

Essay

Misconceptions Are “So Yesterday!”

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At the close of the Society for the Advancement of Biology Education Research conference in July 2012, one of the organizers made the comment: “Misconceptions are so yesterday.” Within the community of learning sciences, misconceptions *are* yesterday’s news, because the term has been aligned with eradication and/or replacement of conceptions, and our knowledge about how people learn has progressed past this idea. This essay provides an overview of the discussion within the learning sciences community surrounding the term “misconceptions” and how the education community’s thinking has evolved with respect to students’ conceptions. Using examples of students’ incorrect ideas about evolution and ecology, we show that students’ naïve ideas can provide the resources from which to build scientific understanding. We conclude by advocating that biology education researchers use one or more appropriate alternatives in place of the term misconception whenever possible.

MISCONCEPTIONS ARE “SO YESTERDAY!”

The title of this essay is excerpted from a broader set of statements one of the organizers of the 2012 Society for the Advancement of Biology Education Research (SABER) Summer conference posed at the closing discussion of the meeting. The attendees were charged with moving biology education research (BER) into its second generation, and one of the suggestions was to strengthen our research foundations by drawing from the learning sciences literature. While discussing the future of BER, the organizer stated: “Misconceptions are so yesterday.” For some biology instructors, this may have seemed to be an odd statement. It certainly cannot be that students in the 21st century no longer have incorrect conceptions. The speaker’s statement, however, may have stemmed from the fact that the word “misconceptions” is very rarely used in current science education and learning sciences literature (e.g., *Journal of Research in Science Teaching*, *Science Education*, *Journal of the Learning Sciences*, *Cognition and Instruction*), even

though it is still common in practitioner-based BER. Why this discrepancy? The goal of this paper is to inform the growing BER community about the discussion within the learning sciences community surrounding misconceptions and to describe how the learning sciences community’s thinking about students’ conceptions has evolved over the past decade. We close by arguing that one’s views on how people learn will necessarily inform pedagogy. If we view students’ incorrect ideas as resources for refinement, rather than obstacles requiring replacement, then this model of student thinking may lead to more effective pedagogical strategies in the classroom.

HISTORICAL BACKGROUND

In the mid-1970s, spurred by research conducted by Piaget (1963, 1971), educational researchers began to acknowledge that children think about the world in very different ways than adults do. Building on Piaget’s studies of cognitive development, researchers sought to investigate how students make sense of a variety of subject matter tasks. As they listened to what children were saying and doing, it became clear that learners did not come to the classroom as blank slates; rather, they developed robust conceptions that were different from the accepted mathematical and scientific concepts presented in instruction. The term misconception was widely used during this time to encapsulate the ideas that students’ incorrect conceptions were often stable, widespread, resistant to change, and could interfere with learning. The natural consequence of this perspective of students’ ideas is that incorrect ideas should be eradicated (Gardner, 1991). Research into

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students' misconceptions continued through the 1980s and 1990s, providing extensive information about the nature of students' understandings (Driver *et al.*, 1985, 1994; Wandersee *et al.*, 1994). Much of this research focused on describing the fundamental differences between students' and experts' ideas within specific scientific and mathematical domains.

The general consensus among education researchers during this time was that students' misconceptions were so prevalent that instruction needed to focus on revealing, confronting, and replacing them (Strike and Posner, 1985). The assumption underlying this view of learning was that misconceptions play no productive role in expert conceptions, and, consequently, misconceptions needed to be removed. Terms such as "interference," "replacement," and "overcome" were prevalent in the literature, in conjunction with the notion that misconceptions pose a hindrance to expert reasoning. This view of conceptual change is still evident in some BER literature today (e.g., Kalinowski *et al.*, 2010; Andrews *et al.*, 2011; Crowther, 2012).

A SHIFT IN THINKING ABOUT STUDENTS' CONCEPTIONS

In the midst of the misconceptions paradigm, Smith *et al.* (1993) published what is now considered a seminal paper arguing on theoretical grounds that the misconceptions perspective contradicts the very premises of constructivism: "Constructivism asserts that prior knowledge is the primary resource for acquiring new knowledge, but misconceptions research has failed to provide any account of productive prior ideas for learning expert concepts and has overemphasized the discontinuity between novice and expert" (p. 151). The authors stressed that the central tenets of constructivism emphasize the foundational role of prior knowledge in learning, and students learn by transforming and refining their prior knowledge into more sophisticated forms. Learning, from this perspective, is *not* the replacement of one concept or idea with another, but instead is a slow refinement of existing knowledge with relatively stable intermediate states of understanding preceding conceptual mastery. In their much-cited paper (cited more than 750 times as of this writing), Smith and colleagues argue that, although the empirical findings of the misconceptions research is valid and valuable, the assumptions about learning that underlie the misconceptions perspective conflict with the fundamental principles of constructivism. In short, if learning is the process of adapting prior knowledge, and misconceptions are viewed as unproductive and must be replaced during instruction, then what would students use as resources for building more sophisticated scientific understandings?

Smith *et al.* (1993) used data on students' conceptions in mathematics and physics to refute the notion that misconceptions are not useful or productive for learning. Through interview transcript excerpts, they demonstrated that when novices and experts consider the same phenomenon, the form and content of their knowledge share many common features: "Expert reasoning centrally involves prior, intuitive knowledge that has been reused or refined" (p. 152). Using explanations of phenomena such as how a bicycle frame is supported, or how the forces on small and large carts interact, Smith and colleagues showed that novices can exhibit expert-like behavior in explaining how a complex but familiar physical

system works. They illustrated that prior knowledge plays a role in scientific expertise by 1) providing raw material for formulating scientific theory, 2) supporting qualitative reasoning, and 3) mapping everyday situations to theoretical representations. Through their numerous examples, they demonstrated that students' conceptions are akin to complex clusters of related ideas rather than separable independent units, and replacement would not be plausible as a learning process. They argued that the mere addition of new expert knowledge and the deletion of faulty misconceptions oversimplifies the change involved in learning novel subject matter. Further support for their claim that learning processes are much more complex than replacement suggests comes from other studies showing that misconceptions once thought to be erased will often reappear (Bransford *et al.*, 1999). Bransford and colleagues argue instead that educators and researchers should highlight the useful and productive aspects of students' science conceptions in addition to their limitations.

Smith *et al.* (1993) and others (e.g., Hammer, 1996) showed that students' initial or naive ideas were valuable resources for developing more sophisticated scientific understanding in physics. We extend this claim to biology and offer a few brief examples in support. First, many of the current college-level "conceptions studies" in biology focus on understanding of evolution and natural selection (Anderson *et al.*, 2002; Hokayem and BouJaoude, 2008; Nehm and Schonfeld, 2008; Abraham *et al.*, 2012; Andrews *et al.*, 2012; Kalinowski *et al.*, 2012). Two common "misconceptions" are: 1) Natural selection involves organisms *trying to adapt*. 2) Natural selection gives organisms *what they need* (University of California–Berkeley's Understanding Evolution project at http://evolution.berkeley.edu/evolibrary/misconceptions_faq.php#b1). These conceptions are considered biologically incorrect because the adaptation of species over time does not involve effort, want, or need. Natural selection acts upon the genetic variation in a population in which some variants may be able to leave more offspring in the next generation than others. Although intention and need do not play a role in the process of natural selection, the reasoning underlying this misconception is a logical extension of what we experience in our own personal lives. To illustrate, consider a situation in which an individual desires to become a better insurance salesperson. If the individual in question recognizes that he or she needs to improve his or her interpersonal skills to achieve this goal, he or she might opt to take a business course that focuses specifically on enhancing that skill set. In this example, the need to better the individual's career is the impetus for change. A student holding the conception that need or want plays a role in evolution can be seen as overgeneralizing his or her personal human experiences to other living organisms, as well as incorrectly thinking that evolutionary processes are driven by need.

The foundation for understanding that some organisms with favorable traits will outsurvive others emerges from the idea that there are favorable and unfavorable traits that affect survival. The student's statement that an organism tries or needs to adapt carries with it the accurate understanding that particular characteristics of organisms allow them to survive longer than others. Thus, the initial idea that beneficial characteristics lead to the prolonging of life for some individuals in a population can provide a valuable foundation upon which to build. Appropriate instruction can help the

student refine that knowledge to include an awareness that individual organisms cannot evolve, but that the frequency of traits in a population are what evolves. We are not trying to argue that the student's ideas about need or want are correct; rather, we contend that the learner's initial naïve idea includes a productive component—specifically, beneficial traits promote survival—that can be emphasized and built upon during instruction. The instructor would clarify with his or her students that needs or wants is an overgeneralization from our own human experiences and would emphasize the role of randomness in evolutionary processes (Coley and Tanner, 2012). Because the concepts of need and want are applicable in our own lives, it is not possible or practical to “eradicate” the idea from the student's mind. Instead, we need to help the learner refine or limit his or her application of that idea.

The second illustrative example examines incorrect conceptions about ecosystems, which are prevalent in many students' explanations. When asked how an ecosystem functions, students frequently refer to “the circle of life” and explain how organisms will cooperate by not giving or taking too much from the system, resulting in an eventual “balance” (Maskiewicz, 2006a; Mohan *et al.*, 2009). A misconceptions approach would suggest that the student has to replace the idea of cooperation among all living organisms with the scientific understanding of selfish pursuits for survival. Yet the students' initial ideas about something “circling” or cycling in an ecosystem provide a valuable foundation for learning about the cycling of matter (Maskiewicz, 2006b). As such, this incorrect idea should not be viewed as *interfering* with learning, but rather as a resource for helping the students begin to think about the transformation of matter in ecosystems. Similarly, within the context of decomposition, many students explain that carbon from a decomposing organism enters the soil (Hartley *et al.*, 2011). Although soil carbon does increase, at least initially, when something dies and begins to break down, the subsequent process of decomposition releases carbon dioxide into the air. The students' initial idea that carbon is cycling from one molecular form to another during decomposition is a productive idea that can be used to form a scientific understanding of the process of decomposition. This pedagogical approach of building on students' initial naïve ideas has been described by many learning sciences researchers (Vosniadou and Brewer, 1992; Clement, 1993; Hammer, 2000; Duit and Treagust, 2003).

THE USE OF THE TERM MISCONCEPTIONS IN CURRENT BER LITERATURE

The brief examples noted above demonstrate that a student's incorrect biology conceptions can provide a rich foundation for building scientifically accurate conceptions. In fact, studies have shown that students may shift from one incorrect conception to another before developing scientific understanding, and such shifts can be viewed as initial steps in meaningful learning (Sadler, 1998). As a result of findings such as these, the learning sciences community began to associate the term misconception with outdated assumptions about learning that include eradicating incorrect ideas and replacing them with new ones. Today, the learning sciences literature rarely uses the term misconceptions. In contrast, misconceptions is still pervasive in the BER literature, is

oftentimes undefined, and in some cases still represents a replacement view of student learning. The following summary of misconceptions within our literature is intended to help educate our community about differences in our use and meaning of the term.

To better characterize the various ways in which the BER community utilizes the term misconception, we engaged in a review of articles, essays, and features (heretofore collectively considered as “articles”) published in *CBE—Life Sciences Education* during a 3-yr period (2010–2012). After narrowing our review to include only those articles that 1) used the term in the title and/or body of the paper, 2) were not book and/or research reviews, and 3) specifically used the term to refer to a scientific phenomenon (rather than a social and/or other scenario, such as classroom behavior), we were left with 41 articles (accessed 15 October 2012). Further examination of these articles revealed a lack of consistency both within a paper and among multiple papers when using the term.

Many of the articles reviewed did not clearly define the term misconception, nor did the authors provide any explanation as to how misconceptions related to a theory of learning. Instead, the word was used once or twice without discussion or elaboration; the reader was left to interpret the meaning of the word via the context in which it was used. The lack of common meaning of the term is noteworthy, in that the manner in which the authors define misconceptions has direct bearing on how they perceive and enact relevant instructional strategies. In some of these articles, the authors seemed to equate misconception with the more traditionally accepted definition of a deeply held conception that is contrary to scientific dogma (Baumler *et al.*, 2012; Cox-Paulson *et al.*, 2012; Crowther, 2012). Others, in contrast, seemed to use the term to reflect an ad hoc mistake or error in student understanding, one that exists prior to or emerges through instruction but, in either case, is not robust, nor does it interfere with learning (Jenkinson and McGill, 2011; Klisch *et al.*, 2012). The authors who considered misconceptions to be “deeply rooted” spoke of instructional strategies designed to specifically elicit, confront, and replace students' incorrect conceptions (i.e., Crowther, 2012). In contrast, authors for whom misconceptions were more tentatively held and/or emergent, suggested that students' incorrect ideas can be amended through tailored instruction grounded in those ideas (i.e., Klisch *et al.*, 2012). This latter perspective on learning is consistent with approaches supported by recent research in the learning sciences community (Carpenter *et al.*, 1989; Ruiz-Primo and Furtak, 2007; Pierson, 2008).

While some of the *LSE* authors used misconception in passing, without defining its use, others made a distinct effort to articulate how they conceptualized the term and, in some cases, openly acknowledged the lack of consensus regarding its meaning (Fisher *et al.*, 2011; Andrews *et al.*, 2012). Andrews and her colleagues (2012), for example, defined a misconception as “a scientifically inaccurate idea about a scientific concept” that “may occur before and after instruction” (pp. 249–250). They also recognized that others in the field had used more restrictive definitions in other studies. Fisher *et al.* (2011) characterized misconceptions as “scientifically inaccurate understandings that students have developed about natural phenomena,” while simultaneously suggesting there could be additional and possibly “more appropriate” ways to represent students' erroneous ideas (pp. 418–419).

Still other authors moved beyond definitions and attempted to connect the term with specific theoretical perspectives on learning (Kalinowski *et al.*, 2010; Stanger-Hall *et al.*, 2010; Tanner, 2010; Andrews *et al.*, 2011; Coley and Tanner, 2012). These authors tended to connect the term with the theoretical perspective of constructivism, most often citing Piaget (1950, as cited in Tanner, 2010; 1971, as cited in Stanger-Hall *et al.*, 2010; 1973, as cited in Andrews *et al.*, 2011; 1978, as cited in Kalinowski *et al.*, 2010); and/or Vygotsky (1978, as cited in Tanner, 2010; Andrews *et al.*, 2011). We commend the BER authors who have grounded their usage of misconception within a theory of learning, yet we caution that drawing upon a theoretical perspective is not necessarily sufficient. Science educators and learning scientists have previously shown that if constructivism is to be taken at its root, then student ideas, both those that are accurate and those that are erroneous, must be seen as components of future understandings. When biology education researchers refer to students constructing new ideas and integrating new ideas with old ones, while concurrently describing students' erroneous ideas as those to be “challenged” and “replaced,” they are demonstrating a misunderstanding of constructivist tenets.

CONCLUSION

Our call from our SABER leaders to move the BER community into its second generation of research means that we must engage in “disciplinary border crossing” (Coley and Tanner, 2012) and build on the existing literature on how people learn. Just as our biology research begins with a theoretical perspective and builds on existing studies, we must conduct our education research with the same standards. There exist many learning theories from which one can base educational research (e.g., constructivism, situated cognition, socioculturalism, and distributed cognition). Each of these theories recognizes and acknowledges the valuable role of students' naïve conceptions in the formation of scientific understandings.

The student misconceptions research from the 1990s and beyond has provided valuable insights into student thinking by revealing the underlying conceptual sense of student errors. These studies have not only advanced the field of education research but have also been essential in informing instructional strategies that promote student understanding. Within the community of learning sciences, however, misconceptions *are* yesterday's news, because the term has been aligned with eradication and/or replacement of conceptions, and the scientific knowledge about how people learn has progressed past this idea. We propose that the BER community acknowledge that, although students do still have incorrect conceptions in biology, these conceptions are the foundation for future knowledge and can be viewed as such. Because a replacement view of learning harkens back to an outdated model of learning, we suggest it should no longer be a part of our dialogue. Just as biologists no longer use obsolete models to explain concepts (e.g., the sandwich model is no longer an accurate way to portray the cell membrane), the term misconception has become associated with a model of student learning that is outdated. While some in the community may disagree with our critique of the term and/or our proposal

to move beyond it, we believe that BER should maintain the same level of respect for the existing learning sciences literature that we extend to biology field or bench research. Further, we should not dismiss this issue as “just jargon.” Our backgrounds in science should demand that we recognize the importance of precision in our employment of terms, allowing the field of BER as a whole to advance.

In light of our discussion, the question remains as to how we should best refer to students' incorrect ideas. In response to this, many researchers have already proposed alternatives and defined their meanings, including: preconceptions (Clement, 1993), naïve conceptions (Fisher and Moody, 2002), naïve ideas (Nehm and Ha, 2011), alternative conceptions (Wandersee *et al.*, 1994; Abraham *et al.* 2012), and commonsense conceptions (Chi, 2005). We conclude by advocating that biology education researchers use one or more of these appropriate alternatives in place of misconception whenever possible. Otherwise, we caution researchers to explicitly define their use of the term misconception, link it to a theory of learning when possible, and take into consideration how their use of the term necessarily informs their pedagogical approach. Without linking our research to current theories of learning, we can potentially misidentify the problem (e.g., incorrect ideas have no value or interfere with learning), and thus our pedagogical solution may not be effective (e.g., erase and replace). Rather than encouraging us to “challenge and replace,” current theories on how people learn guide us to design learning activities that “identify and refine” students' naïve ideas.

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