

The teaching interview offers a similar, albeit yet unexplored opportunity as shown in Figure 9. By presenting students with specific external inputs the teaching interview can be adapted to perform a "double transfer" study. Unlike the Schwartz *et al's* study however, we will not have control of the initial treatment, which in this case is their real-world experience. However, we can study how students associate their prior experiences with instructional experiences provided during the teaching interview. We can also study how their prior experiences affect associations between tools acquired through 'instructional' experiences and those available in the final target scenario.

FIGURE 9 ABOUT HERE

We emphasize that by presenting students with particular 'external inputs' in the 'instructional' segment of the teaching interview, we do not depart from the notion that transfer is ubiquitous. Rather we continue to adopt a stance consistent with our perspective of not pre-supposing what should transfer but rather looking for 'anything' that transfers. The above methodology only increases the likelihood that students transfer the tools that they acquire in the 'instructional' segment of the teaching interview. We do not preclude the possibility that this transfer may not occur or that students may transfer tools gained through other experiences.

SUMMARY

Transfer of learning has often been defined as the ability to apply what one has learned in one context to a different context. Several previous research studies have demonstrated that transfer of learning, defined this way, is rather rare. These findings appear to contradict our everyday experiences as learners in which we often bring to bear previous experiences in any new situation that we encounter. Recently, some researchers have begun to rethink the ways in which to characterize transfer of learning.

We have focused specifically on the perspectives of Bransford & Schwartz (1999), Greeno *et al*. (1993) and Lobato (1996, 2003). All of these emergent views of transfer appear to share at least three common themes. First, they look at transfer from the students' perspective rather than a pre-defined researcher's perspective, i.e. they ask what similarities the student sees in a given situation. Second, they describe transfer as a dynamic phenomenon in which learners construct their knowledge in the target scenario, rather than apply previously learned knowledge. They promote the notion that transfer must be assessed by whether students can learn in the new situation. Finally, they go beyond looking at transfer from a purely cognitive perspective and include socio-cultural factors.

Based on these contemporary perspectives, we have adapted a framework that we had previously developed to analyze student responses in an interview. Our framework is based on the premise that students construct their responses to interview questions dynamically and often make things up on the spot. This notion is consistent with contemporary dynamic models of transfer. Therefore, our framework can be utilized to recognize dynamic transfer in an interview.

Our framework consists of four elements. First are the ‘external inputs’ provided by the interviewer and interview materials. Tools may be acquired in a prior learning (source) context or in the present transfer (target) context: Source tools are the prior knowledge or experiences including those gained from earlier instances in the interview. Target tools include information about the new context that the learner attends to. The third element in our framework is the ‘workbench’ which includes dynamic mental processes that help the learner associate the source and target tools. The fourth element is the ‘answer’ which is either an intermediate stopping point or a final conclusion of the reasoning process, and sometimes a starting point of metacognition.

Our adapted framework to study transfer is consistent with Redish's (2003) two-level theoretical framework of associations and activations controlled by a learner’s epistemic mode. We identify transfer as activation of associations between tools in the source (learning) and target (transfer) contexts. Epistemic resources are ‘meta-tools’ that control which associations a learner activates. For instance, a learner may selectively activate associations between the target scenario and classroom knowledge and ignore her everyday experiences because her epistemic resource directs her to see knowledge as propagated from authority and not created by her based on her everyday experience. Based on the external input, including meta-messages from the interviewer, a learner may be primed into a particular epistemic mode. The view of transfer as a process of epistemologically controlled activation of associations between source (learning) tools and target (transfer) tools is useful in characterizing dynamic transfer in an interview.

The clinical interview is useful in observing how students construct and transfer their knowledge dynamically. However, its goal of 'measuring' while not changing the knowledge state of the learner limits the amount of scaffolding that the researcher can provide to the learner. Therefore, although it may tell us the learner's prior knowledge state, the clinical interview often reveals little about how the learner will construct and transfer knowledge in a true instructional setting when external inputs are provided. The teaching interview affords the researcher the opportunity to investigate dynamic transfer and knowledge construction. The interviewer engages the learners in ways similar to a teacher in a small group instructional setting, often providing scaffolding such as hints, cues, hands-on learning, peer instruction, Socratic dialog, etc. All of these interactions provide a rich repertoire of tools akin to those in a true instructional setting. Therefore, the teaching interview provides yet another tool with which to study dynamic transfer in ways that are consistent with contemporary models of transfer of learning.

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TABLE CAPTIONS

Table 1. Alignment of our analytical framework with some contemporary models of transfer.

FIGURE CAPTIONS

Figure 1. Redish's (2003) "two-level" model showing *associations* and *control*.

Figure 2. Our model of transfer.

Figure 3. The figure accompanying the question asking the student to describe why the listener can hear the speaker across the wall.

Figure 4. The "hockey puck" question -- Question # 8 on the Force Concept Inventory.

Figure 5. The "spaceship" question -- Question # 21 on the Force Concept Inventory.

Figure 6. The sled problem: The person slides a block off the sled once every 10 seconds.

Figure 7. The "airplane" question -- Question # 23 on the Force Concept Inventory.

Figure 8. The "cannon ball" question -- Question # 12 on the Force Concept Inventory.

Figure 9. Adapting the "double transfer" (Schwartz, *et al.,* this volume) with the teaching interview.

TABLES

Elements of Framework	What Some Contemporary Models of Transfer Say
External Inputs [I]: Information provided to the learner through interactions with the interviewer and interview materials.	"Transfer is distributed across mental, material, social [I] and cultural planes." (Lobato, 2003, p. 20) "…activities… can be defined socially [I] … in a transfer situation, to try to relate the situation to previous experience [T]." (Greeno *et al*., 1993, p. 100)
Tools [T]: Knowledge structures of varying grain sizes as well as prior experience, etc. used in reasoning.	"… influence of prior activity [T] on current activity.." ".. a surface feature [T] may be structurally substantive to the learner." (Lobato, 2003, p. 20) "… when transfer occurs it is because of general properties and relations [T] of the person's interactions with features [T] of a situation." (Greeno *et al*., 1993, p. 146) "The PFL (Preparation for Future Learning) perspective fits with Broudy's (1977) arguments..." "People also 'know with' their previously acquired concepts and experiences [T]." (Bransford & Schwartz, 1999, p. 69)
Workbench [W]: Various mental processes used by the student that may utilize information provided by the external input and tools	"What relations of similarity are created [W]?" "Dynamic production of sameness." "Multiple processes [W] are involved." (Lobato, 1996, 2003, p. 20) "…a symbolic representation [T] of structure is generated [W] in the transfer situation, based partly on information about another situation [T] that is retrieved." (Greeno *et al*., 1993, p. 146) "From the PFL perspective, one looks for evidence of initial learning trajectories [W]." "… the focus shifts to whether they (the students) are prepared to learn [W] to solve new problems." (Bransford & Schwartz, 1999, p. 69)
Answer [A]: A 'stopping point' in the reasoning process. It could also be a question or request for information.	"… one determinant about the course of future learning is the questions people ask [A] about a topic, because these questions reshape their learning goals." (Bransford & Schwartz, 1999, p. 69)

TABLE 1

FIGURES

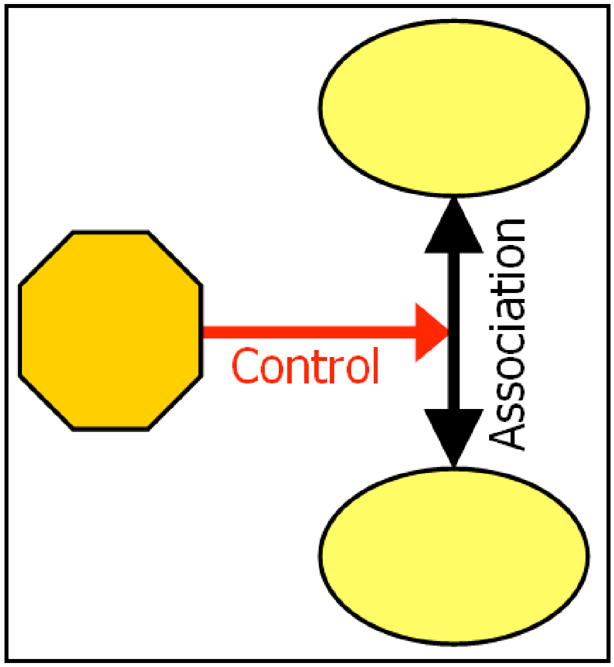
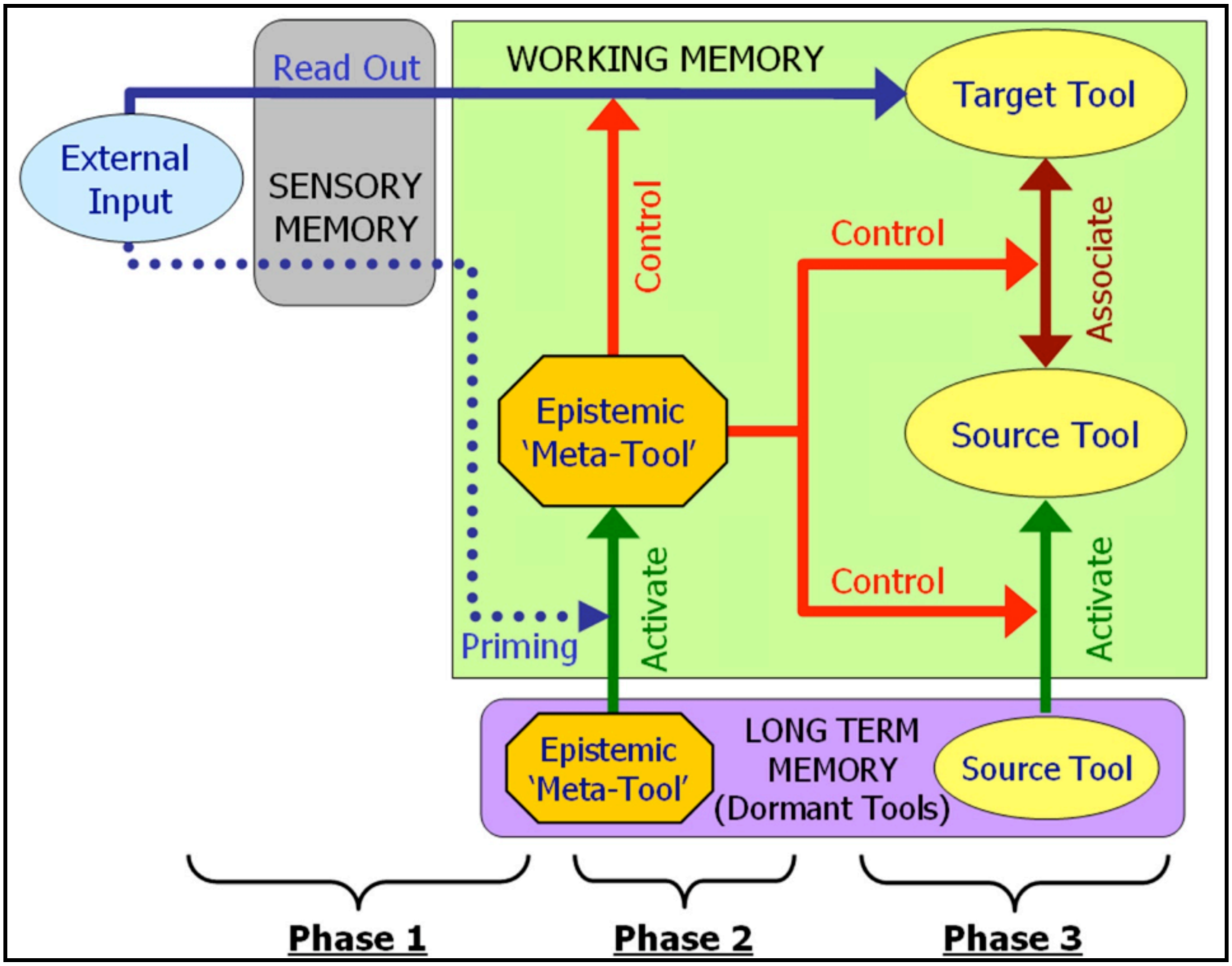


FIGURE 1



Read Out
WORKING MEMORY
Target Tool
External Input
SENSORY MEMORY
Control
Control
Associate
Epistemic 'Meta-Tool'
Source Tool
Control
Activate
Activate
Priming
Epistemic 'Meta-Tool'
LONG TERM MEMORY (Dormant Tools)
Source Tool
Phase 1
Phase 2
Phase 3

FIGURE 2

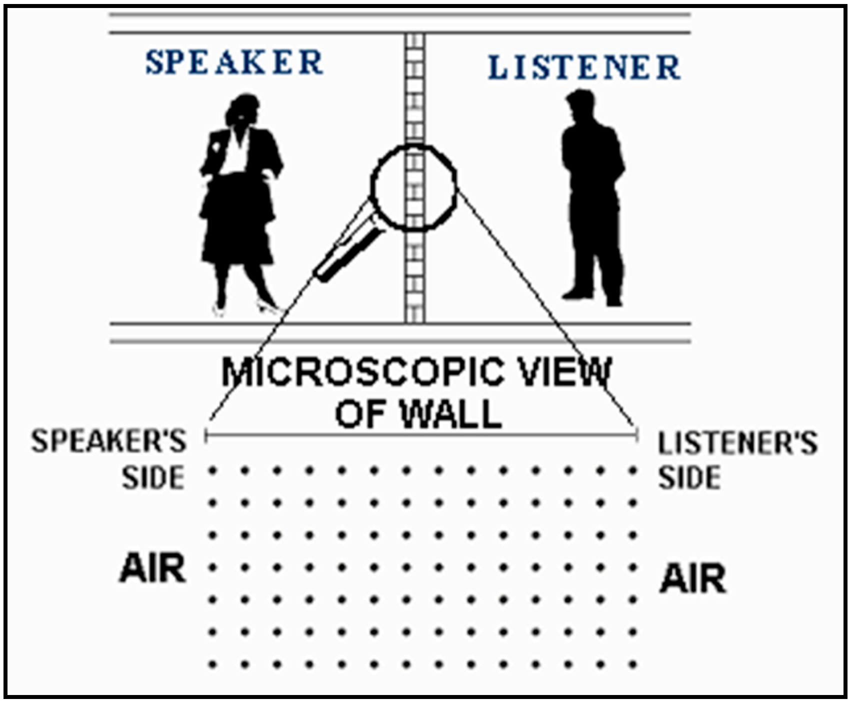

SPEAKER
LISTENER
MICROSCOPIC VIEW
OF WALL
SPEAKER'S
SIDE
LISTENER'S
SIDE
AIR
AIR

FIGURE 3

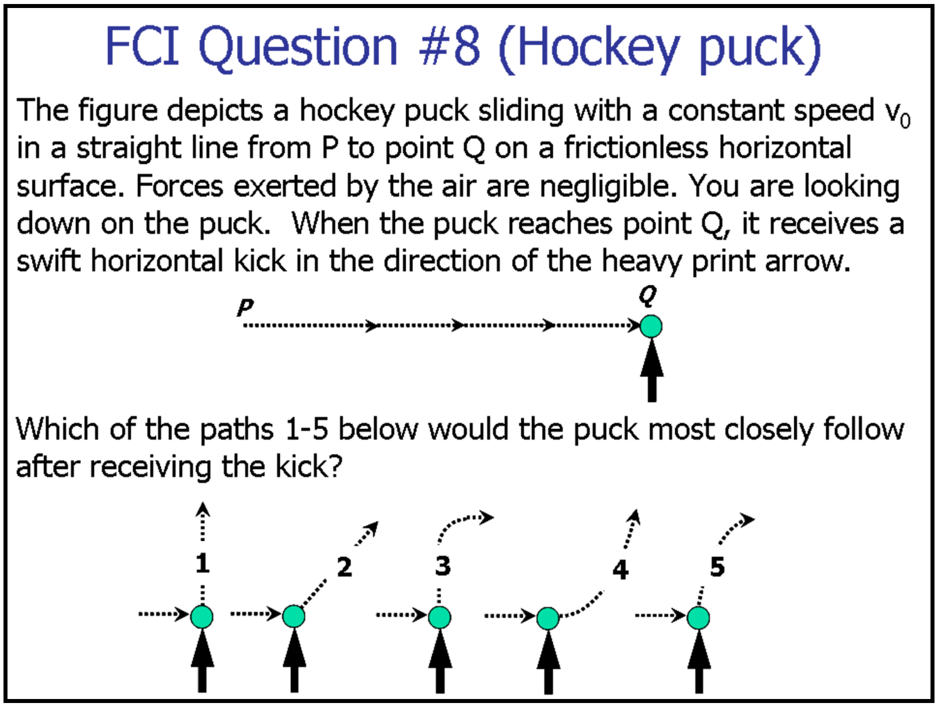

FCI Question #8 (Hockey puck)
The figure depicts a hockey puck sliding with a constant speed v0 in a straight line from P to point Q on a frictionless horizontal surface. Forces exerted by the air are negligible. You are looking down on the puck. When the puck reaches point Q, it receives a swift horizontal kick in the direction of the heavy print arrow.
P
Q
Which of the paths 1-5 below would the puck most closely follow after receiving the kick?
1
2
3
4
5

FIGURE 4

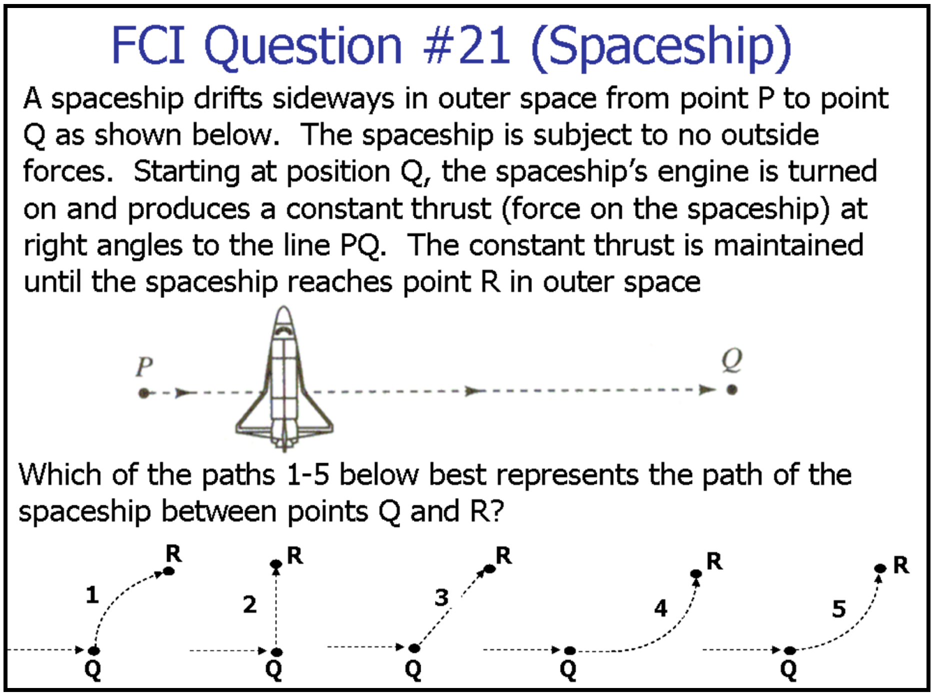

FCI Question #21 (Spaceship)
A spaceship drifts sideways in outer space from point P to point Q as shown below. The spaceship is subject to no outside forces. Starting at position Q, the spaceship's engine is turned on and produces a constant thrust (force on the spaceship) at right angles to the line PQ. The constant thrust is maintained until the spaceship reaches point R in outer space
P
Q
Which of the paths 1-5 below best represents the path of the spaceship between points Q and R?
1
2
3
4
5
R
Q

FIGURE 5

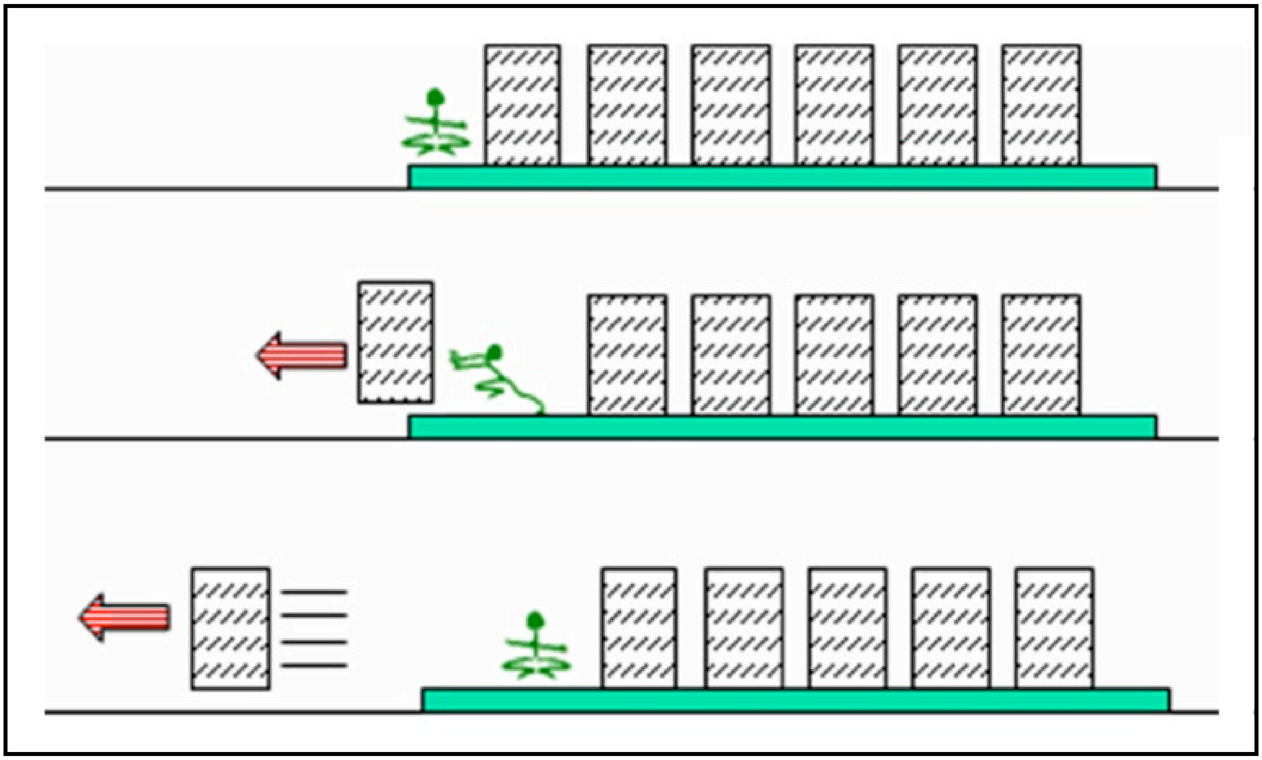


FIGURE 6

FCI Question #23 (Airplane)

A bowling ball accidentally falls out of the cargo bay of an airliner as it flies in a horizontal direction.

As observed by a person standing on the ground and viewing the plane as in the figure below, which path would the bowling ball most closely follow after leaving the airplane?

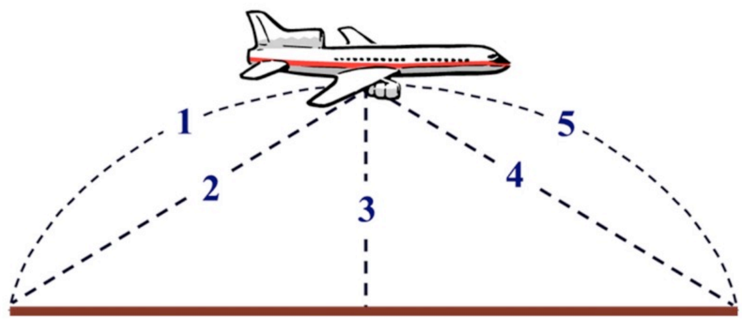


FIGURE 7

FCI Question #12 (Cannon)

A ball is fired by a cannon from the top of a cliff as shown below. Which of the paths 1-5 would the cannon ball most closely follow?

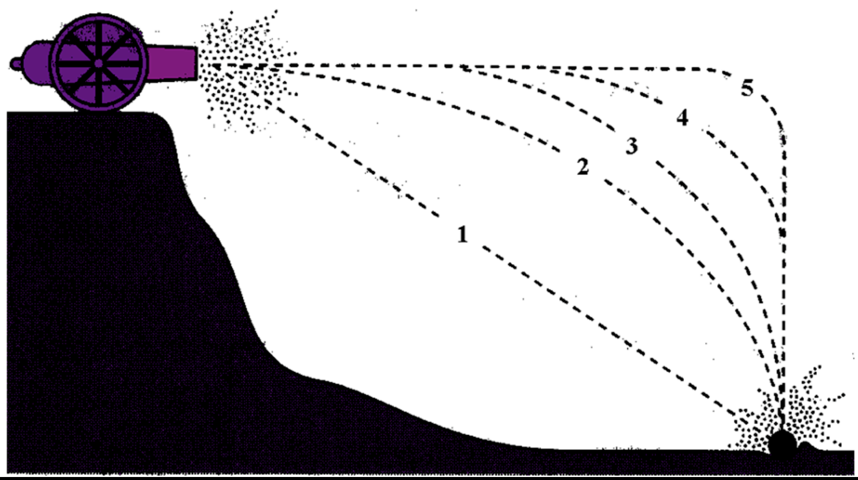


FIGURE 8

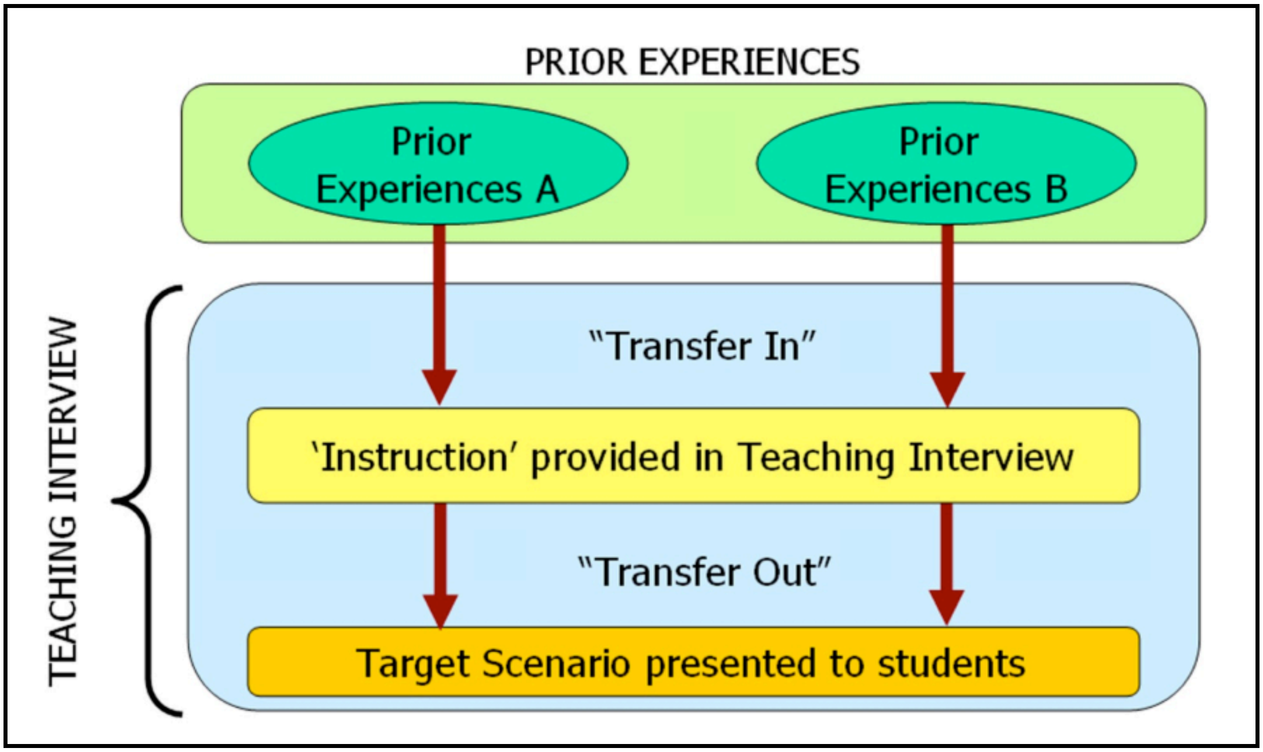

PRIOR EXPERIENCES
Prior Experiences A
Prior Experiences B
TEACHING INTERVIEW
"Transfer In"
'Instruction' provided in Teaching Interview
"Transfer Out"
Target Scenario presented to students

FIGURE 9