Dealing more effectively with alternative conceptions in science

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Many science teachers are aware of the existence of alternative conceptions – notions held by students that are contrary to those generally accepted by mainstream scientists. Authentic alternative conceptions are tenaciously held, and doggedly resistant to change. Only carefully managed efforts by teachers will effectively address them. The author proposes two emphases within the context of the "standard model" for more effectively overcoming alternative conceptions.

Alternative Conceptions

Seventeenth century English philosopher John Locke suggested that students come to school as "tabula rasa" (blank slates) to be "written upon" by teachers. While Hume was correct about a great number of things, this was not one of them. Students come to school with non-traditional ideas that deal with the natural world that are highly resistant to change and strongly influence new learning (Pfundt & Duit, 1991; Carmichael et al., 1990). It is these improper interpretations that are collectively know as alternative conceptions.

The children's book Fish is Fish by Leo Lionni (1970) illustrates this problem beautifully. Lionni tells a story about a fish that is interested in learning about life on land. Unfortunately, the fish cannot explore any place beyond the confines of a small pond. He befriends a tadpole that eventually grows into a frog and moves out of the pond onto the land. The frog subsequently returns to the pond and reports what he has seen to the fish. The frog describes all kinds of things such as people, birds, and cows. The book's illustrations depict the fish's mental representations of each of those things described by the frog; each land creature has a fish-like body that is slightly adapted to accommodate the frog's descriptions. People are imagined to be fish that walk on their tailfins, birds are thought of as fish with wings, and cows are believed to be fish with udders.

This children's story exhibits well both the creative license and dangers inherent in the fact that people construct new knowledge based on prior experiences and understandings. Research has shown that instead of remembering a host of accurate details, people tend to remember events by incorporating a few details within a schema for the event (Silva et al., 2006; Scoboria et al., 2006). Alternative conceptions often result when new experiences are interpreted in light of prior experiences, and new understandings are grafted onto prior understandings. Memories in general are retrieved by first recalling the schema and then the associated details. If a concept does not fit a pre-existing schema and is not all that salient, it likely will be forgotten or even rejected.

To give readers unfamiliar with alternative conceptions in physics a better understanding of the phenomenon, Table 1 exhibits a number of classical examples from the area of mechanics – the area most carefully studied and for the greatest period of time (e.g., Vienot, 1979; Caramaza, McCloskey & Green, 1981; Champagne, Klopfer & Anderson, 1980; Gunstone & White, 1981; Clement, 1982; Minstrell, 1982; Gilbert & Watts, 1983; McDermott, 1984; Camp & Clement, 1994).

1) When force is applied to an object, it produces motion in the direction of the force.
2) Under the influence of constant force, objects move with constant velocity.
3) The velocity of an object is proportional to the magnitude of the applied force.
4) In the absence of a force, objects are either at rest or, if moving, are slowing down.
5) An object moving under a central force will move in a curvilinear path when released.
6) The acceleration of a falling object depends upon its mass.
7) Freely falling bodies can only move downward.
8) There is no gravity in space.
9) Gravity only acts on things when they are falling.
10) An object at rest cannot be undergoing acceleration.

Table 1. Classical examples of alternative conceptions.

Claims Regarding Alternative Conceptions in Science

Following an extensive review of the research literature, Wandersee, Mintzes, & Novak (1994) generated eight "emerging" research-based claims relating to alternative conceptions in science. Summaries can be found in Table 2. Subsequent experiences in science teaching appear to have borne out these claims. For a thorough explanation of these claims, along with pertinent evidence, the reader is referred to the original work.

Table 2. Research-based claims relating to authentic alternative conceptions (continued next page).

Claim 1: *Learners come to formal science instruction with a diverse set of alternative conceptions concerning natural objects and events*. Alternative conceptions span the fields from physics and earth & space science to biology, chemistry, and environmental science. Each associated subfield within the disciplines seems to have its alternative conceptions.

Claim 2: *The alternative conceptions that learners bring to formal science instruction cut across age, ability, gender, and cultural boundaries*. No matter how gifted a group of students concerned, each group will have students with alternative conceptions regardless of background.

Claim 3: *Alternative conceptions are tenacious and resistant to extinction by conventional teaching strategies*. Students' alternative conceptions are very difficult to change; only very specific teaching approaches have shown promise of getting students to accept new explanations.

Claim 4: *Alternative conceptions often parallel explanations of natural phenomena offered by previous generations of scientists and philosophers*. Students often hold to the same views as those held by very early scientists that are frequently referred to as "Aristotelian" in nature.

Claim 5: *Alternative conceptions have their origins in a diverse set of personal experiences including direct observation and perception, peer culture, and language, as well as in teachers' explanations and instructional materials*. The many sources of alternative conceptions are at best speculative, but research and inference suggest that a student's worldview is strongly influenced by his or her social environment.

Claim 6: *Teachers often subscribe to the same alternative conceptions as their students*. It is not at all uncommon for science teacher educators to see alternative conceptions in their teacher candidates; likewise, even experienced science teachers and scientists with advanced degrees will sometimes cling to alternative conceptions that are held by their students.

Claim 7: *Learners' prior knowledge interacts with knowledge presented in formal instruction, resulting in a diverse variety of unintended learning outcomes*. Not only can alternative conceptions be a hindrance to new learning; they can also interact with new learning resulting in "mixed" outcomes. It is not unusual to see different students draw different conclusions from the same experiences and observations.

Claim 8: *Instructional approaches that facilitate conceptual change can be effective classroom tools*. Several conceptual change approaches have been developed to identify, confront, and resolve problems associated with alternative conceptions.

Table 2. Research-based claims relating to authentic alternative conceptions (after Wandersee, Mintzes, & Novak, 1994).

Origins of Alternative Conceptions

The origin of a given alternative conception is often difficult if not impossible to determine. Misunderstanding, miscommunication, miseducation, and even a misapplication of well-established physical principles lead to the formation of alternative conceptions.

Sometimes students can experience the same phenomenon and still draw different conclusions as in the case of demonstrations where there is a lack of critical observation and appropriate follow-up discussion. For instance, haphazardly observing the demonstration of a Lenz's law apparatus (a conducting tube through which apparently identical equal-mass magnetic and non-magnetic plugs are dropped) might lead some students to the false conclusion that weights of equal mass actually can fall at different rates under the "same" circumstances. Taylor & Dana (2003) provide several examples of students who uncritically interpreted experimental data and ended up with contradictory results. For instance, they point to problems with inappropriate conclusions based upon improperly designed experiments, misuse of instruments resulting in unreliable data, overgeneralization from the data, misinterpretation of graphs, logical fallacies in argumentation, and failure to otherwise apply critical thinking abilities. These authors also point to the existance of alternative conceptions and their influence on new learning.

In other cases, students might cling to false notions that result from one or more forms of improper teaching. For instance, students might hold alternative conceptions as a result of a parent's, peer's, or teacher's false or misleading statements, inaccurate or deceptive renderings of drawings (e.g., idealized or inaccurate depiction of physical phenomena – such as using an inconsistent scale – against a natural background, or too literally taking an analogy as real), or even a misunderstanding of technical terms (e.g. force).

In still other cases, students might misapply what correct information they do possess. A misunderstanding of underlying conditions can lead to what appears to be alterative conceptions. Teachers should be acutely aware that alternative conceptions are NOT necessarily naïve viewpoints. Sometimes they are well-reasoned explanations or over generalizations that just happen to be incorrect under certain conditions such as the realm of idealized physics (where friction is often ignored). For instance, some of the alternative conceptions in Table 1 might not appear to be incorrect at all, but actually depict real-world situations. In the absence of wind resistance, some of these alternative conceptions actually are correct. For the sake of this discussion, we will call such conceptions – sometimes correct and sometimes incorrect – paraconceptions.

Teachers who fail to recognize and make this latter distinction risk losing credibility among their students, and all hope of overcoming a particular paraconception. Without being made aware of the dual nature of some alternative conceptions (e.g., correct under certain conditions), students likely will cling to a given paraconception if they are not convinced that their understanding is either right or wrong depending on specific conditions. In this case, we don't want to eliminate paraconceptions; rather, we want to help students understand how these ideas fit in with the ideas of the scientific community and how to use them properly under various conditions. When students encounter these two explanatory paths, they must learn not to "take the best path," but to realize that both paths are legitimate under particular conditions, and to carefully analyze the situation to determine which is the most appropriate solution.

Alternative Conceptions So Called

As Clement et al. (1989) noted, "Not all preconceptions are misconceptions." And with paraconceptions, not every mistaken student expression is indicative of the presence of an alternative conception. Some mistaken expressions are nothing more than students encountering difficulties in explaining new phenomena. For instance, when presented with the question "When a small car and a large bus collide head on, is the magnitude of the force of the bus on the car greater than the magnitude of the force of the car on the bus, or are both forces equal in magnitude?" Students will naturally assume that because the car is often completely crushed in a collision and the bus relatively undamaged that the force of the bus on the car is greater than that of the car on the bus; the concept of equal but opposite forces rarely enters into the mental thought process.

Such so-called alternative conceptions do not necessarily share the characteristics of authentic alternative conceptions, but can represent "difficulties" in the formulation of scientifically acceptable explanations. This might well result from a very logical but inappropriate application of what have become known as phenomenological primitives or p-prims (diSessa, 1988). P-prims are general, irreducible knowledge structures that we all possess as a result of reflecting (perhaps subconsciously) on our experiences, and upon which we tend to rely for explanations. Examples include the principle that "more effort results in more result" and "more resistance implies less result." In the case of the car-bus collision, the greater damage to the car is suggestive of greater force.

As p-prims are refined through subsequent learning, they gradually result in expertise in the content area. For instance, in physics the common sense notion that "motion requires force" is replaced by a proper understanding of Newton's first law, "force is action" is replaced with Newton's second law, and "force is war" is replaced with Newton's third law (Hestenes, 2006).

Considering flawed student ideas to be alternative conceptions might provide a more explicit way to target those ideas that are not consistent with scientific viewpoints, and make it easier for instructors to alter their instructional approach. I am therefore adopting the alterative conceptions approach to frame the following discussion. The term "alternative conception" used in this article encompasses all types of student conceptions consistent with the research-based claims shown in Table 2.

Conceptual Change vs. Concept Exchange Models

In their landmark 1994 article, Wandersee, Mintzes, & Novak noted that instructional approaches for dealing effectively with alternative conceptions (e.g., Hewson, 1981; Posner et al., 1982, etc.) were still in "an embryonic stage of development" (p. 191). Nonetheless, the framework for addressing alternative conceptions was basically in place. For instance, Hewson (1981) proposed two models to explain how alternative conceptions are overcome. Either an alternative conception is suppressed and replaced by a correct understanding (conceptual change), or students retain both views but reject or demote the old conception and adopt the new one as more convincing (concept exchange).

The Conceptual Change Model suggests that when a new concept is learned it weakens or destroys an existing memory. Unfortunately for this model, humans don't overwrite memory as in a computer. Cognitive scientists have identified mechanisms by which memories are encoded (the establishment of new synaptic junctions), but we know of none in which memories are actively destroyed (disestablishment of synaptic junctions). Cognitive research shows that forgetting requires very specific types of actions, and the associated cognitive processes are known as proactive and retroactive interference. Efforts must be undertaken to help students forget an inaccurate conception. Teachers must help students "forget," and this involves more than just letting old memories fade. Instead, we must work to actively replace old memories with new, helping students to see how their initial ideas fit within the framework of scientific understanding.

In the Concept Exchange Model, the old conception is not modified; rather, a new conception comes to exist along side the old conception. As evidence for this model, the alternative conception often reappears after traditional instruction has supposedly banished it. It is also not uncommon when teachers press students to explain their understanding for them to respond to the inquiring teacher, "Do you want my explanation or yours?" Such queries clearly indicate that students some times hold two explanations, one that they "know to be true" based on their own experiences, and another that they "accept as true" because the course instructor told them so.

While conventional wisdom – the stuff of common teaching experiences – seems to favor the concept exchange model over the conceptual change model, similar pedagogies appear to address both models. Under both models, in order for new conceptual understanding to develop, a new conception must satisfy certain conditions stated by Posner et al. (1982). It must be intelligible (students comprehend its meaning), plausible (students believe it to be correct), and fruitful (students find it useful). To the extent that a new conception possesses these characteristics in the mind of the student, the greater the likelihood that learning of the new concept will proceed with comparative ease. To the extent that an alternative conception conflicts with new phenomena, it is modified, or is no longer considered useful, its status drops, and it is rejected as untenable.

Are Extant Models of Alternative Conceptions Flawed?

Hammer (1996, 2000), diSessa (1988), Clement et al. (1989), and Smith et al. (1993/1994), point out that problems do exist with early models of alternative conceptions and how to deal effectively with them. According to Hammer (2000), "First, [these models] provide no account of productive resources students have for advancing in their understanding. Second, descriptions of student difficulties provide no analysis of underlying mechanism, while the perspective of misconceptions cannot explain the contextual sensitivities of student reasoning."

While such criticisms of alternative conception models might well be valid, they do not constitute adequate reason to displace forty years of work in this area. When teachers encounter flawed student expressions, we can't be certain if we are dealing with flawed logic, the presence of alternative conceptions or paraconceptions, or the presence of phenomenological primitives. Assuming that students aren't merely having logic problems, both alternative conception and p-prim models can be useful in interpreting student responses.

The methods of dealing effectively with conceptual difficulties though the terminology of p-prims which includes resources and strategies that build on learners' existing ideas and extend them, through, for example, metaphor or analogy, to a new domain (Hammer, 2000; Scott, Asoko, & Driver, 1998; Camp & Clement, 1994) are not directly addressed in this article.

Pedagogies for Addressing Alternative Conceptions

A wide range of pedagogies has been developed to address alternative conceptions such as learning cycles (Karplus, 1981), Conceptual change theory of Posner et al. (1982), bridging analogies (Clement, 1988; Perschard & Bitbol, 2008), microcomputer-based laboratory experiences (Thornton & Sokolof, 1990; Thornton, 1987), disequilibration techniques (Minstrell, 1989; Dykstra, Boyle, & Monarch, 1992), an inquiry approach coupled with concept substitution strategies (Harrison et al., 1999), metaconceptual teaching on inducing a particularly problematic aspect of the conceptual changes (Wiser & Amin, 2001), and a teaching model (Thomaz et al., 1995).

These approaches tend to have in common the requirement that students encounter phenomena that run counter to their existing beliefs. Doing so, they are put in a state of intellectual disequilibrium or cognitive conflict. Becoming aware of the conflict between what they believe to be correct based on prior experiences and know to be correct based on more recent experience helps them to confront and resolve their conflicting perspectives in favor of a proper understanding. Such pedagogical approaches that emphasize conflict and resolution appear to derive from a Piagetian perspective on learning (Scott, Asoko, & Driver, 1998). In such a viewpoint, the learner's role in reorganizing their knowledge is central to overcoming the alternative conception.

These and other approaches dealing with alternative concepts typically include three fundamental steps – those identified by the University of Washington Physics Education Group: elicit/confront/resolve (McDermott, 1991). In this model a teacher first elicits a response (prediction about what will happen or an indication of agreement or disagreement with a given statement) from students, forcing them to commit to an answer in relation to a specific situation. Next, the students confront a situation that challenges their beliefs and answers, typically in an experiment that the students perform. During this second phase, if the students were incorrect in their prediction, they experience cognitive dissonance when confronting the conflict between prediction and experience. Students quickly come to realize the need for a new understanding about the concept under consideration, and are motivated to resolve the conflict with teacher assistance in phase three.

Another such strategy is that developed for the C^3P Project. According to Olenick (2008) overcoming alternative conceptions requires the following distinct steps:

(1) Teachers must recognize that alternative conceptions exist.
(2) Teachers probe for student's alternative conceptions through demonstrations and questions.
(3) Teachers ask students to clarify their understanding and beliefs.
(4) Teachers provide contradictions to students' alternative conceptions through questions, implications, and demonstrations.
(5) Teachers encourage discussion, urging students to apply physical concepts in their reasoning.
(6) Teachers foster the replacement of the misconception with new concepts through (i) questions, (ii) thought experiments, (iii) hypothetical situations with and without the underlying physical law, and (iv) experiments or demonstrations designed to test hypotheses.
(7) Teachers reevaluate students' understanding by posing conceptual questions.

Conjecture for a More Effective Approach

The traditional approach of overcoming alternative conceptions consists of eliciting, confronting, and resolving has not always been an effective way for teaching and learning physics as can be inferred from the results certain physics education research. Consider, for instance, instructors who use the Modeling Method of Instruction and results obtained from their use of the Force Concept Inventory ([FCI] Hestenes, Wells, & Swackhamer, 1992).

The FCI is regularly used with Modeling mechanics to test the progress of student learning in relation to their non-modeling peers. The FCI, a 30-question standardized exam based strongly on a traditional understanding of alternative conceptions, is used to assess teacher effectiveness for achieving a "minimal teaching performance standard: to teach students to reliably discriminate between the applicability of scientific concepts and naive alternatives in common physical situations" (Modeling website, 2002). It is conceivable that certain tentative conclusions can be drawn from data generated using this instrument in relation to novice versus expert Modelers.

According to the above Modeling website, in studies employing data from a nationwide sample of 7,500 high school physics students, "the average FCI pretest score is about 26%, slightly above the random guessing level of 20%, and well below the 60% score which, for empirical reasons, can be regarded as the threshold for understanding Newtonian mechanics.... After their first year of teaching, posttest scores for students of novice modelers were about 10 percentage points higher" using data from 3,394 students of 66 teachers. "Students of expert modelers do much better. For 11 teachers identified as expert modelers after two years in the Project, posttest scores of their 647 students averaged 69%. Thus, student gains in understanding under expert modeling instruction are more than doubled (40 percentage points gained), compared to traditional instruction (16 percentage points gained)."

No explanation is given by the author(s) of this web site suggesting why it might be that the students of expert Modelers perform better on the FCI than do those of novice Modelers. However, the fact that Modelers who use the standardized FCI test – a test based strongly on alternative conceptions – show little gain in the first years of Modeling Instruction is suggestive that novice Modeling teachers, as they mature into expert Modelers, eventually come to realize that there is more to addressing alternative conceptions than a three-step method of eliciting, confronting, and resolving ideas. Something else clearly must be changing in their approach to dealing with alternative conceptions.

Based on three years of interactions with Modelers in the Chicago ITQ Science Project, the author presents as a tentative explanation that the reason students of expert Modelers perform better on the FCI than do students of novice Modelers is because expert modelers inadvertently have added a fourth and fifth step to their instructional practice. These steps, perhaps introduced by expert Modelers as a result of frustration, consists of identifying the existence of alternative conceptions and then reinforcing student learning in the area of the alternative conception. It is this author's contention that a poorly understood ELICIT-CONFRONT-RESOLVE approach fails to make a substantial lasting difference in the area of alternative conceptions because it fails to clearly IDENTIFY the existence of the alternative conception to students and fails to REINFORCE student learning in the area of the alternative conception. A better approach to dealing with alternative conceptions suggests a more clearly elucidated five-step approach that will be herein referred to as the ECIRR (Elicit-Confront-Identify-Resolve-Reinforce) model.

Including IDENTIFY and REINFORCE

Deductions from studies in the area of cognitive psychology dealing with memory and recall also serve as an additional basis of including IDENTIFY and REINFORCE in the ECIRR model.

IDENTIFY

Memory consists of both declarative and procedural components. Declarative memory is most closely associated with alternative conceptions, and consists of two components – episodic and semantic memory (Tulving, 1972). Episodic memories are memories that relate to personal experiences and take on a personal perspective. Semantic memories include abstracted facts about the world and knowledge of how things work that typically are not derived from personal experiences but, perhaps, from book learning and other forms of communication. Using a metacognitive approach - literally helping students to think about their thinking relative to what they know and how they know it - can provide an effective means for overcoming established alternative conceptions. Clearly identifying an alternative conception as such can be a powerful way to overcome alternative conceptions. Students need to know that alternative conceptions exist and should be put on notice about their pernicious effects. This knowledge enhances students' ability to better overcome existing alternative conceptions and recall new understandings. This notification, coupled with experiences that help students confront their misconceptions can activate both episodic and semantic memory.

The IDENTIFY step consists of making students aware of the fact that alternative conceptions exist and have the pernicious effects outlined in Table 2. The IDENTIFY step does NOT suggest that students are told they are wrong. To do so, especially repeatedly, can cause students to become frustrated and to shut down mentally to resist intellectual change. This step must follow the confrontation step; otherwise, it would conflict with a constructivist viewpoint under which students should draw their own conclusions based on evidence.

REINFORCE

New learning is not always retained as experience has show. Consider the fact that after instruction teachers test students' knowledge and find that an alternative conception still exists. This suggests that the alternative conception has not been replaced by a modified conception, but is temporarily unavailable for recall. While methods exist for making memories (establishment of new synaptic junctions), no method exists for easily erasing memories (disestablishment of old synaptic junctions). What makes a difference is which conception is most likely to be recalled. Cognitive understandings would suggest that there is a well-worn "highway" to the old concept making it habitually accessible during recall; the new conception has only a "footpath" leading to it and this reduces the probability of its recall. The footpath needs to be replaced by a highway, and the highway needs to become a footpath. The highway will be established only when students: (1) over learn the new conception thereby making it more accessible and more likely to be recalled than the old conception or, in the case of a paraconception, (2) learn to analyze a situation and determine which understanding is the best to apply. These approaches will help students improve their ability to retain new learning and preferentially retrieve it from memory under varying conditions.

How the ECIRR Model Works

ELICIT

The teacher probes for students' alternative conceptions through activities that make students' thinking evident such as asking questions, and conducting Socratic dialogues with whiteboarding (Wenning, 2005; Wenning et al., 2006). During such practices teachers ask students to predict, explain, and make clarify statements. Of course, this step assumes that the teacher is cognizant that alternative conceptions exist and what they are. Previous research has shown that in order for a teacher to effectively address student's alternative conceptions, they must be aware of the presence of such ideas (da Silva et al., 2007; Hewson et al., 1999).

The number of alternative conceptions possessed by students is indeed large. Secondary sources providing a collection of alternative conceptions in physics and other areas are plentiful and include such publications as Handbook for Research on Science Teaching and Learning, (Gabel, 1994); Physics Begins with an M (Jewett, 1996a); Physics Begins with another M (Jewett, 1996b), and online resources such as those provided by the C^3P program (Olenick, 2008) and Operation Physics (Weiler, 1998) websites. Internet searches will also provide additional resources.

CONFRONT

The teacher uses discrepant events to provide contradictions to students' statements or predictions and place them in a state of cognitive conflict. They confront alternative conceptions through demonstration, implications, and questions, and encourage discussion. Teachers must keep in mind that the greatest amount of learning will be achieved when the learners' motivation level is high. Motivation (as contrasted with coercion) will be highest when the students' best interests and needs are served, and the subject is relevant to students' day-to-day lives. They also must keep in mind that the greatest amount of learning occurs when the salience of the stimulus is high. Using surprise, mystery, and bedazzlement can serve to increase the salience of a phenomenon.

Taylor and Coll (1997) noted that cognitive conflict has the advantage of helping to address alternative conceptions effectively, but noted too that it might serve also reduce student's confidence in their ability to understand science. Care should be taken to ensure that this does not happen.

IDENTIFY

After alternative conceptions are elicited and confronted, the teacher must clearly and unambiguously identify them as such. Teachers must be careful, however, not to denigrate the value of intuition that often can lead to correct predictions. They must explain the power of alternative conceptions to mislead, and state emphatically that students must not be misled and they should divorce themselves from it because the old conception will compete with the new conception. It is not unreasonable to summarize what research says about alternative conceptions, and even to review the key findings of Wandersee, Mintzes, & Novak (Table 2). To be consistent with a constructivist viewpoint of teaching, IDENTIFY should follow confrontation and not precede it.

RESOLVE

The teacher should foster the replacement of an alternative conception using any of the following approaches: questions, thought experiments, interactive demonstrations, hypothetical situations, and experiments designed to test hypotheses. They should help reevaluate students' understanding by posing conceptual questions, and eliciting student source(s) of alternative conception. To overcome alterative conceptions, teachers should place as much attention on students' prior knowledge as possible, but allow students to actively resolve discrepancies by themselves because teaching by telling simply does not work.

Hestenes (2006, p. 18) points out how the active approaches of Modeling Instruction can be used to address pre-existing cognitive structures:

* Modeling activities that systematically engage students in developing models and providing their own explanations for basic physical phenomena,
* Modeling discourse (centered on visual representations of the models) to engage students in articulating their explanations and comparing them with [properly understood] concepts, and
* Modeling concepts and tools (such as graphs, diagrams, and equations) to help students simplify and clarify their models and explanations.

REINFORCE

When teachers help students develop a new understanding of a phenomenon rooted in an alternative conception, this does not necessarily extinguish prior learning. As experience shows, there are frequently two competing concepts in students' minds. To address alternative conceptions effectively, teachers must reinforce the pathway that leads to the new understanding and extinguish or at least suppress the pathway that leads to the old understanding, or help students to decide in the case of paraconceptions. Failure to do so can result in students recalling the alternative conception preferentially over the desired understanding.

This reinforcement should be done repeatedly, over time, and under varying conditions. This is due in part because retrieval pathways are not well established, and effort must be expended on firmly establishing the retrieval mechanism associated with the new understanding. Several important approaches from cognitive psychology can be used to do so.

Employing levels of processing

Encoding in relation to an alternative conception requires more than just repetition, and the desire to remember is not sufficient for appropriate encoding either. If sustained learning is to take place in order to overcome an alternative conception, then we must think about what we want to remember, we must know from experience that the prior conception is wrong, and we probably should include even some form of "desirable difficulty."

The quality of encoding associated with a new understanding can be improved through the use of levels of processing. Research has shown that the level at which information is processed, not just how long or how often, strongly influences the degree to which students retain new understandings (Craik & Lockhart, 1972). Levels of processing can be described as a continuum running from shallow processing (maintenance rehearsal) to deep processing (elaborative rehearsal). Deep processing is much more closely associated with long-term retention than shallow processing. When students are required to apply information to new situations it is much more likely to be recalled than when asked to memorize that information. Students who merely watch a demonstration are much less likely to remember its significance than those who have discussed it with friends or have been required to write about it.

Levels of processing can include desirable difficulties that are often associated with student study efforts, but can be incorporated by teachers seeking to overcome alternative conceptions. Desirable difficulties are approaches to situations that make studying more challenging and the benefits less obvious in the near term. Desirable difficulties promote long-term retention and the ability to transfer what has been learned to new situations. Teachers create desirable difficulties when they get students to think about their own thinking (metacognition) and learn subject matter using different approaches. Students create desirable difficulties for themselves when they determine the objectives of their study, organize information, and approach the subject matter from a variety of perspectives.

<u>Rehearsing under varying conditions</u>

The encoding specificity principal of cognitive psychology states that retrieval of a memory is most effective when it occurs in the same context as used for encoding. Nearly everyone has had an experience where they walk into one room to get something and fail to recall what was to be retrieved. Upon returning to the point of origin one quickly remembers what one was to pick up – an example of the context reinstatement effect. These effects are most clear when students learn about a phenomenon during a class discussion, but fail to recall it under testing situations.

The encoding specificity principal of context-specific learning comes into play when asked to recall an answer under a testing situation students fail. Still, when back in the original setting, we see the context reinstatement effect. Is this a matter, then, of forgetting where information is permanently lost from memory, or of retrieval block where information is not forgotten but not remembered either? Because memories are resilient, alternative conceptions will not just fade away. Nonetheless, memories can be weakened through the processes of retroactive interference – when concepts learned at the end of a study process reduces a student's ability to recall earlier memories. Cognitive research shows that forgetting requires action, and in the case of alternative conceptions, this cognitive process is retroactive interference.

To help overcome the problems associated with the encoding specificity principal, efforts should be undertaken to ensure that retrieval is practiced repeatedly and under a variety of conditions.

Deploying the ECIRR Model – An Example

When teaching gravitation, teachers are often confronted with the alternative conception that "there is no gravity in space." What follows is an example of how to deal more effectively with this alternative conception. Similar approaches can be used with other alternative conceptions.

Elicit – A teacher uses a historical approach to derive Newton's theory of gravitation, concluding that $F = GMm/r^2$. The teacher then asks the question how this formulation of gravity applies to objects in space – planets, the moon, satellites, the Space Shuttle orbiter… Then the teacher asks the question, "What about astronauts in space? Does gravity apply to them, too?" Students frequently will say "No!" and cite as evidence the fact that astronauts in space float around and are, therefore, weightless. According to one student's explanation, "Someone can be weightless only in the absence of gravity." Others, recognizing the limitless extent of the gravitational force, might say, "Yes, there is gravity in space but it is very small up in orbit. After all, NASA does speak about microgravity in the space environment."

Confront – To be constructivist in their approach, a teacher must allow students to come to see that their statements are not consistent with reality. Having elicited the above alternative conception, the teacher now confronts students with evidence contradicting their alternative conceptions. The teacher might talk about the parabolic aircraft flights on the NASA "Vomit Comet" that result in free floating, or what would happen to a passenger in a freely falling elevator. Clearly, while these people experience weightlessness, they are still under the influence of gravity.

Ideally, a teacher will help students confront an alternative conception by using active learning strategies that fully engage students. A teacher might have students conduct a mathematical calculation to determine the force of gravity on an astronaut, on and at different distances above the surface of the earth. Students will rapidly see that the force at the altitude of the orbit is not all that much less than near the surface of the earth. Clearly, the force of Earth's gravity must extend into space, and must be substantial even at the altitude of the Shuttle orbiter.

Identify – Following the confrontation phase, the teacher identifies the fact that students who believe that weightlessness results from a lack of gravity, or that gravity is "weak," have fallen under the influence of common alternative conceptions. The teacher notes that alternative conceptions exist, and helps students to become fully aware of key findings about them as shown in Table 2.

Resolve – The teacher must now help students overcome their former beliefs by working with students to understand where such alternative conceptions might have come from. Following this, the teacher could go on to explain concepts such as frame of reference, and explain orbital motion is nothing but a fall toward the Earth at a rate which Earth falls out from beneath astronaut (perhaps referencing the image of "the cannon shot round the world"). Another approach would be to have students place a small weight on a string and twirl it around over their heads noting that the string plays a role similar to gravity and the weight an orbiting astronaut. Ask the students, "Upon releasing the string, what happens?" Allow students to develop their own explanations of how this analog applies to the orbiting astronaut situation. Give them an opportunity for whiteboarding as appropriate. Students will come to realize that nothing can stay in orbit with out a central force. Create a graph of acceleration due to gravity ($g = GM/r^2$) for various distances from Earth's surface out to, say, the orbital distance of the moon, and compare the ratio of g-in-orbit to g-at-surface. Computer simulations might be used to help students understand the concept. Students can also be asked to discuss or write about their alternative conceptions in relation to what they now understand to be a correct view.

Reinforce – After the resolution phase, the teacher periodically reviews the alternative conceptions under varying conditions. This might consist of periodic reviews at the end of class, interjection of questions about the alternative conceptions when related topics are discussed or by more formal formative evaluations. By periodically questioning and testing for understanding in relation to the proper understanding of gravitation under varying conditions, teachers help students reinforce weak memories and suppress those alternative conceptions that might otherwise be more easily be recalled during summative evaluations.

In Conclusion

Effectively addressing alternative conceptions requires more than just eliciting, confronting, and resolving a false notion. Forming memories that are easily and accurately retrieved requires more than a desire to remember. Efforts must also include identifying the presence of alternative conceptions and reinforcing new learning. Forgetting takes work, and it is important to include activities that weaken memories and enhance recall of preferred understandings.

Traditional approaches for eradicating alternative conceptions fail to work because they do not implement metacognitive and reinforcement processes so necessary to deal effectively with an alternative conception. So it is with other habits such as smoking, biting fingernails, over eating, or thumb sucking. These bad habits are best broken with the use of explanations and repeated reminders. Explanations and reminders reinforce learning and are important to the habit-breaking process. Study and practice are required if students are to develop a long-lasting change in understanding and the ability to recall that knowledge accurately under a variety of new conditions.

While the EICRR model for dealing more effectively with alternative conceptions is conjectural, findings from both craft wisdom and cognitive psychology would seem to suggest that it is also important to identify alternative conceptions and reinforce student learning in this area. This EICRR conjecture could well be a fruitful area of work by physics education researchers.

References:

Camp, C.W. & Clement, J.J. (1994). *Preconceptions in mechanics: Lessons dealing with students' conceptual difficulties*. Dubuque, IA: Kendall/Hunt Publishing.

Caramaza, A., McCloskey, M., & Green, B. (1981). Naive beliefs in 'sophisticated' subjects: Misconceptions about trajectories of objects, *Cognition 9,* 117-123.

Champagne, A., Klopfer, L., & Anderson,J. (1980). Factors influencing the learning of classical mechanics, *American Journal of Physics, 1074*.

*Clement, J.J. (1*982) Students' preconceptions in introductory mechanics," *American Journal of Physics, 50*(1), 66-71.

Clement, J. (1988). Observed methods for generating analogies in scientific problem solving. *Cognitive Science, 12*(4), 563.

Clement, J., Brown, D., & Zeitsman, A. (1989). International *Journal of Science Education, 11,* 554-565.

Clement, J.J. (1993). Using bridging analogies and anchoring intuitions to deal with students' preconceptions in physics, *Journal of Research in Science Teaching, 30*(10), 1241-1257.

Craik, F. & Lockhart, R. (1972). Levels of processing: A framework for memory research. *Journal of Verbal Learning & Verbal Behavior, 11,* 671-684.

Da Silva, C., Mellado, V., Ruiz, C., & Porlán, R. (2007). Evolution of the conceptions of a secondary education biology teacher: Longitudinal analysis using cognitive maps. *Science Education, 91*(3), 461-491.

diSessa, A.A. (1988). Knowledge in Pieces. In Pufall, George Forman & Peter B. (Eds.), *Constructivism in the Computer Age,* 49-70.

Dykstra, D.I., Boyle, C.F, & Monarch, I.A. (1992). Studying conceptual change in learning physics, *Science Education, 76*(6), 615-652.

Gabel, D.L. (1994). *Handbook for Research on Science Teaching and Learning,* New York: MacMillan.

Gilbert, J.K., & Watts, D.M. (1983). Concepts, misconceptions and alternative conceptions: Changing perspectives in science education. *Studies in Science Education, 10,* 61-98.

Gunstone, R.F., & White, R.T. (1981). Understanding of Gravity. *Science Education, 65,* 291 - 299

Hammer, D. (1996). More than misconceptions: Multiple perspectives on student knowledge and reasoning, and an appropriate role for education research, *American Journal of Physics, 64*(10), 1316-1325.

Hammer, D. (2000). Student resources for learning introductory physics. American Journal of Physics, *Physics Education Research Supplement, 68*(S1), S52-S59.

Harrison, A.G., Grayson, D J., & Treagust, D. F. (1999). Investigation a grade 11 student's evolving coceptions of heat and temperature. *Journal of Research in Science Teaching, 36,* 55-87.

Hestenes, D. (2006). Notes for a modeling theory of science, cognition and instruction, Proceedings of the 2006 GIREP conference: Modelling in Physics and Physics Education, http://modeling.asu.edu/R&E/Notes_on_Modeling_Theory.pdf (retrived September 5, 2008).

Hewson, P.W. (1981). A conceptual change approach to learning science. *European Journal of Science Education, 3*(4), 383-396.

Hewson, P.W. (1992). Conceptual change in science teaching and teacher education. Paper presented at a meeting on "Research and Curriculum Development in Science Teaching," under the auspices of the National Center for Educational Research, Documentation, and Assessment, Ministry for Education and Science, Madrid, Spain, June 1992. http://www.learner.org/channel/workshops/lala2/support/hewson.pdf (Retrieved 3-17-2008).

Hewson, P.W. (2007). Teacher professional development in science. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research on science education*. Mahwah, NJ: Lawrence

Earlbaum Associates.
Hewson P.W., Tabachnik R., Zeichner K.M., & Lemberger J. (1999). Educating prospective teachers of biology: Findings, limitations, and recommendations, *Science Education, 83,* 373-384.
Hestenes, D. (2006). How can we deal with students' preconceptions? http://modeling.asu.edu/modeling-HS.html (Retrieved 3-24-08).
Hestenese, D., Wells, M. & Swackhamer, G. (1992). Force concept inventory, *The Physics Teacher,* March, 141-158.
Jewett, J.W. (1996a). *Physics Begins With an M... Mysteries, Magic, and Myth,* New York: Prentice Hall.
Jewett, J.W. (1996b). *Physics Begins With Another M... Mysteries, Magic, Myth, and Modern Physics*. New York: Allyn & Bacon.
Karplus, R. (1981). Education and Formal Thought--A Modest Proposal. In I. E. Sigel, D. M. Brodzinsky & R. M. Golinkoff (Eds) *New Directions in Piagetian Theory and Practice,* Hillsdale, NJ: Lawrence Erlbaum and Associates.
Lionni, L. (1970). *Fish is Fish*. New York: Random House.
McDermott, L.C. (1991). Millikan Lecture 1990: What we teach and what is learned: Closing the gap. *American Journal of Physics, 59,* 301-315.
McDermott, L.C. (1984). Research on conceptual understanding in mechanics. *Physics Today, 37* (7), 2-10.
McDermott, L.C. (1998). Student's conceptions and problem solving in mechanics, in *Connecting Research in Physics Education with Teacher Education,* Andrée Tiberghien, E. Leonard Jossem, Jorge Barojas (Eds.) International Commission on Physics Education.
Minstrell, J. (1982). Conceptual Development Research in the Natural Setting of a Secondary School Science Classroom. In M.B. Rowe (Ed.) Education in the 80's: Science, Washington, DC: National Education Association.
Minstrell, J. A. (1989). Teaching science for understanding. In L. Resnick & L. Klopfer (Eds.) *Toward the Thinking Curriculum: Current Cognitive Research*. Alexandria: VA: Association for Supervision and Curriculum Development.
Modeling website (2002). How effective is modeling instruction? http://modeling.asu.edu/modeling/support/Mod_Instr-effective.doc (Retrieved 3-24-08)
Olenick, R.P. (2008). Comprehensive Conceptual Curriculum for Physics (C^3P) Project. http://phys.udallas.edu/C3P/Preconceptions.pdf (Retrieved 3-24-08)
Pfundt, H., & Duit, R. (1991). Bibliography. *Students' alternative frameworks and science education* (3rd Ed.). Kiel, Germany: Institute for Science Education at the University of Kiel.
Posner, G.J., Strike, K.A., Hewson, P.W. & Gertzog, W.A. (1982). Accomodation of a Scientific Conception: Toward a Theory of Conceptual Change. *Science Education, 66,* 211.
Rescorla, R.A., & Wagner, A.R. (1972). A theory of Pavlovian conditioning: Variations in the effectiveness of reinforcement and nonreinforcement. In A. H. Black and W. F. Prokasy (Eds.), *Classical Conditioning II: Current Research and Theory*. New York: Appleton-Century-Crofts.
Reif, F., Larkin, J.H., & Brackett, G.C. (1976). Teaching general learning and problem-solving skills, *American Journal of Physics, 44,* 212-217.
Scott, P.H., Asoko, H.M., & Driver, R.H. (1998). Teaching for conceptual change: A review of strategies, in *Connecting Research in Physics Education with Teacher Education,* Andrée Tiberghien, E. Leonard Jossem, Jorge Barojas (Eds.) International Commission on Physics Education.
Scoboria, A., Mazzoni, G., Kirsch, I., & Jimenez S. (2006). The effects of prevalence and script information on plausibility belief and memory of autobiographical events. *Applied Cognitive Psycholgy, 20*(8), 1049-1064.
Smith; J. diSessa, A., & J. Roschelle. (1993/1994) Misconceptions reconceived: A constructivist analysis of knowledge in transition, *J. Learning Sci*. *3*(2), 115-163.
Silva, M., Groeger, J., & Bradshaw, M. (2006). Attention-memory interactions in scene perception. *Spatial Vision, 19,* 9-19.
Taylor, N., & Coll, R. (1997). The use of analogy in the teaching of solubility to pre-service primary teachers. *Australian Science Teachers' Journal, 43*(4), 58-64.
Taylor, J.A. & Dana, T.M. (2003). An illustration of the complex nature of subject matter knowledge: A case study of secondary school physics teachers' evaluation of scientific evidence. *Journal of Physics Teacher Education Online, 1*(4), 3-13.
Thomaz, M.F., Malaquias, I.M., Valente, M.C, & Antunes M.J. (1995). An attempt to overcome alternative conceptions related to heat and temperature. Physics Education, 30, 19-26.
Thornton, R. K. (1987). Tools for Scientific Thinking: Microcomputer-Based Laboratory, *Physics Education, 22*(4), 230-238.
Thornton, R. K. & Sokolof, D. R. (1990). Learning Motion Concepts Using Real-Time Microcomputer-Based Laboratory Tools, *American Journal of Physics, 58*(9), 858.
Tulving, E. (1972). *Episodic and Semantic Memory*. Oxford, England: Academic Press.
Viennot, L. (1979). Spontaneous Reasoning in Elementary Dynamics. *European Journal of Science Education, 1,* 205.
Wandersee, J.H., Mintzes, J.J., & Novak, J.D. (1994). Research on alternative conceptions in science. In: *Handbook of Research on Science Teaching and Learning,* ed. D. Gabel, New York: Simon & Schuster Macmillan, 177–210.
Weiler, W. (1998). Children's Misconceptions about Science, http://www.eskimo.com/~billb/miscon/opphys.html (retrieved August 20, 2008).
Wenning, C.J. (2005). Whiteboarding and Socratic dialogues: Questions and answers. *Journal of Physics Teacher Education Online, 3*(1), September 2005, pp. 3-10.
Wenning, C.J., Holbrook, T.W., & Stankevitz, J. (2006). Engaging students in conducting Socratic dialogues: Suggestions for science teachers. *Journal of Physics Teacher Education Online, 4*(1), Autumn 2006, pp. 10-13.
Wiser, M. & Amin, T. (2001). "Is heat hot?" Inducing conceptual change by integrating everyday and scientific perspectives on thermal phenomena. *Learning and Instruction, 11*(4-5), 331-355.

