Aspects of Constructivism: A Compilation of Resources

Each section provides a sampling of material--excerpts-- from each cited source for the purpose of helping Learning Assistants better understand aspects of constructivism as a learning theory and as a means to help students work with material within their content area.

From: D'Angelo, C., Touchman, S., Clark, D., O'Donnell, A., Mayer, R., Dean, D., and Hmelo-Silver, C., "Constructivism"

http://www.education.com/reference/article/constructivism/

Constructivism As Epistemological Theory, Learning Theory, And Pedagogy
More commonly, educators view constructivism as a learning theory. From the perspective of constructivism, learners construct knowledge based on what they already understand as they make connections between new information and old information. Students' prior ideas, experiences, and knowledge interact with new experiences and their interpretations of the environment around them. Research by Savery & Duffy (1995) suggests that learning how to use constructivist theories involves many interactions between the content, the context, the activity of the learner, and the goals of the learner.

Cognitive conflict drives this knowledge-building process. Cognitive conflict occurs for learners when they encounter and recognize discrepancies between what they already know and new persuasive information that brings their current understanding into question. These discrepancies cause cognitive tension requiring adjustment to reduce the discrepancies. When students resolve these discrepancies they actively figure out ways to reconcile their prior knowledge or understanding with the new information. Students may construct new knowledge from pieces of prior knowledge or restructure prior knowledge. Thus the resolution of cognitive conflict drives learning.

Finally, based on the core ideas of constructivist learning theory, constructivist pedagogy proposes that instruction must take students' prior ideas, experiences, and knowledge into account while providing opportunities for students to construct new understanding.

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Savery, J. R., & Duffy, T. M. (1995). Problem based learning: An instructional model and its constructivist framework. Educational Technology, 35(5), 31–38.

From: Learning in Interactive Environments: Prior Knowledge and New Experience

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http://www.exploratorium.edu/ifi-archive/resources/museumeducation/priorknowledge.html?utm_source=twitterfeed&utm_medium=twitter

Public Institutions for Personal Learning: Establishing a Research Agenda. © 1995, the American Association of Museums.

Prior Knowledge

A large body of findings shows that learning proceeds primarily from prior knowledge, and only secondarily from the presented materials. Prior knowledge can be at odds with the presented material, and consequently, learners will distort presented material. Neglect of prior knowledge can result in the audience learning something opposed to the educator's intentions, no matter how well those intentions are executed in an exhibit, book, or lecture.

Consider a hypothetical book on wool production in Australia. Australian ranchers raise sheep in an extremely hot desert climate. The sheep are raised to have wool so thick that without yearly trimmings the sheep would be unable to walk. To many children, these facts together are absurd. Children think wool is hot; if you put a thermometer inside a wool sweater, the mercury would go up (Lewis, 1991). Wouldn't sheep grow more wool in cold places where they need to stay warm? Is wool hot because the sheep absorb the desert warmth?

Alternatively, consider a hypothetical exhibit on fish schooling. Fish follow each other in close formation that looks highly organized. But no single fish is the leader, and none of the fish know how to command the others. Many people assume that any organized system is the result of a centralized planner who directs the others. They think "there must be an older fish, who is smarter than the rest, and who leads the school. If marine biologists believe otherwise, well I guess it's true, but I'll never be a marine biologist!"

Then again, consider a hypothetical lecture on jazz. Upon a first listening, one might hear the music as ugly, chaotic, and meaningless- "it's just a lot of notes." Many years later, same music provides a rich and rewarding experience, and with more listening, yet more difficult music becomes accessible. How can you learn jazz if all you understand is classical music or pop?

To help people make the most of a new experience, educators need to understand how prior knowledge affects learning. To the child who does not yet understand heat and temperature, no quick explanation can possibly resolve the contradiction between the hot desert and the warm wool; it takes weeks to years for this understanding to emerge (Lewis, 1991). The adult who is unfamiliar with the possibilities of decentralized systems can't quickly be convinced that schooling fish have no leader (Resnick, 1992) - and instead they may be alienated from the setting. There is no way to give the first-time jazz listener the epiphany available to more practiced ears. Prior knowledge determines what we learn from experience.

Prior knowledge also forces a theoretical shift to viewing learning as "conceptual change." (Strike & Posner, 1985; West & Pines,1985). Previously learning was considered a process of accumulating information or experience. Prior knowledge is the bane of transmission-absorption models of learning. Mere absorption cannot account for the revolutionary changes in thought that must occur. The child simply can't absorb knowledge about wool, because prior knowledge about heat renders incoming ideas nonsensical.

On the other hand, it is impossible to learn without prior knowledge. Eliminating prior understanding of heat won't explain why that sweater is still so nice in the winter, or how thick-coated sheep can be raised in the desert. The idea of decentralized systems must be built from some anchor in prior experience. It is easiest to appreciate unfamiliar music by starting with "crossover" artists who populate the periphery between jazz and rock or classical music.

The aspects of learning, prior knowledge and experience drawn out in these examples have a solid basis in research on learning. There is widespread agreement that prior knowledge influences learning, and that learners construct concepts from prior knowledge (Resnick, 1983; Glaserfeld, 1984). But there is much debate about how to use this fact to improve learning.

This article presents a set of research findings, theories, and empirical methods that can help the designer of interactive experiences work more effectively with the prior knowledge of their audience. It focuses on the central tension that dominates the debate about prior knowledge. This tension is between celebrating learners' constructive capabilities and bemoaning the inadequacy of their understanding. On one hand, educators rally to the slogan of constructivism: "create experiences that engage students in actively making sense of concepts for themselves." On the other hand, research tends to characterize prior knowledge as conflicting with the learning process, and thus tries to suppress, eradicate, or overcome its influence.

The juxtaposition of these points of view creates a paradox: how can students ideas be both "fundamentally flawed" and "a means for constructing knowledge?" The question cuts to the heart of constructivism: constructivism depends on continuity, because new knowledge is constructed from old. But how can students construct knowledge from their existing concepts if their existing concepts are flawed? Prior knowledge appears to be simultaneously necessary and problematic. This version of the learning paradox (Bereiter, 1985) is called the "paradox of continuity" (Roschelle, 1991). Smith, diSessa, and Roschelle (1993) argue that educational reforms must include strategies that might avoid, resolve, or overcome the paradox.

Empirical Findings in Science and Mathematics Learning

New knowledge does not replace prior knowledge, rather new knowledge re-uses prior knowledge. Re-use is made possible by a process in which prior knowledge is refined, and placed in a more encompassing structure. The more encompassing structure comes in part from the social discourse norms that prevail within a community of practice.

Analyzing conceptual change, Toulmin (1972) argues that conceptual change is not the mere replacement of one theory by another. Conceptual change occurs slowly, and involves a complex restructuring of prior knowledge to encompass new ideas, findings, and requirements. Thus Einstein does not merely replace Newton, he transforms Newtonian ideas and places them inside a new, encompassing analysis of space and time. Toulmin emphases that conceptual change, like normal science, is continual and incremental. It is mediated by physical tools, and regulated by social discourse. Only from the distant perspective of history does a paradigm shift appear as replacement. From a close-up perspective, conceptual change looks like variation and selection in an interrelated system of knowledge. Individual scientists vary the meaning of concepts and the use of methods. Given specific social rules and a long time over which to operate, selection can result in large scale changes in concepts.

In general, learning involves three different scales of changes. Most commonly, learners assimilate additional experience to their current theories and practices. Somewhat less frequently, an experience causes a small cognitive shock that leads the learner to put ideas together differently. Much more rarely, learners undertake major transformations of thought that affect everything from fundamental assumptions to their ways of seeing, conceiving, and talking about their experience. While rare, this third kind of change is most profound and highly valued.

Studies of Science Learning: Deepening the Paradox

Studies of students' prior knowledge in science and mathematics began in the 1970s and have since produced a voluminous literature (see reviews in Confrey, 1990; McDermott, 1984; Eylon & Linn, 1988). Interest in prior knowledge began with the careful documentation of common errors made by students in solving physics and mathematics problems. Analysis of interviews with these students reveals that the errors are not random slips, but rather derive from underlying concepts.

For example, when students are asked to explain a toss of a ball straight up in the air, they describe the motion in terms of an "initial upwards force" which slowly "dies out," until it is "balanced" by gravity at the top of the trajectory. Physicists, in contrast, explain the ball toss in terms of a single constant force, gravity, which gradually changes the momentum of the ball: On its way upwards, the momentum is positive and decreasing; at the top, it is zero; and going down, the momentum is negative and increasing.

From analysis of students' thinking, researchers have determined that this "mistaken" explanation is not peculiar to this problem. Students commonly give explanations in terms of "imparting force," "dying out," and "balancing"(diSessa, 1993). From these commonsense ideas, students can generate endless explanations for different situations. In many cases, these explanations disagree with conventional Newtonian theory.

After they established the existence of prior concepts, researchers investigated the consequences of those concepts for subsequent learning. Most studies have looked at the role of prior knowledge in a conventional science course. The results depend on the nature of the task used to probe students' learning. If the task is procedural calculation, students can often learn to get the right answer independent of their prior knowledge. However, if the task requires students to make a prediction, give a qualitative explanation, or otherwise express their understanding, studies show that their prior knowledge "interferes." diSessa (1982), for instance, found students who were receiving an "A" grade in freshman physics at MIT, but could not explain the simple ball toss problem correctly. Using their prior knowledge, students often construct idiosyncratic, nonconforming understandings of the scientific concepts.

The processes by which "misconceptions" arise from a combination of prior knowledge and instructed subject matter are not unique to Newtonian mechanics. Children have concepts that differ from scientists in biology (Carey, 1985; Keil 1979), heat and temperature (Lewis, 1991; Wiser & Carey, 1983), electricity (Cohen, Eylon & Ganiel, 1983; Gentner & Gentner, 1983), mathematics (Resnick & Ford, 1981; VanLehn, 1989), probability (Shaughnessy, 1985), statistics (Tversky & Kahneman, 1983) and computer programming(Spohrer, Soloway, & Pope, 1989), and encounter difficulties as they interpret the scientific theories of these subjects. Furthermore, it’s not just children who produce mistaken interpretations by combining prior knowledge with instruction. Consider Tversky & Kahneman's (1982) findings about simple statistics. They have identified erroneous prior concepts about statistical phenomena that are widespread among professional psychologists - scientists who use statistics regularly. For example, both students and scientists suffer from "confirmation bias" that distorts experience to fit prior theory.

Prior knowledge exists not only at the level of "concepts," but also at the levels of perception, focus of attention, procedural skills, modes of reasoning, and beliefs about knowledge. Trowbridge and McDermott (1980) studied perception of motion. Students perceive equal speed at the moment when two objects pass, whereas scientists observe a faster object passing a slower one. Anzai and Yokohama (1984), Larkin (1983), and Chi, Feltovich, and Glaser (1990) studied how students perceive physics problems and found they often notice superficial physical features, such as the presence of a rope, whereas scientists perceive theoretically-relevant features, such as the presence of a pivot point. Larkin, McDermott, Simon and Simon (1980) studied students' solutions to standard physics problems and found that students often reason backwards from the goal towards the known facts, whereas scientists often proceed forward from the given facts to the desired unknown. Similarly, Kuhn (Kuhn, Amsel, & O'Loughlin, 1988) studied children's reasoning at many ages and found that children only slowly develop the capability to coordinate evidence and theory in the way scientists do. Finally, Songer (1988) and Hammer (1991) studied students beliefs about the nature of scientific knowledge. They found that students sometimes have beliefs that foster attitudes antagonist to science learning.

In summary, prior knowledge comes in diverse forms. It affects how students interpret instruction. While it may not prevent them from carrying out procedures correctly, it frequently leads to unconventional and unacceptable explanations. Prior knowledge is active at levels ranging from perception to conception to beliefs about learning itself. Moreover, its effects are widespread through lay and professional population, from young children through to adults, and from low to high ability students.

Implications of Prior Knowledge: Learning as Conceptual Change

The overwhelming weight of the evidence has forced informed educators to fundamentally change the way science is taught. Learners are more likely to construct an interpretation that agrees with prior knowledge, and consequently disagrees with the viewpoint of the teacher. Thus, the effects of prior knowledge require a change from the view that learning is absorption of transmitted knowledge, to the view that learning is conceptual change (Resnick, 1983; Champagne, Gunstone, & Klopfer, 1985). Over time, learners need to accomplish the rarest form of change, a paradigm shift in their basic assumptions about the natural world, and the accompanying ways they see, conceive, and talk about the world. Conceptual change is a process of transition from ordinary ways of perceiving, directing attention, conceptualizing, reasoning, and justifying. Slowly learners transform prior knowledge to accommodate new scientific ideas (Posner, Strike, Hewson, & Gertzog, 1982).

Most of the data on science learning stresses differences between prior knowledge and scientific knowledge, rather than commonalities (Smith, et al, 1993). This has had an unfortunate consequence: rather than making education seem easier, it now appears to be impossible. Teachers get the impression that students need prior knowledge to learn new concepts, but prior knowledge misleads students to unconventional interpretations of concepts. Moreover, as the perception of a gap has increased, the metaphors used to describe the learning process have become more adversarial: prior knowledge must be confronted, challenged, overcome, replaced, eradicated, or destroyed in order for new knowledge to take its place. Educators celebrate students' constructive capabilities, and then roll out the heavy artillery to destroy it. The weight of the evidence makes paradox of continuity appear as a gaping void- there seems to be no bridge from prior knowledge to desired knowledge, with many apparent pitfalls along the way.

Undoing the Paradox of Continuity in Science Learning

Smith et al. (1993) recently investigated the paradox of continuity that arises in science education research. They suggest a interpretative theoretical framework that accepts the flawed character of some prior knowledge, but still gives it a positive role. The gist of their argument is that the paradox arises from implicit biases in theory and method. To undo the paradox, one must reconsider the implicit assumptions in science learning research.

First, one must recognize a bias in the data set. Almost all the data begins from identifying learning failure-examining a situation in which students make errors, and then identifying the concept that causes the error. If we start, on the other hand, by identifying success, and then investigating the concepts that enable success, we find an equally strong role for prior knowledge. Prior knowledge is properly understood not as a causes of errors or success, but rather as the raw material that conditions all learning.

Second, biases in research methodology tend to produce "attributes" of prior knowledge which might be better understood as "attributes of the learning task." For example, prior knowledge is said to be resistant to change by conventional instruction. Students might be resisting the learning experience, and not the knowledge. For example, most conventional science courses focus on manipulating mathematical expressions that refer to idealized situations, i.e. a frictionless plane. We should not expect such an abstract experiences to enable much change in familiar concepts of motion. When learning experiences are more concrete, related to familiar situations and interactive, "resistance" often disappears, and students construct new concepts quickly. Prior knowledge and conventional instructed knowledge may not be in conflict, but rather may be ships passing in the night.

Likewise, research methods that compare expert and novice performance tend to characterize their findings in dichotomies. For example, Larkin (1983) suggests that scientific knowledge is abstract, whereas prior knowledge is concrete. Other popular dichotomies are general vs. superficial, theoretical vs. familiar, and structural vs. superficial. A methodology based on dichotomies is well suited to sorting objects onto a bipolar spectrum, but is not well suited to analysis of how emergent wholes integrate pre-existing parts. For example, dichotomy-based methods mistakenly assert that science is abstract, and cannot identify how scientific knowledge successfully coordinates both concrete and abstract elements. A bias to dichotomies obscures the continuing roles prior knowledge plays in a more encompassing knowledge structures.

Third, one must be careful about the status that is attributed to prior knowledge. Researchers have termed prior knowledge "preconceptions." "alternative conceptions," "naive conceptions" "misconceptions" as well as "naive theories" and "alternative theories." Each term is loaded with theoretical connotations, that may be quite misleading and inaccurate, even if unintentionally so.

Terms that ascribe the status of a "theory" to prior knowledge are particularly misleading. For example, some researchers have drawn analogies between students ideas and historical theories, such as medieval impetus theory (McCloskey, 1983). However, children are not "short scientists" nor are ordinary adults "medieval scientists." All people, including scientists, build knowledge from a pool of familiar metaphors like "balancing" and "dying out." This pool of metaphors is not structured like a theory; it is not necessarily consistent, complete, or deductively sound. Rather it is a loose aggregate of useful ideas that can be flexibly applied. Although children and ordinary adults sometimes produce explanations that sound like medieval theory, they do not necessarily hold their knowledge in the same regard that a scientist holds a theory.

Terms that focus on the mistaken or alternative status of prior knowledge are also misleading. Prior knowledge can produce mistakes, but it also can produce correct insights. Sometimes the same element of prior knowledge can provide both an incorrect alternative to one theory and be a component of a correct theory in another topic area. For example, consider the common idea of "force as a mover," which holds that an applied force results in a proportional velocity (diSessa, 1983). This is often misapplied to situation in which a constant force acts on a frictionless object. Conventional electromagnetism texts, however, assert that "an electron moves with a velocity proportional to the applied electromotive force." Thus "force as a mover," can be either a misconception or a sanctioned modeling concept, depending on the context of use. The consequence of such observations is that educators should treat prior knowledge as a store of generative metaphors, not a collection of wrong theories. Prior knowledge is like a set of building blocks, and not like an enemy fortress.

In summary, we see that students quickly acquiring many different kinds of knowledge, but only slowly acquire the ability to coordinate and integrate these different sources of understanding. Students can learn to calculate from mathematical formulas, and can learn to give qualitative explanations but it takes a long time to acquire to the ability to coordinate qualitative explanations with mathematical formulas that represent a theory.

In the previous section on scientists use of prior knowledge, it was emphasized that knowledge changes slowly by restructuring, not replacement. This is equally true for science students. Moreover, to overcome the paradox of continuity for science learning, we should attend to several guidelines for interpreting prior knowledge:

- Study success, not just failure, and identify how prior knowledge enables success.
- Use methods that allow observations of students constructing integrated wholes, not just shifting valences on a bipolar scale.
- Be wary of viewing prior knowledge as an enemy fortresses that is wrong, alternative, or theoretical in character, and instead see prior knowledge as a disorganized collection of building blocks.
- Expect learning to occur through gradual refinement and restructuring of small component capabilities in a large, distributed system, with increasing coordination.

In summarizing the broad sweep of research, perhaps the most important lessons are these. First, we must give up the notion of transmitting knowledge to absorbent minds; learning is a process of conceptual change. Second, conceptual change is a slow, transformative process. Rather than rejecting prior knowledge and accepting instructed knowledge, learners must gradually refine and restructure their prior knowledge. Third, to overcome the paradox of continuity, we should study success, avoid dichotomy-based empirical methods, see prior knowledge as providing building blocks, look for learning as long-term transformation knowledge into larger, more systematically coordinated wholes.

Prior Knowledge in Theories of Learning

In Piaget's account of conceptual change, knowledge grows by reformulation. Piaget identifies a set of invariant change functions, which are innate, universal, and age independent. These are assimilation, accommodation, and equilibration. Assimilation increases knowledge while preserving of structure, by integrating information into existing schemata. Accommodation increases knowledge by modifying structure to account for new experience. For Piaget, the critical episodes in learning occur when a tension arises between assimilation and accommodation, and neither mechanism can succeed on its own. Equilibration coordinates assimilation and accommodation, allowing the learner to craft a new, more coherent balance between schemata and sensory evidence. Reformulation does not replace prior knowledge, but rather differentiates and integrates prior knowledge into a more coherent whole.

The restructuring process that intertwines spontaneous and specialized concepts occurs in social interaction, and is mediated by sign systems, such as language and drawing. Whereas Piaget focuses on disequilibrium among schemata, Vygotsky turns our attention to the "Zone of Promixal Development (ZPD)" (Wertsch, 1985; Newman, Griffith, & Cole, 1989). The ZPD is formed by the difference between what a child can do without help and the capabilities of the child in interaction with others. In this construction zone, the child can participate in cultural practices slightly above his or her own individual capability. Successful participation can lead to internalization. In Vygotsky's account, the primary resources for restructuring prior knowledge come from culture. Moreover, the restructuring process itself occurs externally, in social discourse. Children share, negotiate and try out meanings in social experience, and adults can shape those meanings by bringing them into the framework of cultural practice.

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From: Designing learning environments to promote conceptual change in science

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Conceptual Change
3.2. Metaconceptual awareness
It is important to take into consideration the fact that students are often not aware of the presuppositions and beliefs that constrain their learning. Students are not, for example, aware that they consider force as a property of objects. Even when they become aware of such presuppositions they do not always understand their theoretical nature. They take them to be facts about the way the physical world operates rather than propositions in a hypothetical explanatory framework subject to verification and falsification. Finally, as diSessa (1993) has pointed out, the explanatory frameworks students use usually lack the systematicity and coherence of the theory of physics used by experts. In other words, conceptual change involves not only change in specific beliefs and presuppositions but also the development of metaconceptual awareness and the construction of explanatory frameworks with greater systematicity, coherence, and explanatory power.

3.3. The importance of mental representations
In addition to deeply entrenched presuppositions, the specific mental representations children use when they try to understand new information seem to exert their own, unique influence on the knowledge acquisition process. We have used the construct of the “mental model” to describe individuals’ representations of the physical world. This construct has been used differently by different researchers (e.g. Johnson-Laird, 1983; Gentner & Stevens, 1983). It is used here to refer to an analog and generative representation which can be manipulated mentally to provide causal explanations of phenomena (see Fig. 2). It is assumed that most mental models are created on the spot to deal with the demands of specific situations.

The mental models individuals generate during cognitive functioning can constrain the knowledge acquisition process in ways similar to presuppositions as described earlier. For example, students' explanations of the day/night cycle are often constrained by their mental models of the earth (Vosniadou & Brewer, 1994). Thus, students with a rectangle, disc or dual earth model explain the day/night cycle by saying that the sun goes down behind the mountains (see Fig. 2, sketch 1) or other similar explanations based on everyday experience. These students do not provide explanations of the day/night cycle in terms of the axis rotation of the earth (see Fig. 2, sketches 3 and 4), or even explanations according to which the sun "goes down to the other side of the earth" (see Fig. 2, sketch 2). These latter explanations are obviously inconsistent with the mental model of a flat, stationary earth rooted on the ground. It is only when the model of a spherical earth, suspended in space, is formed that explanations of the day/night cycle in terms of the rotation of the earth become available to students.

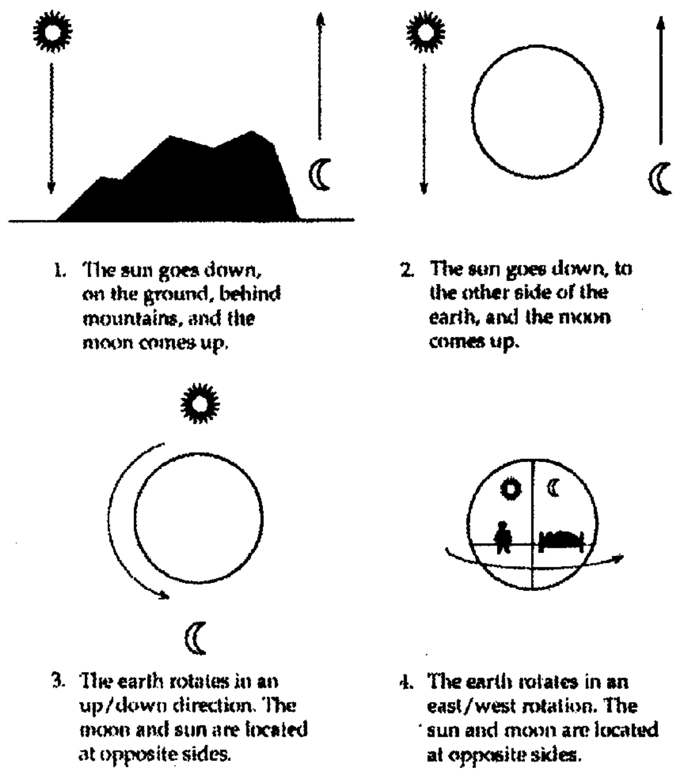

Fig. 2. How students' mental models of the earth influence their explanations of the day–night cycle.

3.5. Summary

Cognitive science and science education research have produced important findings about the nature and process of conceptual change. One is the finding that by the time they enter elementary school, children have already constructed initial conceptual structures about the physical world which are in many ways different from the scientific concepts to which they will be exposed through instruction. These initial conceptual structures form the basis upon which further information is incorporated. The process of conceptual change appears to be a gradual and complex affair during which information that comes in through observation and/or instruction is incorporated into the existing knowledge base and can produce different outcomes. It can add new knowledge, it can create new explanations, synthetic models, it can restructure the knowledge base, and so on.

4.3. Taking into consideration students' prior knowledge
The realization that students do not come to school as empty vessels but have representations, beliefs and presuppositions about the way the physical world operates that are difficult to change has important implications for the design of science instruction. Teachers need to be informed about how students see the physical world and learn to take their points of view into consideration when they design instruction. Instructional interventions need to be designed to make students aware of their implicit representations, as well as of the beliefs and presuppositions that constrain them. It is important to provide meaningful experiences that lead students to understand the limitations of their explanations and to motivate to change them. Finally, it is necessary to provide the necessary cultural support for the reorganization of existing knowledge, necessary for learning science.

4.4. Facilitating metaconceptual awareness
Although students are relatively good interpreters of their everyday experiences, they do not seem to be aware of the explanatory frameworks they have constructed and of the presuppositions that constrain them. Even when they start to achieve this metaconceptual awareness they do not understand that their explanations are hypotheses that can be subjected to experimentation and falsification. Therefore, their explanations remain implicit and tacit. Lack of metaconceptual awareness of this sort prevents students from questioning their prior knowledge and facilitates the assimilation of new information into existing conceptual structures. This type of assimilatory activity seems to form the basis for the creation of synthetic models and misconceptions and lies at the root of the surface inconsistency so commonly observed in students' reasoning.

To help students increase their metaconceptual awareness, it is necessary to create learning environments that make it possible for them to express their representations and beliefs. This can be done in environments that facilitate group discussion and the verbal expression of ideas. It is also important to create learning environments that make it possible for students to express their internal representations of phenomena, to compare them with those of others. Such activities may be time-consuming, but they are important for ensuring that students become aware of what they know and what they need to learn.

4.5. Addressing students' entrenched presuppositions
It is very often the case in science instruction that counterintuitive information is introduced as a fact. For example, in astronomy, students are often simply told that "the earth rotates around its axis", "the sun is much bigger than the earth", or "the sun is a star", without an explanation of how it is possible for the earth to move when we do not feel any movement, how it is possible for the sun to be bigger than the earth when it appears to be much smaller, and how it is possible for the sun to be a star when stars appear in the sky only in the night, have a different shape than the sun, are smaller, and so on.

It is important in instruction to distinguish new information that is consistent with prior knowledge from new information that runs contrary to prior knowledge. When the new information is consistent with prior knowledge, it can be incorporated easily into existing conceptual structures. This type of information is most likely to be understood even if it is presented as a fact without any further explication. However, when the new information runs contrary to existing conceptual structures, simply presenting the new information as a fact may not be adequate. In this situation students seem to have two courses of action available to them. One is simply to add the new fact to their existing conceptual structures. If they do this the new representation will probably be inconsistent with the old. The other is to distort the new fact to make it consistent with the existing structure. In this case the result will most probably be a synthetic model. In order for the counterintuitive information to be understood, students must restructure the conceptual structures they already hold to make them consistent with the new information. This is difficult and hard work and the students need to be motivated enough to undertake it.

4.6. Motivation for conceptual change

Students often do not see the reason to change their beliefs and presuppositions because they provide good explanations of their everyday experiences, function adequately in the everyday world, and are tied to years of confirmation. In order to persuade students to invest the substantial effort required to become science literate and to re-examine their initial explanations of physical phenomena, we need to provide them with an environment that will motivate such changes and relate them to the social and cultural environment outside the narrow context of the school. Students need meaningful experiences, for example in the form of systematic observations or the results of hands-on experiments, that will prove to them that the explanations they have constructed are in need of revision. If we want these experiences to be useful in the process of conceptual change we need to select them carefully so that they are theoretically relevant. What we mean by theoretically relevant is that they address the underlying presuppositions and beliefs that constrain students' representations and influence the way they interpret scientific information and show them that these presuppositions are not adequate to explain the known empirical facts.

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Teaching Science as Practice
Main Findings:

- Students learn science by actively engaging in the practices of science, including conducting investigations; sharing ideas with peers; specialized ways of talking and writing; mechanical, mathematical, and computer-based modeling; and development of representations of phenomena.
- All major aspects of inquiry, including managing the process, making sense of data, and discussion and reflection on the results, may require guidance.
- Instruction needs to build incrementally toward more sophisticated understanding and practices. To advance students' conceptual understanding, prior knowledge and questions should be evoked and linked to experiences with experiments, data, and phenomena. Practices can be supported with explicit structures or by providing criteria that help guide the work.
- Discourse and classroom discussion are key to supporting learning in science. Students need encouragement and guidance to articulate their ideas and recognize that explanation rather than facts is the goal of the scientific enterprise.
- Ongoing assessment is an integral part of instruction that can foster student learning when appropriately designed and used regularly.

Embedding Instructional Guidance in Students' Performance of Scientific Tasks
Learners face many obstacles in learning science as practice, and they require support in order to engage in it productively. For example, in conducting and interpreting science, students often confuse evidence with its interpretation (the "theory/evidence" confusion), are unfamiliar with the strategy of controlling variables in order to design experiments to test a hypothesis, and do not continually reevaluate hypotheses in light of new evidence. Their entering understandings of and experiences with the physical, biological, and social worlds may confound their efforts to master new knowledge. Their prior exposure to science, including science instruction, may leave them with a distorted impression of the scientific enterprise. Explicit support is required to help students learn the practices, the concepts, and the very nature of science. Students left free to explore, as in pure "discovery learning" approaches, may continue to face these obstacles, interfering with their ability to learn through inquiry. Simple experience with inquiry alone does not lead to acquisition of better experimentation skills or conceptual mastery (Roth, 1987; Klahr, 2000). Students need firsthand experiences working on meaningful scientific problems, as developing expertise in a discipline entails developing more sophisticated strategies for solving problems (VanLehn, 1989) and much of the knowledge involved in solving problems is tacit. Thus pure explicit instruction will fail to produce awareness, understanding, or knowledge of appropriate use of important strategies (Greeno, Collins, and Resnick, 1996).

Instead of pure discovery or pure direct instruction, students need strategic "scaffolds" that embed instructional guidance in ongoing investigations to call attention to important decision points and to make data patterns more explicit . Scaffolding has been defined broadly and used to mean different things; however, recent analyses of scaffolding emphasize the ways that support can be embedded in students' ongoing performance of tasks to support learning (Hogan and Pressley, 1997; Linn, Bell, and Davis, 2004; Quintana et al., 2004; Reiser, 2004; Sherin, Reiser, and Edelson, 2004). We think of scaffolding as strategic support that enables students to do scientific tasks with a higher degree of sophistication than they could without it. Scaffolding may structure students' interactions with one another or their thinking about a particular model, concept or practice, or it may guide students' interpretation of scientific tools and representations. It might also entail teachers telling things to students—giving them clear canonical explanations, or facts to build upon.

Scaffolding

Scaffolding is ongoing guidance provided to students as they perform a task, which facilitates performance and learning. Scaffolding can be viewed as the additional support built around a core (baseline) version of a task to make it more tractable and useful for learning. Scaffolding is always defined relative to some assumed baseline version of the task (Sherin, Reiser, and Edelson, 2004).

The original scaffolding metaphor included the eventual removal or "fading" of the scaffolding. This aspect of scaffolding has yet to be thoroughly investigated. Most studies of scaffolding are not extensive enough to include the fading of scaffoldings. A notable exception is the recent study by McNeill et al. (2006) of scaffolds for students' evidence-based explanations. They found that middle school students in a 2-month project-based unit performed better on posttests requiring explanations if the scaffolding was gradually faded during the instructional unit, rather than if the scaffolding was continued throughout the entire unit. More research is needed to explore the time frame and approaches for fading scaffolds.

Scaffolding can be support for students provided by a teacher, tutor, or peer (Palincsar, 1998). For example, through scripts, peers may learn to ask questions that help classmates clarify their reasoning or justify claims by linking them with evidence.
Scaffolding can be support embedded in students' performance of a task that transforms the task to make it more tractable for learners. For example, to facilitate students use of data sets in computer-based investigations, software systems can provide more meaningful ways to refer to and manipulate data.

Scaffolding may work to guide or structure problem solving, focusing students on important aspects of the task that are productive for learning and that they might otherwise overlook or treat superficially (Reiser, 2004).

Various approaches to scaffolding scientific tasks have emerged in the literature. A central theme is to make a process or concept more explicit for learners by enabling them to do something they could not do without some crucial element provided through scaffolding. The elements might come through teacher actions, instructional materials, or actions of other students. Students might be cued to reflect, reminded to incorporate a key concept in their work, or prompted to reflect on their experiences. In this section, we describe three ways in which scaffolds can support students' learning. Scaffolding can structure experiences to draw attention to the elements of scientific practice, provide guidance in students' efforts to engage in social processes around scientific problems, and help them track the important conceptual aspects of the problems they are working on. Furthermore, these different approaches to scaffolding science learning can mutually reinforce one another and together provide necessary guidance, enabling students to perform in complex ways that they could not do without the scaffolding.

Scaffolding Conceptual Models

Instructional supports can be designed with conceptual models or dynamic simulations that make science concepts more transparent for learners, helping them connect their prior understandings with more sophisticated scientific understandings. These scaffolds can remind learners of important concepts that they need to include in their work or draw their attention to important conceptual distinctions, problematizing these issues and focusing their attention in productive ways. Interactive simulations can also highlight key concepts, helping students see concepts within a network of interrelated ideas.

Scaffolding can help students examine, scrutinize, and critically appraise their understanding of key scientific concepts. Visualizations can help learners connect patterns in data to a better understanding of the scientific phenomenon.

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