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How Do I Get My Students Over Their Alternative Conceptions (Misconceptions) for Learning?

Removing barriers to aid in the development of the student

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When teachers provide instruction on concepts in various subjects, they are teaching students who already have some pre-instructional knowledge about the topic. Student knowledge, however, can be erroneous, illogical or misinformed. These erroneous understandings are termed **alternative conceptions or misconceptions** (or intuitive theories). Alternative conceptions (misconceptions) are not unusual. In fact, they are a normal part of the learning process. We quite naturally form ideas from our everyday experience, but obviously not all the ideas we develop are correct with respect to the most current evidence and scholarship in a given discipline. Moreover, some concepts in different content areas are simply very difficult to grasp. They may be very abstract, counterintuitive or quite complex. Hence, our understanding of them is flawed. In this way, even adults, including teachers, can sometimes have misconceptions of material (Burgoon, Heddle, & Duran, 2010).

In addition, things we have already learned are sometimes unhelpful in learning new concepts/theories. This occurs when the new concept or theory is inconsistent with previously learned material. Accordingly, as noted, it is very typical for students (and adults) to have misconceptions in different domains (content knowledge areas). Indeed, researchers have found that there is a common set of alternative conceptions (misconceptions) that most students typically exhibit. There is one class of alternative theories (or misconceptions) that is very deeply entrenched. These are "ontological misconceptions," which relate to ontological beliefs (i.e., beliefs about the fundamental categories and properties of the world).

Alternative conceptions (misconceptions) can really impede learning for several reasons. First, students generally are unaware that the knowledge they have is wrong. Moreover, misconceptions can be very entrenched in student thinking. In addition, students interpret new experiences through these erroneous understandings, thereby interfering with being able to correctly grasp new information. Also, alternative conceptions (misconceptions) tend to be very resistant to instruction because learning entails replacing or radically reorganizing student knowledge. Hence, conceptual change has to occur for learning to happen. This puts teachers in the very challenging position of needing to bring about significant conceptual change in student knowledge. Generally, ordinary forms of instruction, such as lectures, labs, discovery learning, or simply reading texts, are not very successful at overcoming student misconceptions. For all these reasons, misconceptions can be hard nuts for teachers to crack. However, several instructional strategies have proven to be effective in achieving conceptual change and helping students leave their alternative conceptions behind and learn correct concepts or theories.

Do's and don'ts

Do's:

Instructional strategies that can lead to change in students' alternative conceptions (misconceptions) and to learning of new concepts and theories:

1. Ask students to write down their pre-existing conceptions of the material being covered. This allows you to overtly **assess their preconceptions** and provides them with an opportunity to see how far their understanding has come after learning the new concepts.
2. Consider whether student preconceptions could potentially be beneficial to their learning process. It is possible that preconceived notions about material, even if not entirely accurate, could provide a base from which to build knowledge of new concepts. For example, using students' correct conceptions and building on those by creating a **bridge of examples** to the new concept or theory is a beneficial strategy to help students over misconceptions.
3. Present new concepts or theories that you are teaching in such a way that students see as plausible, high-quality, intelligible and generative.
4. Use **model-based reasoning**, which helps students construct new representations that vary from their intuitive theories.
5. Use **diverse instruction**, wherein you present a few examples that challenge multiple assumptions, rather than a larger number of examples that challenge just one assumption.
6. Help students become aware of (raise **student metacognition** about) their own alternative conceptions (misconceptions).
7. Present students with experiences that **cause cognitive conflict** in students' minds. Experiences (as in strategy 3 above) that can cause cognitive conflict are ones that get students to consider their erroneous (misconception) knowledge side-by-side with, or at the same time as, the correct concept or theory.
8. Engage in **Interactive Conceptual Instruction** (ICI).
9. Develop **students' epistemological thinking**, which incorporates beliefs and theories about the nature of knowledge and the nature of learning, in ways that will facilitate conceptual change. The more naïve students' beliefs are about knowledge and learning, the less likely they are to revise their misconceptions.
10. Use **case studies** as teaching tools to further solidify understanding of new material and reduce student misconceptions.
11. Help students "**self-repair**" their misconceptions. If students engage in a process called "self-explanation," then conceptual change is more likely (Chi, 2000). Self-explanation entails prompting students to explain text aloud as they read.
12. Once students have overcome their alternative conceptions (misconceptions), **engage them in argument** to strengthen their newly acquired correct knowledge (representations).

Don'ts:

1. Do not rely solely on lectures.
2. Do not rely solely on labs or hands-on activities.
3. Do not rely solely on demonstrations.

4. Do not rely solely on having students simply read the text.
5. Do not rely solely on a singular perspective when there are multiple ways to interpret material.

Assess and build on preconceptions

Assessing preconcecptions

When presenting new information to students, it is helpful to first assess any preconceptions they have of the material. This allows the instructor to get a more accurate reading on potential misconceptions and offers students an opportunity to see how far they have come in their understanding of newly learned concepts. For example, this tack was taken in a preliminary assessment of student knowledge when teaching students about climate change to measure:

- Understandings of the distinction between weather and climate.
- Knowledge about the concept of "deep time."
- Perceptions of human-induced climate change at the beginning of the course, and later compared to perception at end of the course.

See Lomardi & Sinatra (2012). Also, see Haudek, Kaplan, Knight, et al (2011) on how new technology involving automated text analysis helps in assessing student preconceptions in STEM.

Building on preconceptions

After assessing student preconceptions about material, it is important to consider which components of their already acquired knowledge could be beneficial in building a more robust understanding of new concepts. When students come into a class with an initial impression of the curriculum, even if it is inaccurate, it could be evidence of previous content coverage or a tool for priming student thinking. Though it may seem that misconceptions are only a barrier to learning, when used properly they could serve a productive purpose in the classroom (Larkin, 2012).

Present new concepts or theories

In presenting new concepts or theories, teachers should be sure to show these theories or concepts as:

- **Plausible.** The new information should be shown to be consistent with other knowledge and able to explain the available data. Learners must see how the new conception (theory) is consistent with other knowledge and a good explanation of the data
- **High quality.** Of course, the theory/concept to be taught is of high quality from a scientific point of view, since it is a correct theory. However, the presented theory should take a better account of the data than what students currently have available to them. For example, the instructor should deal with the problem from the perspective of the students (e.g., students for whom a "flat earth" theory provides a better account of the data available than does a "spherical earth" theory). Hence, students must consider the quality of the new theory along with previously learned information.

- **Intelligible.** Teachers should do what they can to increase the intelligibility of the new theory. Learners must be able to grasp how the new conception works. To increase intelligibility, teachers can use methods such as:
  a. Analogies (see Chiu & Lin, 2005).
  b. Models (both pictorial conceptual and physical) (See Mayer, 1993; Vosniadou, Ioannides, Dimitrakopoulou, & Papademetriou, 2001 for 5th and 6th graders; Clement, 1993 for high school students; Mayer & Gallini, 1990 for college students).
  c. Direct exposition (see Klahr & Nigam, 2004).
- **Generative/fruitful.** Teachers should show that the new concept/theory can be extended to open up new areas of inquiry. Learners must be able to extend the new conception to new areas of inquiry. Teachers might accomplish this by illustrating the application of the new concept/theory to a range of problems. These problems can include familiar ones and new ones.

(See Chinn & Brewer, 1993; Mayer, 2008; Posner, Strike, Hewson, & Gertzog, 1982).

Bridging analogies

One of the best ways that teachers can correct misconceptions is by a strategy called "**using bridging analogies**." This strategy attempts to bridge pupils' correct beliefs (called "anchoring conceptions") to the new concept/theory (target) by presenting a series of intermediate similar or analogous examples between the students' initial correct conception and the new concept or theory (target) to be learned. (see Brown, 1992; Brown & Clement, 1989; Clement, 1993; Minstrell, 1982; Yilmaz, Eryilmaz, & Geban, 2006)

Using bridging analogies: connected sequence

Many high school students hold a classic misconception in the area of physics, in particular, mechanics. They erroneously believe that "static objects are rigid barriers that cannot exert forces." The classic target problem explains the "at rest" condition of an object. Students are asked whether a table exerts an upward force on a book that is placed on the table. Students with this misconception will claim that the table does not push up on a book lying at rest on it. However, gravity and the table exert equal, but oppositely directed forces on the book thus keeping the book in equilibrium and "at rest." The table's force comes from the microscopic compression or bending of the table. At the same time that students hold the misconception about static objects, they also believe that a spring pushes up on one's hand when the hand is pushing down on the spring.

Physicists understand that these two situations — book on table and hand pressing on a spring — are equivalent. The bridging strategy establishes analogical connections between situations that students initially view as not analogous as a means to getting students to extend their valid intuitions (the spring) to initially counterintuitive target situations (the table). The use of bridging analogies entails use of concrete examples for a connected sequence, starting from an anchor (situation in which most students believe there is upward force), through an intermediate example(s), to a target situation (book on table).

1. **Anchor example**: hand on spring.
2. **Bridging example 1**: book resting on flexible foam pad.

3. **Bridging example 2**: book resting on board.
4. **Target example**: book on table.

A similar strategy teachers can try is the use of the "bridging representation."

Using bridging analogies: representation

In physics instruction, use of the SRI (**symbolic representation of interactions**) diagram has been found to be helpful. SRI emphasizes forces as interactions and makes identification of the mechanical interaction between pairs of objects explicit. It is contrasted with the free-body diagram that concentrates on the forces acting on one target object. The pedagogic function of the SRI is to provide a bridge, referred to as a "bridging representation."

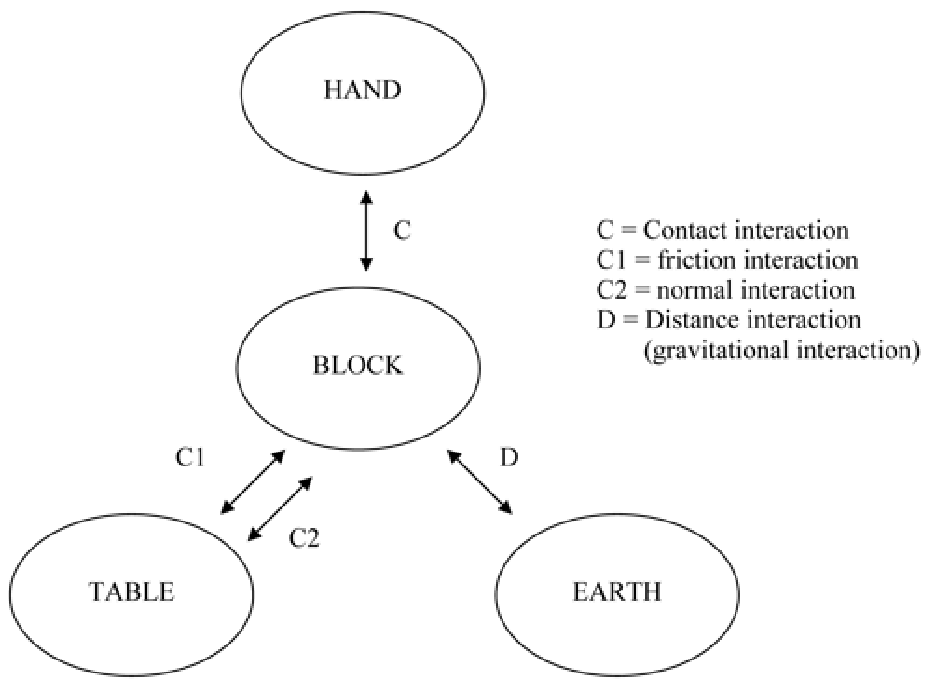


Figure 2. A SRI diagram of a block sliding on a horizontal table. Interaction type is indicated by C or D (contact or distant interaction).

See Savinainen, Scott, & Viiri (2005).

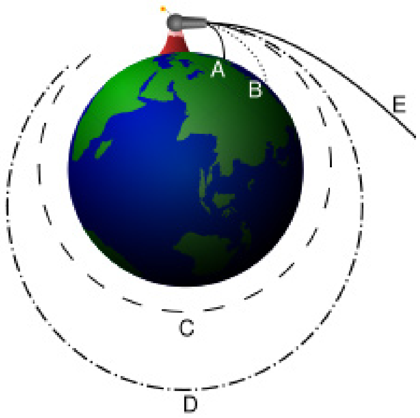
Model-based reasoning

Effective science learning often requires that students construct new representations that vary in important ways from ones used in everyday life. Science entails new ways of seeing data in terms of idealized representations or models. Science generally entails mathematical relations, physical intuitions and sensorimotor action schemes in these models. Teachers should teach idealization techniques, such as thought experiments and limiting case analyses. These techniques are integral to constructing abstract representations that can facilitate student recognition of deep analogies between superficially different phenomena.

A thought experiment, in the broadest sense, is the use of a hypothetical scenario to help us understand the way things actually are. There are many different kinds of thought experiments. All thought experiments, however, employ a methodology that is a priori, rather than empirical, in that they do not proceed by observation or physical experiment. Scientists tend to use thought experiments in the form of imaginary, "proxy" experiments which they conduct prior to a real, "physical" experiment. In these cases, the result of the "proxy" experiment will often be so clear that there will be no need to conduct a physical experiment at all. Scientists also use thought experiments when particular physical experiments are impossible to conduct.

Newton's cannonball was a thought experiment that Isaac Newton used to hypothesize that the force of gravity was universal and that it was the key force for planetary motion.

Newton's cannonball



In this experiment Newton visualizes a cannon on top of a very high mountain. If there was no force of gravitation, the cannonball would follow a straight line away from Earth. So long as there is a gravitational force acting on the cannon ball, it will follow different paths depending on its initial velocity.

1. If the speed is low, it will simply fall back to Earth. (A and B)
2. If the speed equals some threshold orbital velocity, it will go on circling around the Earth in a fixed circular orbit just like the moon. (C)
3. If the speed is higher than the orbital velocity, but not high enough to leave Earth altogether (lower than the escape velocity), it will continue rotating around Earth along an elliptical orbit. (D)
4. If the speed is very high, it will indeed leave Earth. (E)

Diverse instruction

Diverse instruction simultaneously challenges at least two erroneous beliefs that underlie a misconception (alternative conception). It is based on a literature that shows adults and children draw stronger inductive inferences from information that impacts diverse aspects of their underlying beliefs (see Hayes, Goodhew, Heit, & Gillan, 2003, for review). Hayes et al. extend the diversity principle to conceptual change and propose that shifts in intuitive theories or alternative conceptions (misconceptions) are more likely to occur when people encounter new information that challenges several features or assumptions of these models. Conceptual change is more likely if students are presented with a few examples that challenge multiple assumptions, rather than with a larger number of examples that challenge just one assumption.

In an illustration of diverse instruction, an inquiry-based 5E (engage, explore, explain, extend and evaluate) learning model that incorporates different teaching styles to engage students with varying learning modalities has been tried with student misconceptions (Ray & Beardsley, 2008). Within this model, misconceptions can provide a basis for hypothesis testing that encourage exploration of previously held beliefs and build more accurate understanding of complicated processes. This further advocates for diversifying instruction to uncover student strengths and use preconceptions as a basis for deeper academic inquiry.

Example: shape of the earth

The effect of diverse instructional strategies on children's understanding of the shape of the earth has been studied (Hayes et al., 2003). Children's erroneous beliefs about the earth (their nonbelief in a spherical earth) can be linked to two more general misconceptions (Vosniadou & Brewer, 1992). One is the belief that the earth appears flat to an observer on the ground. The second is a poor understanding of gravity and failure to understand the influence of gravity on objects located on different parts of the earth's surface. Indeed, in considering the earth's surface, when students think that unsupported objects fall, they are likely to construct either a "disk" model of the earth or a "dual earth" model (with a round earth located in space co-existing with a flat earth where people live).

In the study, 6-year-old children were randomly assigned to one of three conditions: control (no training); single-belief training (all four instructional videos focused on either the relative size of the earth or the effects of gravity); or dual-belief training (four instructional videos where two focused on the relative size of the earth and two focused on the effects of gravity). Results showed that only children receiving instruction about two core beliefs showed an increased rate of acceptance of a spherical earth model at post-test time.

Student metacognition

Student metacognitive abilities may be critical to achieving conceptual change (Beeth, 1998; Beeth & Hewson, 1999; Case, 1997; Chinn & Brewer, 1993; Gelman & Lucariello, 2002; Inagaki & Hatano, 2002; Minstrell, 1982,1984). Metacognition entails a range of processes, including monitoring, detecting incongruities or anomalies, self-correcting, planning and selecting goals, and reflecting on the structure of one's knowledge and thinking (Gelman & Lucariello, 2002).

Several good methods help students think metacognitively:

- **Engage students in representing their thinking through interactive discussion and open exchange and debate of ideas.**
  To help students increase their metaconceptual awareness (awareness of their own cognition), it is important to create learning environments that make it possible for them to express their knowledge, including misconception knowledge. This can be done in environments that facilitate group discussion and the verbal expression and debate of ideas. The learning environment should allow for students to express their knowledge and compare it with those of others. Such activities assist students in becoming aware of what

they know and what they need to learn. (See Kuhn, 2006: Minstrell, 1982, 1989; Savinainen & Scott, 2002; Vosniadou et al., 2001)

- **Elicit student predictions on the topic, followed by a teacher-led demonstration that tests those predictions. Discussion works towards arriving at a common observation and then reconciles differences between prediction and observation.**
  Keep in mind that students (or anyone) can be biased by the ideas (in this case, misconceptions) they already have when observing things. As such, this can actually interfere with observing events correctly. Chinn & Malhotra (2002) have noticed "theory bias at the observation stage." For example, only about 26 percent of children correctly predicted that a heavy and light rock would hit the ground at the same time (cited in Mayer 2008). An important point is to make the data (to be observed) so obvious that it minimizes incorrect observations by students (Mayer, 2008).
  (See Kuhn, 2006; Champagne, Gunstone, & Klopfer, 1985; Gunstone, Robin Gray, & Searle, 1992: Use of Predict-Observe-Explain (P-O-E); Mayer, 2008; Minstrell, 1982)
- **Provide opportunities for reflective inquiry and assessment (White & Frederickson, 1998).**
  White and colleagues designed a computer-based micro-world **"Thinker Tools" (TT)** (1993; White & Frederiksen, 1998). This is a middle school science curriculum that engages students in learning about and reflecting on the processes of science inquiry as they construct increasingly complex models of force and motion phenomena. The TT inquiry curriculum centers around a metacognitive model of research, called the **inquiry cycle**, and a metacognitive process, called **reflective assessment**, in which students reflect on their own and each other's inquiry strategies.

Predict-observe-explain teaching strategy

In the "predict-observe-explain" (P-O-E) strategy, the teacher plans/presents a demonstration or example that s/he will subsequently conduct/explicate. The topic or issue of the demonstration or example should be one that relates to possible student misconceptions and the design of the demonstration/example should be to elicit such misconceptions. Before conducting the demonstration, pupils predict what will occur. The teacher then conducts the demonstration (explicates the illustration/example) and the students observe this. After the demonstration (illustrative example), the students must explain why their observations conflicted with their predictions.

The P-O-E strategy does not entail the traditional hands-on laboratory work done by students themselves. When the teacher does the demonstration, it allows students to focus more of their intellectual resources on the conceptual issues at hand, including making predictions.

Inquiry cycle

The inquiry cycle guides students' research and helps them understand what the research process is all about.

1. It begins with formulating an investigable **question**.
2. It moves to a **predict** phase, wherein students generate alternative hypotheses and predictions with respect to the question.
3. Next comes the **experiment** phase, wherein students design and carry-out experiments in the real world and on the computer.
4. Students then move to the **model** phase, wherein they analyze their data to construct a conceptual model that includes scientific laws that would predict and explain their findings.

5. Finally, comes the **apply** phase, wherein students apply their model to different situations to investigate the model's utility and limitations. This raises new questions in the process and the cycle begins again.

Students go through the inquiry cycle for each research topic in the curriculum. They engage in reflective assessment at each step in the inquiry cycle and after each completion of the cycle.

The **reflective assessment** component provides students with "criteria for judging research":

- Goal-oriented criteria, such as "understanding the science."
- Process-oriented criteria, such as "being systematic" and "reasoning carefully."
- Socially-oriented criteria, such as "communicating well."

Three teachers in 12 urban classes (across grades 7 to 9) implemented the TT curriculum. The sample included many low-achieving and disadvantaged students. Findings show that the reflective assessment component greatly facilitated student learning.

Cognitive conflict

The idea that cognitive conflict or disequilibrium can lead to learning is rooted in Piagetian theory. Piaget proposed that cognitive conflict or "disequilibrium" arises when students encounter experiences that they are not able to assimilate or that are incongruous with their current cognitive structures/conceptions. Cognitive conflict can lead to conceptual change or accommodation of current cognitive concepts.

There are a variety of ways that teachers generate cognitive conflict in the mind of the student:

- **Present students with anomalous data** (data that do not accord with their misconception). This strategy is thought to be a major means of eliciting cognitive conflict and getting students to change or abandon their current erroneous theories and adopt new ones. However, just presenting anomalous data is not sufficient. Students have been found to ignore or reject such data, profess uncertainty about their validity, and reinterpret the data, among other things (Chinn & Brewer, 1998). There are certain optimal ways to represent such data.
- **Present students with refutational texts** (texts wherein a misconception is explicitly refuted by presenting contrasting information).
  Present refutational texts alone or in combination with discussion, conducted under teacher guidance. The discussion, which can occur between peers, should require students to articulate and support their views with evidence from the text.

  A refutational text introduces a common misconception, refutes it, and offers a new (alternative) theory that proves to be more satisfactory. In this way, refutational texts are a means to create cognitive conflict. The following text from Hynd (2001) is an example of refutational text:

  "Despite the fact that many people think that a rolling ball will slow or stop on its own, this will not happen... Moving objects will keep moving at a constant rate unless they are slowed or stopped, or their direction is changed because of an outside force such as friction." (See

Diakidoy, Kendeou, & Ioannides, 2003; Guzzetti, Snyder, Glass, & Gamas, 1993; Guzzetti, 2000; Hynd, 2001; Maria & MacGinitie, 1987).

- **Present students with text that presents the new theory or concept.** At the same time use teacher strategies or activities that elicit the students' misconceptions such that they consider the conflict between the two.
- **Conduct conceptual change discussions.**

Best ways to present anomalous data

Of course, students might not accept the anomalous or contradictory data and therefore not change their minds. Teachers can increase the chances of anomalous data being accepted and leading to conceptual change by:

- **Making the anomalous data credible.** This can be done in a few ways. Teachers can make it clear that the data were collected according to accepted principles. In addition, live demonstrations and hands-on experiences may also increase the credibility of the anomalous data. Also teachers can appeal to real-world data that students already know about (as in the use of anchoring conceptions as described earlier in the bridging analogies strategy discussion)
- **Avoiding ambiguous data.** Choose data that are perceptually obvious. Also, if teachers are aware of the specific misconceptions their students have, they can choose data, in light of that, that will be unambiguous to their students
- **Presenting multiple lines of data when necessary.** In presenting anomalous data, single experiments are often not convincing. Hence, introducing multiple lines of data, such as use of a series of experiments, should be helpful. If using a single experiment/demonstration, it is useful to be prepared to address student objections effectively
- **Introducing the anomalous data early in the instructional process.** This might be helpful because it appears that the more background knowledge in the topic students possess the more their misconceptions impede the acceptance of anomalous data
- **Engaging students in justification of their reasoning about the anomalous data.** (See Chinn & Brewer 1993 and Posner et al., 1982)

Activities to produce cognitive conflict

Some activities that produce cognitive conflict when used in combination with text are:

- **Augmented activation activities.** This activity has two components. One is the activation activity designed to activate or bring to students' attention their misconception knowledge (e.g., by asking them to recall or reiterate their belief; by reminding them of their belief). The second is directing the reader's attention to contradictory information in the text or providing illustrative demonstrations that are incongruous with the misconception. This instructional strategy is similar to the Socratic teaching method and involves students in dialogues that compel them to handle counterexamples and face contradictions to their misconceptions.
- **The Discussion Web.** This is a discussion strategy led by teacher. It can entail using a graphic aid to form students' positions around a central question. Students are required to take a stance (e.g., on the shape of the earth), defend their positions, and persuade each other with evidence from the text. Direct questioning helps students rethink their prior conceptions.

- **Think sheets.** This is a written contrast of student-generated and text-generated ideas of a concept posed as a central question. It is a text-based activity that contrasts learners' preconceptions to scientific conceptions from text. Learners then self-monitor their prior knowledge in light of information from the text and from the discussion.

(See Guzzetti, 2000; Guzzetti et al., 1993; Hynd, 2001.)

Protocol for conceptual change discussion

From Eryilmaz (2002)

The conceptual assignments were chosen as topics for the discussions for all groups. Discussions were held according to the following guidelines that were provided to the teachers:

1. Use the conceptual question as an exposing event that helps students expose their conceptions about a specific concept or rule.
2. Allow all students to make their own conceptions or hypotheses explicit (verbally and pictorially).
3. Ask what students believe or think about the phenomena and why they think so.
4. Write or draw students on the blackboard even if they are not correct.
5. Be neutral doing the discussion. If one or some students give the correct answer, take it as another suggestion and play the devil's advocate.
6. Be patient. Give enough time to the students to think and respond to the questions.
7. Ask only descriptive questions in this part to understand what students really think about the phenomena.
8. Try to get more students involved in the discussion by asking questions of each student.
9. Assist students in stating their ideas clearly and concisely, thereby making them aware of the elements in their own preconceptions.
10. Encourage confrontation in which students debate the pros and cons of their different preconceptions and increase their awareness and understanding of the differences between their own preconceptions and those of their classmates.
11. Encourage interaction among students.
12. Create a discrepant event, one that creates conflict between exposed preconceptions and some observed phenomenon that students cannot explain.
13. Let students become aware of this conflict: cognitive dissonance, conceptual conflict, or disequilibrium.
14. Help students to accommodate the new ideas presented to them. The teacher does not bring students the message, but she or he makes them aware of their situation through dialogue.
15. Make a brief summary from beginning to the end of discussion.
16. Show explicitly where oversimplification, exemplification, association, and multiple representations have happened, if any. If not, give exemplification, associations with other

topics, and multiple representations for the topic.

17. Give students a feeling of progress and growth in mental power, and help them develop confidence in themselves and their abilities.

Interactive conceptual instruction (ICI)

Interactive conceptual instruction (ICI), described and studied by Savinainen & Scott (2002), incorporates several key pedagogical aspects:

- Use of interactive approaches that entail ongoing teacher-student dialogue, which focuses on developing conceptual understandings and wherein students have the opportunity to talk through their understandings with the support of the teacher.
- Teacher use of research-based instruments (questionnaires/assessments/ inventories) that afford quick and detailed formative assessments of students' knowledge in a subject-area.
- Teachers' development of a detailed map of the conceptual terrain of the subject area, including knowledge of the canonical information in the subject, student misconceptions and the representations (understandings) between these two.

Develop student thinking about knowledge and learning

Conceptual change is facilitated if students view knowledge as:

- Complex (not simple).
- Uncertain and evolving (not stable and absolute).

Conceptual change is facilitated if students view learning as:

- A gradual, slow process (not as "quick or not at all").
- An ability that is improvable (malleable) (not fixed or unmodifiable).

Conceptual change is also facilitated by addressing students' epistemologies about specific domains.

For example, with respect to science, having students reflect on the nature of science (see Smith, Maclin, Houghton, & Hennessey, 2000) and on the criteria that characterize good research facilitate conceptual change in science.

(See Mason, 2002, for review.)

Engage argument to strengthen newly acquired correct knowledge

Engaging in argument may be a central way that a student's new conceptual system becomes strengthened and overtakes a student's alternative conceptions (misconceptions). Argument entails asking students to evaluate or debate the adequacy of a new system with competing alternative conceptions (misconceptions). Students, even in the elementary school years, are sensitive to many of the features that make for a good concept/theory, such as plausibility, fruitfulness and explanatory coherence.

Children actually seem to prefer accounts that explain more, are not ad hoc, are internally consistent, and fit the empirical data (Samarapungavan, 1992).

(See Committee on Science Learning, Kindergarten through Eighth Grade, 2007. See also Duschl & Osborne, 2002, for how to support and promote argumentation type discourse.)

Use case studies

The effect of using case studies in teaching chemistry on student understanding of the material and their level of misconceptions after being exposed to the new content has been studied (Ayyldz & Tarhan, 2013). Students who received instruction that included case studies rather than a traditional lecture format demonstrated higher knowledge and fewer misconceptions through achievement test scores. These case studies were "real world" scenarios with accompanying references that required explanation through properties learned in the chemistry classroom.

For example, students may be asked to explain how it is possible for a fly to walk on water but it is not possible for a human to do the same. Rather than simply asking about comparing the density of liquids and solids, this offered students the opportunity to apply the concepts and build a more robust grasp of the material. This suggests that teaching students new material through the use of case studies can lead to greater understanding of the material and prevent future misconceptions.

Why and how do these teaching strategies work?

Students do not come to school as blank slates to be filled by instruction. Children are active cognitive agents who arrive at school after years of cognitive growth (Committee on Science Learning, Kindergarten through Eighth Grade, 2007). They come to the classroom with considerable knowledge based on intuitions, every day experiences, or what they have been taught in other contexts. This pre-instructional knowledge is referred to as preconceptions. Since a considerable amount of our knowledge is organized by subject areas, such as mathematics, science, etc., so too are preconceptions.

It is important for teachers to know about the preconceptions of their students because learning depends on and is related to student prior knowledge (Bransford, Brown, & Cocking, 2000; Gelman & Lucariello, 2002; Piaget & Inhelder, 1969; Resnick, 1983). We interpret incoming information in terms of our current knowledge and cognitive organizations. Learners try to link new information to what they already know (Resnick, 1983). This kind of learning is known as assimilation (Piaget & Inhelder, 1969). When new information is inconsistent with what learners already know it cannot be assimilated. Rather, the learner's knowledge will have to change or be altered because of this new information and experience. This kind of learning is known as accommodation (of knowledge/mental structures).

Whether learning is a matter of assimilation or accommodation depends on whether student preconceptions are anchoring conceptions or alternative conceptions (misconceptions), respectively. Student preconceptions that are consistent with concepts in the assigned curriculum are anchoring conceptions. Learning, in such cases, is a matter of assimilation or conceptual growth. It consists in enriching or adding to student knowledge. Assimilation is an easier kind of learning because prior knowledge does not interfere with learning. Rather, prior knowledge is a base the learner can rely on to build new knowledge.

Culture can have a considerable impact on students' preconceptions about material, as the world in which they live provides a meaning-making lens for what they learn in school. Some students may find that they are able to balance new information and experiences with those that they have already incorporated into their life by being "cultural straddlers" (Carter, 2006). For other students who have more difficulty achieving this balance, it may be that more directed work is necessary to help them understand concepts that are more foreign to them at the time of their teaching.

Student preconceptions that are inconsistent with, and even contradict, concepts in the curriculum, are alternative conceptions or misconceptions (or intuitive theories). Intuitive theories are very typical and children and adults possess them. They develop from the natural effort to make sense of the world around us. For example, the "distance theory" (a misconception) that explains seasonal/temperature change in terms of different distances between the Earth and the Sun in summer and winter could easily develop from one's everyday experience with heat sources (Kikas, 2004). Sometimes even textbooks themselves can be the cause of alternative theories. For instance, a diagram of the earth's orbit commonly used in textbooks presents a stretched-out ellipse (although it more closely resembles a circle) that can contribute to the erroneous "distance theory" of seasonal change (Kikas, 1998). Hence, intuitive theories or misconceptions are not a reflection of a cognitively deficient child. Rather, they reflect a child with a cognitively active mind, who has already achieved considerable complex and abstract knowledge. Indeed, young children are not limited to concrete reasoning. Nor should they be viewed as a bundle of misconceptions.

Alternative conceptions (misconceptions) interfere with learning for several reasons. Students use these erroneous understandings to interpret new experiences, thereby interfering with correctly grasping the new experiences. Moreover, misconceptions can be entrenched and tend to be very resistant to instruction (Brewer & Chinn, 1991; McNeil & Alibali, 2005). Hence, for concepts or theories in the curriculum where students typically have misconceptions, learning is more challenging. It is a matter of accommodation. Instead of simply adding to student knowledge, learning is a matter of radically reorganizing or replacing student knowledge. Conceptual change or accommodation has to occur for learning to happen (Carey, 1985; 1986; Posner et al., 1982; Strike & Posner, 1985, 1992). Teachers will need to bring about this conceptual change.

According to conceptual change theory, learning involves three steps (see Mayer, 2008 for summary):

1. **Recognizing or detecting an anomaly.** This refers to becoming aware that your current mental model (representation or theory or conception) is inadequate to explain observable facts. The student must realize that he/she has a misconception(s) that must be discarded or replaced
2. **Constructing a new model.** This entails finding a better, more sufficient model that is able to explain the observable facts. It involves the students' replacing one model with another
3. **Using a new model.** This refers to students using the new model to find a solution when presented with a problem. This reflects an ability to solve problems with the new model.

Hence mental models (representations of theories or concepts) are at the core of conceptual-change theory. For example, you are using a mental model when you think of the earth as hollow.

Traditional methods of instruction used in isolation, such as lectures, labs, discovery learning or simply reading text have not been found to be effective at achieving conceptual change (Chinn & Brewer, 1993; Kikas, 1998; Lee, Eichinger, Anderson, Berkheimer, & Blakeslee, 1993; Roth, 1990; Smith, Maclin, Grosslight, & Davis, 1997). Recommended alternative teaching strategies are included in this module.

FAQs

Is it normal for students to have misconceptions? Do most students have them?

Yes, it is very typical for students to have misconceptions. They are acquired or formed through everyday experiences, through instruction on other topics, and because some concepts are very complex to master.

Are there typical common misconceptions that students have in different academic subjects?

Yes, there are typical misconceptions that students have in the different subjects, such as math and science. Being aware of the typical misconceptions students have in these subject areas can help you focus your instruction to address the most common misconceptions.

Are these strategies to correct student misconceptions applicable to all children?

These strategies are general enough to be effective with most children. However, various strategies are optimally appropriate and effective at specific grade levels. Moreover, a teacher should use his or her judgment about which strategies might be most effective, given the particular students in the class. For example, for students that have language difficulties (e.g., difficulty reading and processing text and articulating thoughts verbally) the teacher might rely more on the less-verbal strategies (e.g., use of bridging analogies) with those students.

When do do these recommendations work?

Age

Almost all these recommendations can be used with students from the elementary grades (beginning at around 5th Grade) through high school. In the case of using bridging analogies (recommendation #2), this strategy is most suitable for high school students.

Individual differences

We know very little about how these recommendations might vary by gender or ethnicity. There is good reason to believe, however, that most, if not all, of these recommendations would be generally successful with most students. The little research that has been conducted with different sub-groups of children and youth suggests that these strategies would be comparably effective with low-achieving children (as well as with better performing children).

Contextual factors

We know very little about how these recommendations might vary by contextual factors, such as for children living in poverty and different kinds of family constellations. We do know that misconceptions are quite universal. There is good reason to believe, however that most, if not all, of these recommendations for getting students over their misconceptions would be generally successful with most students. The little research that has been done with 7th through 9th grade urban classes that had many disadvantaged students suggests that these strategies would be effective for low-SES children. There is no reason to believe that family variables would play any role in the effectiveness of these strategies.

Where can teachers get more information?

Bransford, J. D., Brown, A. L., & Cocking, R. R. (Eds.). (2000). How people learn: Brain, mind, experience, and school. Washington, DC: National Academies Press.

Brown, J. S., & Burton, R. R. (1978). Diagnostic models for procedural bugs in basic mathematical skills. *Cognitive Science*, 2, 155-192.

Committee on Science Learning, Kindergarten through Eighth Grade. (2007). Taking science to school: Learning and teaching science in grades K-8. Washington, DC: National Academies Press.

Duschl, R., & Osborne, J. (2002). Supporting and promoting argumentation discourse. Studies in Science Education, 38, 39-72.

Eryilmaz, A. (2002). Effects of conceptual assignments and conceptual change discussions on students' misconceptions and achievement regarding force and motion. Journal of Research in Science Teaching, 39, 1001-1015.

Guzzetti, B. J., Snyder, T. E., Glass, G. V., & Gamas, W. S. (1993). Promoting conceptual change in science: A comparative meta-analysis of instructional interventions from reading education and science education. Reading Research Quarterly, 28, 116-159.

Haudek, Kevin C., Kaplan, Jennifer J., Knight, Jennifer, Long, Tammy, Merrill, John, Munn, Alan, ... Urban-Lurain, Mark. (2011). Harnessing Technology to Improve Formative Assessment of Student Conceptions in STEM: Forging a National Network. *CBE - Life Sciences Education,* (2), 149-155.

Hayes, B. K., Goodhew, A., Heit, E., & Gillan, J. (2003). The role of diverse instruction in conceptual change. *Journal of Experimental Child Psychology*, 86, 253-276.

Hynd, C. R. (2001). Refutational texts and the change process. International *Journal of Educational Research*, 35, 699-714.

Mayer, R. E. (2003). Learning and instruction. Upper Saddle River, NJ: Pearson Education, Inc.

Mayer, R. E. (2008). Learning and instruction (2nd ed.). Upper Saddle River, NJ: Pearson Education, Inc.

Minstrell, J. (1982). Explaining the "at rest" condition of an object. *The Physics Teacher*, 20, 10-14.

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientifc conception: Toward a theory of conceptual change. Science Education, 66, 211-227.

Resnick, L. B. (1983). Mathematics and science learning: A new conception. Science, 220, 477-478.

Siegler, R. S. (2003). Implications of cognitive science research for mathematics education. In J. Kilpatrick, W. B. Martin, & D. E. Schifter (Eds.), A research companion to principles and standards for school mathematics (pp. 219-233). Reston, VA: National Council of Teachers of Mathematics.

References

Alexander, P. A. (2006). Psychology in learning and instruction. Upper Saddle River, NJ: Pearson Education, Inc.

Arnaudin, M., & Mintzes, J. (1985). Students' alternative conceptions of the human circulatory system: A cross-age study. Science Education, 69(5), 721-733.

Arnaudin, M., & Mintzes, J. (1986). The cardiovascular system: Children's conceptions and misconceptions. Science and Children, 23(5), 48-51.

Atwood, R. K., & Atwood, V. A. (1996). Preservice elementary teachers' conceptions of the causes of seasons. *Journal of Research in Science Teaching*, 33(5), 553-563.

Ayyldz, Y., & Tarhan, L. (2013). Case study applications in chemistry lesson: Gases, liquids, and solids. *Chemistry Education Research and Practice,14*(4), 408-420.

Baxter, J. (1995). Children's understanding of astronomy and Earth sciences. In S. M. Glynn & R. Duit (Eds.), Learning science in the schools (pp. 155-178). Mahwah, NJ: Erlbaum.

Beeth, M. E. (1998). Teaching science in 5th grade: Instructional goals that support conceptual change. Journal of Research in Science Teaching, 35(10), 1091-1101.

Beeth, M. E., & Hewson, P. W. (1999). Learning goals in an exemplary science teacher's practice: Cognitive and social factors in teaching for conceptual change. *Science Education*, 83(6), 738-760.

Bransford, J. D., Brown, A. L., & Cocking, R. R. (Eds.). (2000). How people learn: Brain, mind, experience, and school. Washington, DC: National Academy Press.

Brewer, W. F., & Chinn, C. A. (1991). Entrenched beliefs, inconsistent information, and knowledge change. In L. Birnbaum (Ed.), The International Conference of the Learning Sciences: Proceedings of the 1991 conference (pp. 67-73). Charlottesville, VA: Association for the Advancement of Computing in Education.

Brown, D. E. (1992). Using examples and analogies to remediate misconceptions in physics: Factors infuencing conceptual change. Journal of Research in Science Teaching, 29(1), 17-34.

Brown, D. E., & Clement, J. (1989). Overcoming misconceptions via analogical reasoning: Abstract transfer versus explanatory model construction. International Science, 18, 237-261.

Brown, J. S., & Burton, R.R. (1978). Diagnostic models for procedural bugs in basic mathematical skills. *Cognitive Science*, 2, 155-192.

Burgoon, Jacob N., Heddle, Mandy L., & Duran, Emilio. (2010). Re-Examining the Similarities between Teacher and Student Conceptions about Physical Science. *Journal of Science Teacher Education,* (7), 859-872.

Carey, S. (1985). Conceptual change in childhood. Cambridge, MA: MIT Press.

Carey, S. (1986). Cognitive science and science education. American Psychologist, 41, 1123-1130.

Carter, Prudence L. (2006). Straddling Boundaries: Identity, Culture, and School. *Sociology of Education,79*(4), Vol.79(4), p.304.

Case, R. (1997). The development of conceptual structures. In D. Kuhn & R. S. Siegler (Eds.), Handbook of child psychology (Vol 2): Perception, cognition, and language (pp. 745-800). New York: Wiley.

Champagne, A. B., Gunstone, R. F., & Klopfer, L. E. (1985). Effecting changes in cognitive structures among physics students. In H. T. West & A. L. Pines (Eds.), Cognitive structure and conceptual change (pp. 61-90). Orlando, FL: Academic Press.

Chi, M. T. H. (1992). Conceptual change within and across ontological categories: Implications for learning and discovery in science. In R. Giere (Ed.), Minnesota studies in the philosophy of science (Vol XV): Cognitive models of science (pp. 129-186). Minneapolis, MN: University of Minnesota Press.

Chi, M. T. H. (2000). Self-explaining: The dual processes of generating inference and repairing mental models. In R. Glaser (Ed.), Advances in instructional psychology (Vol 5): Educational design and cognitive science (pp. 161-238). Mahwah, NJ: Erlbaum.

Chi, M. T. H. (2005). Commonsense conceptions of emergent processes: Why some misconceptions are robust. The Journal of the Learning Sciences, 14, 161- 199.

Chinn, C. A., & Brewer, W. F. (1993). The role of anomalous data in knowledge acquisition: A theoretical framework and implications for science instruction. Review of Educational Research, 63, 1-49.

Chinn, C. A., & Brewer, W. F. (1998). An empirical test of a taxonomy of responses to anomalous data in science. Journal of Research in Science Teaching, 35(6), 623-654.

Chinn, C. A., & Malhotra, B. A. (2002). Children's responses to anomalous scientific data: How is conceptual change impeded? Journal of Educational Psychology, 94(2), 327-343.

Chiu, M. H., & Lin, J. W. (2005). Promoting fourth graders' conceptual change of their understanding of electric current via multiple analogies. *Journal of Research in Science Teaching*, 42(4), 429-464.

Clement, J. (1982). Students' preconceptions in introductory mechanics. *American Journal of Physics*, 50(1), 66-71.

Committee on Science Learning, Kindergarten through Eighth Grade (2007). Taking science to school: Learning and teaching science in grades K-8. Washington, DC: National Academies Press.

Diakidoy, I. A., Kendeou, P., & Ioannides, C. (2003). Reading about energy: The effects of text structure in science learning and conceptual change. *Contemporary Educational Psychology*, 28(3), 335-356.

Duschl, R., & Osborne, J. (2002). Supporting and promoting argumentation discourse. Studies in Science Education, 38, 39-72.

Eryilmaz, A. (2002). Effects of conceptual assignments and conceptual change discussions on students' misconceptions and achievement regarding force and motion. Journal of Research in Science Teaching, 39(10), 1001-1015.

Falkner, K. P., Levi, L., & Carpenter, T. P. (1999). Children's understanding of equality: A foundation for algebra. *Teaching Children Mathematics*, 6(4), 232-236.

Fischbein, E., Deri, M., Nello, M., & Marino, M. (1985). The role of implicit models in solving verbal problems in multiplication and division. Journal for Research in Mathematics Education,16, 3-17.

Gelman, R., & Lucariello, J. (2002). Role of learning in cognitive development. In H. Pashler (Series Ed.) & C. R. Gallistel (Vol. Ed.), Stevens' handbook of experimental psychology: Vol. 3. Learning, motivation, and emotion (3rd ed., pp. 395- 443). New York: Wiley.

Goulding, M., Rowland, T., & Barber, P. (2002). Does it matter? Primary teacher trainees' subject knowledge in mathematics. British Educational Research Journal, 28(5), 689-704.

Gunstone, R. F., Robin Gray, C. M., & Searle, P. (1992). Some long-term effects of uninformed conceptual change. Science Education, 76(2), 175-197.

Guzzetti, B. J. (2000). Learning counter-intuitive science concepts: What have we learned from over a decade of research? *Reading & Writing Quarterly*, 16(2), 89-98.

Guzzetti, B. J., Snyder, T. E., Glass, G. V., & Gamas, W. S. (1993). Promoting conceptual change in science: A comparative meta-analysis of instructional interventions from reading education and science education. Reading Research Quarterly, 28, 116-159.

Hartnett, P., & Gelman, R. (1998). Early understandings of numbers: Paths or barriers to the construction of new understandings? *Learning and Instruction*, 8(4), 341-374.

Hatano, G., Siegler, R. S., Richards, D. D., Inagaki, K., Stavy, R., & Wax, N. (1997). The development of biological knowledge: A multi-national study. *Cognitive Development*, 8, 47-62.

Hayes, B. K., Goodhew, A., Heit, E., & Gillan, J. (2003). The role of diverse instruction in conceptual change. *Journal of Experimental Child Psychology*, 86, 253-276.

Hynd, C. R. (2001). Refutational texts and the change process. *International Journal of Educational Research*, 35(7), 699-714.

Inagaki, K., & Hatano, G. (2002). Young children's naïve thinking about the biological world. New York: Psychology Press.

Keil, F. C. (1979). Semantic and conceptual development: An ontological perspective. Cambridge, MA: Harvard University Press.

Kieran, C. (1981). Concepts associated with the equality symbol. *Educational Studies in Mathematics*, 12, 317-326.

Kieran, C. (1992). The learning and teaching of school algebra. In D. A. Grouws (Ed.), Handbook of research on mathematics teaching and learning (pp. 390- 419). New York: Macmillan.

Kikas, E. (1998). The impact of teaching on students' definitions and explanations of astronomical phenomena. *Learning and Instruction*, 8(5), 439-454.

Kikas, E. (2003). University students' conceptions of different physical phenomena. *Journal of Adult Development*, 10(3), 139-150.

Kikas, E. (2004). Teachers' conceptions and misconceptions concerning three natural phenomena. *Journal of Research in Science Teaching*, 41, 432-448.

Klahr, D. & Nigam, M. (2004). The equivalence of learning paths in early science instruction: Effects of direct instruction and discovery learning. Psychological Science, 15, 661-667.

Knuth, E. J., Alibali, M. W., McNeil, N. M., Weinberg, A., & Stephens, A. C. (2005). Middle school students' understanding of core algebraic concepts: Equivalence and variable. International Journal of

Mathematics Education, 37, 1-9.

Kuchemann. (1978). Children's understanding of numerical variables. Mathematics in School, 7(4), 23-26.

Kuhn, D. (2006). Do children and adults learn differently? *Journal of Cognition and Development*, 7, 279-293.

Larkin, Douglas. (2012). Misconceptions about "Misconceptions": Preservice Secondary Science Teachers' Views on the Value and Role of Student Ideas. *Science Education,* (5), 927-959.

Lee, O., Eichinger, D. C., Anderson, C. W., Berkheimer, G. D., & Blakeslee, T. D. (1993). Changing middle school students' conceptions of matter and molecules. Journal of Research in Science Teaching, 30(3), 249-270.

Lombardi, Doug, & Sinatra, Gale M. (2012). College Students' Perceptions about the Plausibility of Human-Induced Climate Change. *Research in Science Education,* (2), 201-217.

MacGregor, M., & Stacey, K. (1997). Students' understanding of algebraic notation: 11-15. Educational Studies in Mathematics, 33, 1-19.

Maria, K., & MacGinitie, W. (1987). Learning from texts that refute the reader's prior knowledge. Reading Research and Instruction, 26, 222-238.

Mason, L. (2002). Developing epistemological thinking to foster conceptual change in different domains. In M. Limon & L. Mason (Eds.), Reconsidering conceptual change: Issues in theory and practice (pp. 301-335). Netherlands: Kluwer Academic Publishers.

Mason, K., & Ruddock, G. (1986). Decimals. Windsor, Ontario, Canada: APU/NFER-Nelson.

Mayer, R. E. (1993). Illustrations that instruct. In R. Glaser (Ed.), Advances in instructional psychology (Vol. 4, pp. 253-284). Hillsdale, NJ: Erlbaum.

Mayer, R. E. (2008). Learning and instruction (2nd ed.) . Upper Saddle River, NJ: Pearson Education, Inc.

Mayer, R. E., & Gallini, J. K. (1990). When is an illustration worth ten thousand words? Journal of Educational Psychology, 82(4), 715-726.

McCloskey, M. (1983). Intuitive physics. Scientific American, 248(4), 122-130.

McCloskey, M., Caramazza, A., & Green, B. (1980). Curvilinear motion in the absence of external forces: Naïve beliefs about the motion of objects. Science, 210, 1139-1141.

McNeil, N. M., & Alibali, M. W. (2005). Why won't you change your mind? Knowledge of operational patterns hinders learning and performance on equations. *Child Development*, 76, 883-899.

Minstrell, J. (1982). Explaining the "at rest" condition of an object. *The Physics Teacher*, 20, 10-14.

Minstrell, J. (1984). Teaching for the development of understanding of ideas: Forces on moving objects. In C. W. Anderson (Ed.), Observing classrooms: Perspectives from research and practice (pp. 67-85). Columbus, OH: Ohio State University.

Minstrell, J. (1989). Teaching science for understanding. In L. B. Resnick & L. E. Klopfer (Eds.), Toward the thinking curriculum: Current cognitive research (pp. 129-149). Alexendria, VA: Association for Supervision and Curriculum Development.

Nunes, T., & Bryant, P. (Eds.). (1996). Children doing mathematics. Oxford: Blackwell.

Ojala, J. (1997). Lost in space? The concepts of planetary phenomena held by trainee primary school teachers. International Research in Geographical and Environmental Education, 6, 183-203.

Pelaez, N. J., Boyd, D. D., Rojas, J. B., & Hoover, M. A. (2005). Prevalence of blood circulation misconceptions among prospective elementary teachers. *Advances in Physiology Education*, 29, 172-181.

Piaget, J., & Inhelder, B. (1969). The psychology of the child. New York: Basic Books,.

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientifc conception: Toward a theory of conceptual change. Science Education, 66(2), 211-227.

Ray, A., & Beardsley, P. (2008). Overcoming Student Misconceptions about Photosynthesis: A Model- and Inquiry-Based Approach Using Aquatic Plants. *Science Activities: Classroom Projects and Curriculum Ideas,45*(1), 13-22.

Resnick, L. B. (1983). Mathematics and science learning: A new conception. Science, 220, 477-478.

Resnick, L. B., Nesher, P., Leonard, F., Magone, M., Omanson, S., & Peled, I. (1989). Conceptual bases of arithmetic errors: The case of decimal fractions. Journal for Research in Mathematics Education, 20(1), 8-27.

Rosnick, P. (1981). Some misconceptions concerning the concept of variable. *Mathematics Teacher*, 74, 418- 420.

Roth, K. J. (1990). Science education: It's not enough to "do" or "relate". American Educator, 13(4), 16-22, 46-48.

Ryan, J., & McCrae, B. (2005). Subject matter knowledge: Errors and misconceptions of beginning pre-service teachers. In P. Clarkson, A. Downtown, D. Gronn, M. Horne, A. McDonough, R. Pierce, & A. Roche (Eds), Building Connections: Research, Theory and Practice: Proceedings of the 28th Annual Conference of the Mathematics Education Research Group of Australasia, (Vol. 2, pp. 641-648). Melbourne, Australia: Deakin University.

Sackur-Grisvard, C., & Leonard, F. (1985). Intermediate cognitive organization in the process of learning a mathematical concept: The order of positive decimal numbers. Cognition and Instruction, 2, 157-174.

Samarapungavan, A. (1992). Children's judgments in theory choice tasks: Scientifc rationality in childhood. *Cognition*, 45, 1-32.

Savinainen, A., & Scott, P. (2002). The Force Concept Inventory: A tool for monitoring student learning. Physics Education, 37(1), 45-52.

Savinainen, A., Scott, P., & Viiri, J. (2005). Using a bridging representation and social interactions to foster conceptual change: Designing and evaluating an instructional sequence for Newton's third law. *Science Education*, 89(2),175-195.

Siegler, R. S. (2003). Implications of cognitive science research for mathematics education. In J. Kilpatrick, W. B. Martin, & D. E. Schifter (Eds.), A research companion to principles and standards for school mathematics (pp. 219-233). Reston, VA: National Council of Teachers of Mathematics.

Smith, C. L., Maclin, D., Grosslight, L., & Davis, H. (1997). Teaching for understanding: A study of students' pre-instruction theories of matter and a comparison of the effectiveness of two approaches to teaching about matter and density. *Cognition and Instruction*, 15(3), 317-393.

Smith, C. L., Maclin, D., Houhgton, C., & Hennessey, M. G. (2000). Sixth-grade students' epistemologies of science: The impact of school science experiences on epistemological development. *Cognition and Instruction*, 18(3), 349-422.

Steinberg, R. M., Sleeman, D. H., & Ktorza, D. (1990). Algebra students' knowledge of equivalence of equations. Journal for Research in Mathematics Education, 22(2), 112-121.

Stovall, G., & Nesbit, C. R. (2003). Let's try action research! Science and Children, 40, 44-48.

Strike, K. A., & Posner, G. J. (1985). A conceptual change view of learning and understanding. In L. H. T. West & A. L. Pines (Eds.), Cognitive structure and conceptual change. New York: Academic Press.

Strike, K. A., & Posner, G. J. (1992). A revisionist theory of conceptual change. In R. A. Duschl & R. J. Hamilton (Eds.), Philosophy of science, cognitive psychology, and educational theory and practice (pp. 147-176). Albany, NY: Statue University of New York Press.

Tirosh, D. (2000). Enhancing prospective teachers' knowledge of children's conceptions: The case of division of fractions. Journal for research in Mathematics Education, 31(1), 5-25.

Vosniadou, S. (1994). Capturing and modeling the process of conceptual change. *Learning and Instruction*, 4(1), 45-69.

Vosniadou, S., & Brewer, W. F. (1992). Mental models of the earth: A study of conceptual change in childhood. *Cognitive Psychology*, 24, 535-585.

Vosniadou, S., & Brewer, W. F. (1994). Mental models of the day/night cycle. *Cognitive Science*, 18, 123-183.

Vosniadou, S., Ioannides, C., Dimitrakopoulou, A., & Papademetriou. E. (2001). Designing learning environments to promote conceptual change in science. *Learning and Instruction*, 11(4), 381-419.

Welder, Rachael M. (2012). Improving Algebra Preparation: Implications from Research on Student Misconceptions and Difficulties. *School Science and Mathematics,* (4), 255-264.

White, B. Y. (1993). Thinker Tools: Causal models, conceptual change, and science education. *Cognition and Instruction*, 10(1), 1-100.

White, B. Y., & Frederiksen, J. R. (1998). Inquiry, modeling, and metacognition: Making science accessible to all students. *Cognition and Instruction*, 16(1), 3-118.

Williams, J., & Ryan, J. (2000). National testing and the improvement of classroom teaching: Can they coexist? British Educational Research Journal, 26(1), 49-73.

Winner, E. (1997). The point of words: Children's understanding of metaphor and irony. Cambridge, MA: Harvard University Press.

Yilmaz, S., Eryilmaz, A., & Geban, O. (2006). Assessing the impact of bridging analogies in mechanics. School Science and Mathematics, 106(6), 220-230.

Yip, D. (1998). Teachers' misconceptions of the circulatory system. Journal of Biological Education, 32(3), 207-216.

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