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Transfer(*)

Abstract

This essay has three foci. First, it provides a brief overview of the history of research on transfer, highlighting the difference between meaningful and rote learning, high-road and low-road transfer, transferring-in and transferring-out, and the importance of sagacity in fostering high-road transfer. Second, it contrasts two important educational objectives, learning in depth and learning for breadth, and suggests that both goals may not be diametrically opposed even though instructional time is a limited resource. Third, it provides an example of a middle school science curriculum that attempts to reconcile the expectation of fostering high-road transfer with both breadth and depth of learning by building off inter- and intra-unit coherence.

The overview of transfer is based on a document I prepared for NSF; time-to-learn is based on a manuscript submitted to the Journal of Research in Science Education; IQWST is drawn from a chapter in the Handbook of Research in Science Education (in print).

(*)The Initiative for Applied Research in Education's A Proposal to Revamp Schooling for the 21st Century expert committee commissioned the scientific survey.

- The findings are in the author's own words and the conclusions reached are his own.
- Any mention or quote from the survey must be referenced in the following manner: Fortus, D. (2011), Transfer, a Survey Commissioned by the Committee: A Proposal to Revamp Schooling for the 21st Century
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Transfer

Modern schooling has traditionally focused on transfer – the replication and application of knowledge (Broudy, 1977) in contexts different from those in which it was learned. In the former, the multiplication table is memorized and subsequently used as needed in arithmetic computation. In the second, one deduces a solution to a problem from the facts and principles one has learned. Thus, the principles of physics can be applied when repairing an automobile. Based on these two foci it seems that much of schooling is a failure, for the amount of rote learning one retains – unless there is an opportunity for frequent recall – is meager (Healy & Sinclair, 1996; R. A. Schmidt & Bjork, 1992). Similarly, most of us do not apply our studies of physics in repairing our cars. There exists a gap between understanding scientific principles and being able to apply them to create existential changes.

Despite the fact that the transfer appears not as automatic as one would wish, "a belief in transfer lies at the heart of our educational system" (Bransford & Schwartz, 1999, p. 61). Why do we continue to invest heavily in schooling that does not seem to pay off? The first answer is political: a reliance on transfer is regarded as the main feature distinguishing between education for critical thinking and training for direct application of skills frequently encountered by the average citizen. By removing the focus on transfer "schooling may be polarized into reasoning for the elite and practice for the masses. This … [would be an] embarrassment to a culture that is committed to abolishing this distinction" (Broudy, 1977, p. 8). The second answer is pedagogical: transfer may be uncommon because traditional instructional methods are not promoting it. In the rest of this section I will elaborate on this answer.

This "belief in transfer" was implicit. It was assumed that proper schooling would lead to the development of general capacities that could be applied in a wide range of contexts. Although this assumption was first explicitly challenged by Thorndike in the beginning of the 20th century, it became an important theoretical construct only during the "cognitive" paradigm shift in the 80's. Even today, few curriculum developers explicitly think of ways to foster transfer; at best they usually adopt a number of rules-of-thumb that research has indicated may promote transfer. Only few studies actually assess whether these curricula succeed in fostering transfer.

Historically, transfer was explained by the doctrine of 'formal discipline', according to which the mind is composed of a number of general faculties, such as observation, discrimination, and reasoning. The functioning of the mind could be improved by exercising these faculties. The substance of the exercises had little influence on the development of this 'mental muscle'; what was important was the level of effort exerted in these exercises (Anderson, 1982). This is the origin of the belief that studying taxing subjects such as Latin or geometry was beneficial. Transfer in this perspective is general, spanning domains that do not overlap. Thorndike (1906) demonstrated that transfer was more limited than predicted by the doctrine of formal discipline and proposed the theory of 'identical elements' according to which there are countless mental elements, each which is highly specialized. As suggested by the doctrine of 'formal discipline', transfer occurs between two situations when they rely on identical mental elements, but this happens very seldom because specialization of the mental elements.

The type of learning involved in Thorndike's studies was all rote; no higher-level mental processes were involved. A main criticism of Thorndike was that his studies had not shown that transfer was necessarily very specific and narrow, but that it was in the absence of effective learning (Woodrow, 1927). In a classic study, Judd (1908) demonstrated the importance of combining meaningful instruction with experience:

> Two groups of pupils in the fifth and sixth grades were required to hit with a small dart a target which was placed under water. The difficulty of hitting the target arises, of course, from the deflection which the light suffers thru refraction. The target is not where it seems to be, and the boy must fit his aim to conditions which differ from those which he knows in ordinary life. In this experiment one group of boys was given a full theoretical explanation of refraction. The other group of boys was left to work out experience without theoretical training. These two groups began to practice with the target under 12 inches of water. It is a very striking fact that in the first series of trials the boys who knew the theory of refraction and those who did not gave about the same results. That is, theory seemed to be of no value in the first tests. All the boys had to learn how to use the dart, and theory proved to be no substitute for practice. At this point the conditions were changed. The 12 inches of water were reduced to 4. The difference between the two groups of boys now came out strikingly. The boys without theory were very much confused. The practice gained with 12 inches of water did not help them with 4 inches. Their errors were large and persistent. On the other hand, the boys who had the theory fitted themselves to 4 inches very rapidly. Note that theory was not of value until it was backed by practice, but when practice and theory were both present the best adjustment was rapidly worked out…theory is not a substitute for direct experience; it is rather a frame in which experiences may be properly held apart and at the same time held together (Judd, 1908, pp. 37-38).

So, it appears that transfer can occur, but it is highly dependent upon the instruction given and the experiences provided. Many studies have also shown that the likelihood of transfer is largely dependent on the type of representations constructed and the type of instruction given. The gestalt psychologists distinguished between the *senseless learning* studied by Thorndike and *meaningful* *learning*, which occurs when an understanding of the structural relations within a problem develops (Katona, 1940). For example, the theory of identical elements predicts that learning one melody should not lead to the recognition of another identical, but transposed melody, since the number of shared notes between them would be very small. On the other hand, the gestalters realized that the character of a melody lay in the *functional relations* between the notes, not in the notes themselves (Wertheimer, 1945). This can be interpreted as saying that although there is very little physical overlapping between the original and the transposed melody, their cognitive representations are very similar.

Many studies found that generalizing a mental representation by constructing it in more than one context enhances the potential salient similarities between the learning and transfer contexts, thereby increasing the probability that transfer will occur. James (1890, p. 335) used the term *sagacity* to describe the skill of selecting "a partial aspect of a thing which *for our purpose* we regard as its essential aspect, as the representative of the entire thing". *Meaningful* learning (Katona, 1940) can be understood as learning that focuses on understanding structural relations and sagacity, on developing generalized representations that identify and clarify those aspects of new material that may be relevant for future use.

This body of research was summarized by Salomon & Perkins by distinguishing between low- and high-road transfer (1989). Low-road transfer is defined as the ability of people to use unintentionally and automatically skills that have been learned and over-practiced in a large number of contexts. The fundamental characteristics of low-road transfer are *varied practice* and *automaticity*. Your ability to read this text without struggling over the meaning and spelling of each word is a result of low-road transfer. An executive who raises her hand in a meeting to get the chair-person's attention is engaged in low-road transfer of a behavior learned in school. Although this kind of transfer is often not held in high esteem, higher mental processes would be clumsy without its ready availability.

High-road transfer is the ability of people to apply their existing knowledge mindfully in knowledge-rich environments, where new learning is required in order to solve problems. The key aspect of high-road transfer is *mindful abstraction*. *Mindfulness* means the volitional, meta-cognitively guided employment of non-automatic processes. *Abstraction* involves the extraction from or identification of some generic or basic qualities, attributes, or patterns in a learned unit of material, in a situation or in a behavior. These extracted qualities are then cognitively represented in a manner devoid of contextual specificity that affords application to other instances.

To summarize what has been presented till now, for high-road transfer to occur, a number of conditions must be realized:

1. First, there must be meaningful learning in the sense that it leads to the construction of representations of the initial problem that deal with its structural relations and not just its superficial features.
2. Learning should be done in several contexts in order to assist in the construction of generalized and abstract representations that can be mapped onto new situations.
3. Learning should be preferably done in the context of problems in order to develop students' sagacity by focusing their attention on the aspects of the issue at hand that are relevant to its application.
4. Students should be given opportunities to apply their learning in different contexts requiring new learning.

Bransford & Schwartz (1999) distinguished between transferring *out* and transferring *in*. In transferring, prior knowledge is used in new situations. Everything described until now has been examples of transferring *out*. Constructivism predicates that we draw upon existing knowledge when constructing new knowledge, or we transfer *in*. Thus, the ability to learn something new depends on the availability and quality of prior learning. Since, in the present day economy the purpose of much of formal schooling is to provide the basis for life-long learning, transferring *in* as the preparation for future learning cannot be ignored. While transferring *out* is typically assessed through sequestered problem solving where students are isolated from external sources of information and from interpersonal interactions, transferring *in* is best assessed in knowledge-rich environments where new learning is required in order to solve problems.

There is broad consensus that schooling in general and science education in particular shouldn't focus solely on the high-road transfer of content knowledge but also of scientific practices. Numerous studies have demonstrated that although students can respond correctly to items on tests they may be unable to draw on the same content knowledge to explain a phenomenon, to design an experiment, or develop a model. For students to be able to be able to engage in a scientific practice while drawing on relative science content, the scientific practices need to be meaningfully learned just as science content needs to be meaningfully learned (Perkins, 1993). Luckily, learning these scientific practices does not necessarily require additional instructional time. Appropriately integrating content knowledge with appropriate practices results can result in meaningful learning of both without unduly increasing the instructional time (McNeill & Krajcik, 2009; Schwarz et al., 2009).

Time to Learn in Science

Breadth and depth are two worthy educational objectives that are diametrically opposed because time is a limited resource. The standards of most OECD nations have advocated that students construct *a deep understanding* of *a wide variety of scientific topics*. In the US, this is expected to occur within the optimistic constraint of about 1000 hours of instruction (approximately 180 allotted class days a year for suburban settings x 7 years of middle and high school x 1 science lesson of 50 minutes a day). In many urban settings only 65% of the *allotted* instructional time actually becomes *enacted* instructional time, meaning that urban teachers and students have only 650 hours of instructional time to achieve this goal (Smith, 2000). I find this to be fantastically optimistic. Clearly we would prefer students to develop deep and meaningful, rather than superficial understanding of every topic they are taught. It is also obvious that constructing deep understanding takes more time than superficial understanding. How long does it take to construct deep understanding of one topic?

Consider the following example. A group at the University of California at Berkeley developed a high school unit on thermodynamics (Clark & Linn, 2003). The unit was enacted by a master teacher in four different versions, each successive one more streamlined than the previous one. The streamlining of the unit was achieved by shortening the final projects, allotting less time to each activity, and jig-sawing activities (dividing the class in half, having some students perform one experiment while the others perform a different experiment, and then having the students share results). Enactments of the full version lasted 61 hours (≈ 1/5 of the annual total time allotted to non-AP science education in high school!), while the most streamlined version lasted 32 hours, or about half of the full version. For urban settings this would be about ½ the annual time available for science education. The results of the study, in which 3000 students participated, showed that decreasing instructional time was strongly related to weaker understanding. Now, for the sake of the argument, let’s assume that any other science topic of comparable breadth could be learned and understood deeply in the same time it took the students in Clark and Linn’s study to construct integrated knowledge of thermodynamics. This means that in an ideal situation, when all allotted time is actually used for instruction, only 8 other topics could be covered in all of high school. Assuming that only 65% of the allotted instructional time actually becomes enacted instructional time, only 4 other topics could be covered. A look at the present US national standards (National Research Council, 1996) shows that there are at least 20 different topics of the scope of thermodynamics that are supposed to be learned during high school. So, as this bit of math seems to show, we cannot have both breadth and depth. One or both have to capitulate.

This calculation is based on two assumptions: A) There is no transferring *in* between topics, so the time to learn one is independent of whether others have been already learned, and B) the unit developed at Berkeley was highly efficient in that there was no shorter way for students to construct meaningful knowledge of thermodynamics. It also assumes, albeit implicitly, that all the 20 topics in the US standards are critical to science literacy. I claim that all three assumptions may be untenable.

The National Research Council has recognized that the existing national science education standards are overloaded, that they lead to curricula that are a mile wide but an inch deep, that meaningful understanding of few central ideas is preferable so superficial knowledge of many (Duschl, Schweingruber, & Shouse, 2007). In a draft of the new science education standards that are expected to be published in February 2011, NRC suggested that: “a more effective approach to science learning and teaching is to teach and develop systematically an understanding of the **core ideas** [my emphasis] of science over a period of years rather than weeks or months… As a result of our effort to identify fewer core ideas of science and engineering, some scientists and educators may be disappointed to find little or nothing of their favorite science topics included in this framework. The committee is convinced that by building a strong base of core knowledge and competencies, understood at a deep enough level to be used and applied, students will leave school with a better grounding in scientific knowledge and practices and greater interest in further learning in science, than those whose instruction “covers” multiple disconnected pieces of information, to be memorized and forgotten as soon as the test is done” (Committee on Conceptual Framework for New Science Education Standards, 2010). Thus, the NRC has taken the first step in prioritizing certain ideas over others, and by doing so allowing teachers to spend more instructional time on each core idea, increasing the chances that their students will actually construct meaningful knowledge of these ideas.

Traditional science curricula typically follow the logical structure of the discipline they aim to teach, which is typically bottom-up: First they define basic underlying notions and terms, then introduce basic concepts, and on to more complicated ones. For example, physics textbooks typically start with simple uni-dimensional kinematics, then bi-dimensional kinematics, then the relation between forces and motion, then linear momentum, then energy transformation and conservation, and so on. However, the logical structure of a discipline is not necessarily psychologically the best way to learn the discipline. The bottom-up structure does little to motivate students about the relevance and value of what is being presented. It does not create a need to learn. We typically learn best when we have a need to know, as when there is a personal question we want answered or a problem that we need to solve (Adams et al., 1988; Bransford, Brown, Cocking, Donovan, & Pellegrino, 2000). The questions that interest younger children are not those that interest older ones (Baram-Tsabari & Yarden, 2009). Also, this way of learning presents physics as disconnected from chemistry, biology, and earth science, and does not build on what student already think, correctly or not, from their everyday experiences and prior education. Much of science is anti-intuitive for novices (Driver & Bell, 1986) and without confronting everyday knowledge, school knowledge tends to remain just that – inert and isolated from relevant everyday contexts. Thus, for science curricula to be *efficient* they need to consider multiple years and multiple disciplines, not just grade clusters. Depictions of how knowledge of core concepts develops over extended periods of time are called *learning progressions*. This approach to improving science education is relatively new and since their development involves by necessity longitudinal research, few studies have yet been published (Duschl, et al., 2007).

IQWST

For the past 8 years I have been involved in a NSF-funded curriculum development project called "Investigating and Questioning our World through Science and Technology" (IQWST, pronounced IQuest). In this project, an entire middle school (grades 6-8) in physics, chemistry, biology, and earth science was developed and tested with thousands of students across the US. IQWST is unique: it is the first time I know of that an attempt has been made to develop a coherent science curriculum. There are several kinds of curricular coherence, but the more important ones in the discussion of transfer and time-to-learn are intra- and inter-unit coherence. Intra-unit coherence results from the coordination between four dimensions: a unit's content learning goals, scientific practices, inquiry tasks, and assessments, preferably within a project-based framework (Fortus & Krajcik, in print). In a coherent unit a progression occurs along each of these dimensions. While designing the progression along any one of these dimensions is not a simple task, coordinating between all three progressions is very difficult and involves multiple design iterations.

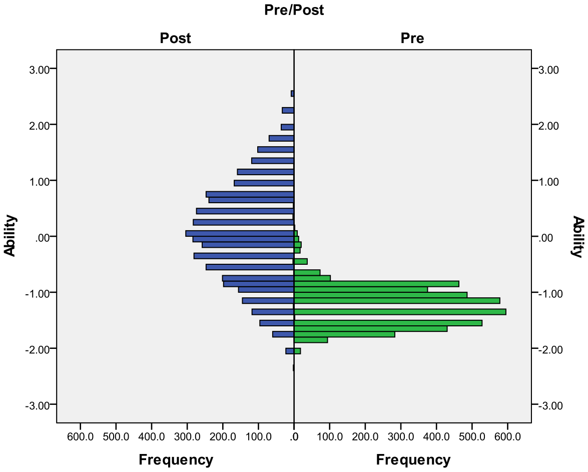
Inter-unit coherence is similar to intra-unit coherence, except it relates to larger inquiry sequences, multiple scientific practices, and different content domains within and across years. Inter-unit coherence deals with the question of how to coordinate among units to support the development of meaningful knowledge of core content ideas and practices across several years of instruction. A coherent curriculum is comprised of individual units, each one of which is independently coherent, but which are subjected to additional constraints and requirements, that allow them to build off one another, for ideas to flow from one to the others, and for the students to reach a higher degree of knowledge integration (Roseman et al. 2008) than would have been possible than if the units were truly stand-alone entities, with no explicit connections between them. To describe how this can be done, I present an example of how a progression for the *flow of matter and energy between organisms and their environment* was implemented in IQWST through grade levels and across disciplines, in multiple units, each of which provides a necessary element of this idea (Shwartz et al. 2008, p. 214). The following table identifies various content standards from the National Standards (National Research Council, 1996) and their sequencing in the curriculum needed to support understanding of this idea.

Key idea	**Where it is addressed**
All matter is made up of atoms	6th-grade chemistry
Food provides the fuel and the building material for all organisms. Plants use the energy in light to make sugars out of carbon dioxide and water	6th-grade biology – macroscopic perspective 8th-grade chemistry – molecular level
Atoms that make up the molecules of existing substances rearrange to form new molecules of new substances	7th-grade chemistry
Conservation of matter in a chemical reaction	7th-grade chemistry
Energy transformations and conservation in living things	7th-grade physics
Animals get energy from oxidizing their food, releasing some of its energy as heat.	8th-grade chemistry - oxidation reactions
Food energy comes originally from sunlight	6th-grade biology 7th-grade physics - energy from the sun 8th-grade chemistry – photosynthesis
Matter and energy are transferred from one organism to another repeatedly and between organisms and their physical environment	6th-grade biology – food chains 8th-grade chemistry – cellular respiration and photosynthesis

This progression of the ideas is not linear. It provides opportunities to revisit, enhance, build further, and apply knowledge in different disciplinary units and grades to construct a meaningful understanding of the transformations of matter and energy in eco-systems and create a powerful view of explaining the world. The same key ideas are often addressed in different units, at different levels of sophistication and highlighting different aspects, explicitly supporting students as the *transfer in* ideas previously learned. Such inter-unit coherence ensures that the key ideas are not just dealt with for a short time, but that they "stay" in the curriculum and are revisited repeatedly from different points of view. This helps students make connections and gradually build meaningful knowledge of the core ideas.

This approach is different than that found in traditional non-coherent curricula or in what has been called spiral curricula. It emphasizes that real-world phenomena are complex, the knowledge needed to make sense of them is not limited to a single discipline, and that understanding develops over time. In a traditional curriculum, photosynthesis will usually be presented as a topic in biology. The molecular aspects of the process, as well as understanding its importance in transforming light energy into chemical energy are not emphasized. Few middle school chemistry and physics curricula actually deal with the different aspects of photosynthesis (Schmidt, Wang, & McKnight, 2005).

The national field tests of IQWST have ended and my colleagues and I are analyzing the results. The following graph is a pre/posttest comparison of students' understanding of concepts related to light, how it propagates and interacts with matter, and how it is detected and perceived. The tests were difficult, requiring a sophisticated level of understanding to answer correctly. Several thousand students from all across the US are represented, many of them from inner-city urban schools. The posttest was given at the end of the school year, regardless of when the relevant content was presented in class. The results were analyzed using IRT so that the graph shows students' abilities rather than scores. The effect size is very large – over 3.0. Clearly, this approach to curriculum has great promise.



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