Chapter 67
Constructivism and Realism: Dueling Paradigms

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If anyone can show that a particular scientist is right, it is that scientist … If anyone can show that you are mistaken, it is your opponents.

(Hull 1988, p. 348)

…'paradigms'. These I take to be universally recognized scientific achievements that for a time provide model problems and solutions to a community of practitioners.

(Kuhn 1970, p. viii)

In general, skepticism takes the form of a request or justification of … knowledge claims, together with a statement of the reason motivating that request.

(Grayling 1996)

To be vibrant is to be "pulsating with life, vigor, or activity" (Mish 2003). Science education, like science, is a vibrant discipline. It pulsates due to competition among individuals and groups holding disparate views, as portrayed above (Hull 1988). One source of pulsation is the question: Can we justify that anything we know represents some aspect of reality? My purpose herein is to review an on-going dialectical discussion between communities of scholars that hold different views about whether or not knowledge represents reality, the nature of knowledge, and the process of coming to know. The adversaries, realism and constructivism, constitute different paradigms (Kuhn 1970) or models for characterizing knowledge and the

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process of coming to know, for conducting research, and for recommending best practices in teaching and learning science.

To achieve my purpose, I will take five steps: (1) define and describe knowledge; (2) describe realism, constructivism, and truth; (3) cite points of divergence, convergence, and peaceful coexistence; (4) review the key issue over which realism and constructivism collide from a constructivist perspective; and (5) offer a closing thought.

Knowledge

Merriam-Webster's Collegiate Dictionary (Mish 2003) defines knowledge as: "the circumstance or condition of apprehending truth or fact through reasoning" (p. 691). Scholarly study of the nature of knowledge and its justification is called epistemology and includes three components: features that define knowledge; conditions or sources of knowledge; and the limits of knowledge and its justification (Audi 1999). The history of epistemology extends back to the ancient Greeks and before, and the rich, diverse landscape of issues set forth and argued throughout its history prohibit any attempt herein to represent them; therefore, I return to the question stated above in order to introduce the protagonists in this paradigmatic debate.

Realism, Constructivism, and Truth

Realism

Three broad categories of answers to the question "Can we justify that anything we know represents some aspect of reality?" exist: "Yes"; "no"; and "withhold judgment." Idealists respond "no" agnostics reply "withhold judgment"; realists say "yes." Idealists and agnostics typically employ epistemological skepticism as portrayed in the introductory quotation (Grayling 1996) in making their choices. I do not imply here that practicing scientists who are realists do not employ skepticism in their work. They do, but the context of scientific skepticism focuses on whether or not the theoretical frameworks explain the natural phenomena studied, not whether or not the theoretical knowledge represents the natural world as it is.

Realism is the time honored philosophical position that a world exists a priori, external to, separate from, and independent of human consciousness, which also exists a priori. Realism is a theory of ontology, of reality's existence. Scientific realists argue that we come to know this world as it is, albeit imperfectly, through science. Assuming that reality exists and is comprehensible, science as a way of knowing begins with common sense and embraces realism through the generation of knowledge about empirical objects and events – natural phenomena – that are primarily independent of scientific theory. Because the methods of science are not without error and its knowledge claims are approximate, scientists feel warranted in approving the strongest findings of science as knowledge that represents these objects and events in reality (e.g. Gauch 2003).

Truth

Realism, the view that reality exists, and truth as a representation of reality are not identical. When we say that knowledge represents reality, we say that:

> … these representations, such as beliefs and statements, purport to be about and to represent how things are in reality. To the extent that they succeed or fail, they are said to be true or false, respectively. They are true if and only if they correspond to the facts in reality. This is (a version of) the correspondence theory of truth. (Searle 1995, p. 151)

Truth as correspondence is not implied by realism because no name is specified for the relation between knowledge and reality. Other truth theories can be used within a realist perspective. Truth as correspondence, however, does imply realism because any true knowledge claim must correspond with its object, which is reality (Searle 1995).

Truth as correspondence is the venerable theory of truth in epistemology. There exists, however, another, more recent theory of truth, called truth as coherence. Knowledge is coherently true when its various assembled components hold together in relation to each other, thereby forming a consistent or coherent network.

Constructivism

Constructivism is a diverse school of epistemological thought, with two dominant strands, radical/psychological and social constructivism. Today's radical and social constructivist views are descended from somewhat different sources. Regarding radical constructivism, the Italian philosopher Giambattista Vico (1668–1744), who labored to distinguish mysticism from rationality, was the first scholar to set forth the notion that humans actively construct rational knowledge (Glasersfeld 1995). That humans actively construct knowledge is a foundational element of all constructivist theory. Immanuel Kant's (1724–1804) idealism (e.g., Kant 1995) contains this element, the concept of space and time as structures in the human mind, and other notions, thereby making important constructivist contributions a century later. The trail of Kant's ideas to radical constructivism in modern science education leads to Jean Piaget (1896–1980) and Ernst von Glasersfeld. Piaget's genetic epistemology (e.g., Piaget 1970) describes the individual's active internal formulation and pragmatic characterization of knowledge as a higher function of the biological processes of assimilation and accommodation. Glasersfeld (e.g., 1995) articulates radical constructivism as an epistemology, the root paradox as the point of collision between constructivism and realism, and a history of constructivist concepts and scholars.

Radical constructivism, in contrast with realism, does not assume the existence of external reality a priori. Advocates of radical constructivism are sometimes labeled as solipsists, but radical/psychological constructivism should be viewed as an escape from solipsism. Readers who seek to know the details of such an escape should consult Foerster (1984) or Staver (1998).

Radical constructivism contains four core assertions. First, an individual does not receive knowledge from external sources through the senses or via communication with others; rather, a person actively and internally builds up knowledge. Second, whereas others do not pass their knowledge to an individual, social interaction with others is a core element in an individual's active, internal construction of knowledge. Third, individual cognition is functional and adaptive in a biological context; functional refers to the notions of fit and viability, and adaptive refers to evolution. Fourth, the purpose of cognition is not to understand reality as it is; rather, the purpose is to organize an individual's experiences, thereby increasing the coherent understanding of an individual's experiential world. Radical/psychological constructivism embraces a coherence theory of truth (Glasersfeld 1995).

Social constructivism in today's science education is a blend of three sub-types. One stream flows from Kant and Kuhn, describing scientific work as influenced by a quasi-metaphysical causal structure based in the dominant paradigm; a second is tied to the concept of science as a social process that is vulnerable to factors that influence all social processes; the third is the strong program in the sociology of scientific knowledge, in which social power relations in the broad community and the scientific community largely or exclusively determine scientific knowledge (Boyd 2002). Social constructivism contains three core assertions. First, humans are able to develop meaning in language because their social interdependence serves as the channel for such development. Second, language occurs within a context of social interdependence; therefore, its meaning is dependent on this context. Third, the function of language is primarily communal, in that it serves as the conduit for establishing and maintaining relationships among the individuals within and across communities (e.g., Gergen 1995). Social constructivism, like radical constructivism, embraces a coherence theory of truth.

Points of Convergence and Divergence Between Radical and Social Constructivism

The principal point of divergence between radical/psychological and social constructivism lies in their respective foci. Social constructivism is an epistemological model for using language to study the making of meaning in groups. Radical constructivism, on the other hand, is an epistemological model for examining cognition in an individual as he or she makes meaning of experiences. Psychological and social constructivism also share much in common beyond their conception of truth as coherence. Their principles, introduced above, can be integrated as follows:

> First, knowledge is actively built up from within by each member of a community and by a community itself … Second, social interactions between and among individuals in a variety of community, societal, and cultural settings are central to the building of knowledge by individuals as well as the building of knowledge by communities, societies, and cultures. Third, the character of cognition and a language, which is employed to express cognition is functional and adaptive. Fourth, the purpose of cognition and language is to bring coherence to an individual's world of experience and a community's knowledge base, respectively. (Staver 1998, pp. 504–505)

Lev Vygotsky (1896–1934), the Russian psychologist who coined the term "zone of proximal development," did seminal work on the social character of human cognition. Vygotsky's work was largely unavailable in the West during his working years, yet he is perhaps the exemplar of a scholar who worked at the intersection of psychological and social constructivism (Kozulin 1990).

Constructivism and Realism: Points of Peaceful Coexistence

Before describing the competition between constructivist and realist views in science education, I think it is well worth noting areas in which little or no competition exists.

In their report on how learners learn, Bransford et al. (2000) characterize paradigmatic changes in research on the human mind: "a new theory of learning is coming into focus that leads to very different approaches to the design of curriculum, teaching, and assessment than those often found in schools today" (p. 3). Also referring to the new model as a "new science of learning" (p. 9), Bransford et al. present research-based summaries on how students learn, and set forth implications for teaching and classroom learning environments. Among the points made about learning are: "… its emphasis on learning with understanding" (p. 8) and "…its focus on the processes of knowing" (e.g., Piaget 1978; Vygotsky 1978). Moreover, "In the most general sense, the contemporary view of learning is that people construct new knowledge and understandings based on what they already know and believe" (p. 10). This quotation contains five citations of Piaget's work and two citations of Vygotsky's work. With respect to teaching, Bransford et al. assert: "the teaching of metacognitive skills should be integrated into the curriculum in a variety of subject areas" (p. 21). Regarding learning environments, "Schools and classrooms must be learner centered" (p. 23). Whereas their personal epistemological views are unknown to me, Bransford et al.'s discussions of how students learn, implications for teaching, and learning environments are consistent with implications of constructivist epistemology. I take this as an indication that constructivist epistemology, while perhaps not representing the dominant epistemological view in the development of a new science of learning, has nonetheless served as an influential contributor. Moreover, employing "constructivism as a referent for teaching and learning" (Tobin and Tippins 1993, p. 3) has gained acceptance, even respect, among researchers and scholars in science education as well as among P-12 teachers of science. Additional early indications of such acceptance were provided by constructivism's critics (e.g., Matthews, 1992; Osborne, 1996; Phillips, 1995) who:

> … acknowledge its contributions such as: (a) moving epistemological issues into the foreground in discussions of learning and curriculum; (b) providing empirical data to enhance our knowledge of difficulties in learning science; (c) fostering the development of innovative methods of science teaching; and (d) increasing our awareness of learners. (Staver 1998, p. 501)

In the last 15 years or so, terms such as "constructivist learning environment," "constructivist teaching," "constructivist learning," and "constructivist curriculum" (occasionally the term "student-centered" is substituted) have become acceptable in the practice literature, but less so in the research and scholarly literature of science education. Regarding the reason, my working hypothesis is that practitioners and administrators in the K-12 sector do not yet understand that constructivism and realism are epistemological models with implications for teaching, learning and learning environments, not learning, instructional, or learning environment models.

Constructivism and Realism: The Point of Collision

Despite the agreements discussed above, constructivists and realists remain deeply divided over the question: Can we justify that anything we know represents some aspect of reality? My brief synopsis of the current state of the conflict is based on Boyd (2002) and Ladyman (2007). Readers will notice that I present the issue in the context of science, not science education. Science itself has historically embraced realism, and science education has followed the lead of science, which represents the more difficult domain.

Scientific realists take the position that unobservable entities predicted and described by science's strongest theoretical frameworks exist. The strongest argument in support of scientific realism is known as the no-miracles argument, which holds that science's success rests on the condition that scientific theories are at least approximately true explanations and predictions of reality. If this condition were false, then science's success as a way of knowing would be miraculous.

A new form of realism, called structural realism (Worrall 1989), attempts to represent the strengths of each adversary while simultaneously avoiding each competitor's weaknesses. Structural realism does not accept scientific realism, with its acceptance that the strongest theories explain and predict the nature of unobservable entities that are the source of observable natural phenomena. Simultaneously, structural realism does not take antirealist views about science. Instead, structural realism advocates an epistemic commitment only to the mathematical and structural concepts of scientific theory. Such a commitment recognizes structural retention throughout changes in theory, dodges the continuing theory change argument, and denies the characterization of science as a miraculous enterprise.

On the other hand, skeptics stand behind the under-determination argument and an argument based on continuing radical change in theoretical frameworks over the course of the history of science. The under-determination argument holds that any competing theory can be demonstrated to be equally empirically adequate to its competitors with respect to observable phenomena, but evidence concerning any competing theory's explanations and predictions of unobservable phenomena is impossible. Consequently, making a decision between empirically equivalent, competing scientific knowledge of theoretical entities is under-determined, even in the presence of all possible observable data. The under-determination argument is effective only when it is applied to large-scale scientific conceptions of reality.

The second skeptical argument contemplates the history of science, portraying it as a theoretical graveyard, with past theories that insufficiently explained and predicted natural phenomena, and were subsequently replaced by new theories. Given this lengthy, rich history of theoretical abandonment, we should expect that current scientific theories will be left behind; thus, we should not think they reflect reality.

Scholars from other fields as well philosophers throughout history have voiced skepticism in a variety of contexts, all of them controversial. Let us consider three examples. First, linguists view language and thought as closely related; however, much controversy exists with respect to the nature of the relationship. The Sapir-Whorf hypothesis sets forth two relations: Linguistic relativity – language shapes culture – and linguistic determinism – language influences thought. The strength of each aspect of the relation and their relative strength with respect to each other remain hotly debated issues nearly eighty years after Sapir and Whorf first asserted that:

> Human beings do not live in the objective world alone, nor alone in the world of social activity as ordinarily understood, but are very much at the mercy of the particular language which has become the medium of expression for their society. It is quite an illusion to imagine that one adjusts to reality essentially without the use of language and that language is merely an incidental means of solving specific problems of communication and reflection. The fact of the matter is that the 'real world' is to a large extent unconsciously built upon the language habits of the group. No two languages are ever sufficiently similar to be considered as representing the same social reality. The worlds in which different societies live are distinct worlds, not merely the same world with different labels attached … We see and hear and otherwise experience very largely as we do because the language habits of our community predispose certain choices of interpretation. (Sapir 1958 [1929] p. 69)

Second, space and time are two fundamental concepts that humans use to interpret experience; however, where do space and time reside?

> Space and time are sensible objects in appearance, not representations of an object *in itself*. It is the coordination of the manifold of intuition under one concept of empirical representation, insofar as both are made by the subject, rather than given to it, and the latter presents itself and constitutes an absolute whole. (Kant 1995, p. 176)

Third, the problem of the criterion; this paradox ranks among the most important and difficult problems in philosophy:

> To know whether things really are as they seem to be, we must have a *procedure* for distinguishing appearances that are true from appearances that are false. But to know whether our procedure is a good procedure, we have to know whether it really *succeeds* in distinguishing appearances that are true from appearances that are false. And we cannot know whether it does really succeed unless we already know which appearances are *true* and which ones are *false*. And so we are caught in a circle. (Chisholm 2002, p. 590).

In an earlier publication, I presented a case for constructivist epistemology as sound theory for explaining the practice of science and science teaching. My argument was based primarily on epistemological concepts – truth, rejection of solipsism, experience, instrumentalism, and relativity (Staver 1998). I will say nothing further herein about the rejection of solipsism, and instrumentalism. I am deeply skeptical that further epistemological discussions will resolve any or all of the above-mentioned problems, yet I am cautiously hopeful that science itself holds promise to further our understanding of these problems. My earlier discussion on experience and relativity included a scientific as well as an epistemological perspective; therefore, I will focus herein on additional scientific information about experience, specifically about consciousness as the source of experience and vision as a specific aspect. This information is based on an article published in *Cultural Studies in Science Education* (Staver 2010). I begin with consciousness.

Consciousness

Consciousness is composed of two categories of awareness, primary and higher order: "Primary consciousness is the state of being mentally aware of things in the world, of having mental images of the present… higher order consciousness involves the ability to be conscious of being conscious" (Edelman 2004, p. 9). Scientific work on human consciousness and on *homo sapiens* as a species descended from simpler forms of life is conducted under the auspices of evolutionary theory. The human brain's ability to portray nature in divergent and viable ways is the product of heritable variation and natural selection (Changeaux 2004). Human consciousness and cognitive function are emergent capacities of the electrical and biochemical activity and biological architecture of the human brain (Edelman 2004).

Applying evolutionary theory to consciousness as a phenotypic property of a living entity raises a fundamental question: Do consciousness and the capacity for cognitive function and knowledge as emergent properties of the brain's activity confer on humans the capacity to know nature as it is or to survive and thrive better in nature through our capacity to organize our experiences better than our evolutionary relatives who also exhibit consciousness? Humans' nearest living evolutionary relatives are the great apes, and more than 90% of our genomes are identical. Among the great apes, our closest living evolutionary relative is the chimpanzee; these two sets of genomes are about 96% identical. Exhibiting consciousness, does a chimpanzee construct knowledge that corresponds to nature as it is, or does a chimpanzee construct knowledge that helps it succeed by organizing its experiences? If the answers to these questions are no and yes, respectively, then how should we respond with respect to humans?

Vision

Normal humans use five senses; we see, hear, smell, touch, and taste to interact with a world external to, separate from, and independent of our consciousness. Because vision dominates the other senses and because vision, more than the others, appears to permit humans to see nature as it is, a brief look at research on vision is appropriate.

Regarding the question posed above, two vision scientists write: "What, then, is wrong with the seemingly sensible idea that the purpose of vision is to perceive the world as it is and that this obviously beneficial goal is achieved by neuronal hardware that detects the elemental features of the retinal image and, from these, reconstructs a representation of the external world according to a set of more or less logical rules instantiated in visual processing circuitry" (Purves and Lotto 2003, p. 5)? Their answer is that "the sources of any retinal stimulus (and thus its significance for subsequent action) are unknowable directly" (p. 5), and "the retinal image also conflates the arrangement of the underlying objects in space" (p. 5). Last, they offer a caution: "Rather, the discrepancies between retinal images and the related percepts ('illusions') are the signature of an empirical strategy of vision in which percepts are neither correct nor incorrect representations of reality but simply a consequence of having incorporated into visual processing the statistics of visual success or failure in phylogenetic and ontogenetic experience" (p. 15). These assertions converge on Foerster's (1984) principle of undifferentiated encoding, that a surface nerve cell's response is to encode only how much stimulus it receives, not the physical nature of the source of the stimulus.

Quantum Mechanics

At a fundamental level, individual surface receptor neurons, when sufficiently stimulated, send electrical signals along nerve pathways to the brain, where more electromagnetic, biochemical activity occurs in complex neural networks. Quantum mechanics explains such electromagnetic activity at a foundational level. Quantum mechanics predicts as well or better than any theoretical framework in the history of science. No prediction of quantum mechanics has been demonstrated by experiment to be incorrect, and the theoretical bedrock of about one-third of our economy is quantum mechanics. Modern technology that uses transistors, lasers, and nuclear magnetic resonance is built on a quantum mechanical platform (e.g., Rosenblum and Kuttner 2006).

Despite its superlative predictive record and extensive practical applications, quantum mechanics remains a controversial theory because it ultimately connects the well-defined discipline of physics with the ill-defined concept of consciousness. (A full treatment of this controversy is well beyond the scope of this essay. Readers seeking largely non-mathematical discussions may consult Hey and Walters (2003), Rae (2004), or Rosenblum and Kuttner (2006)). Specifically, the results of quantum experiments present an enigma about the nature of reality that challenges our common sense foundation of scientific inquiry and humans' classical view of the world in terms of realism. In brief, the enigma is "…observation creates the reality observed" (Rosenblum and Kuttner 2006, p. 99). Regarding common sense "is it not just common sense that one object cannot be in two distant places at once? And, surely, what happens here is not affected by what happens at the same time someplace very far away. And does it not go without saying that there is a real world "out there," whether or not we look at it? Quantum mechanics challenges each of these intuitions by having (conscious) observation actually *create* the physical reality observed" (Rosenblum and Kuttner 2006, pp. 3–4). Moreover, these challenges are well documented by experimental results, which show that one object can be in two distant places at once, events here can be affected by simultaneous events at great distances, and conscious observation creates reality.

Quantum mechanics was founded, defined, and described by Planck, Einstein, Born, Heisenberg, Bohr, de Broglie, Schrödinger and others during the first part of the twentieth century. Einstein, Schrödinger, and others verbalized their discomfort with the implications of quantum theory. Bohr, Heisenberg, and their colleagues developed the Copenhagen interpretation, which competed with other interpretations and won the support of most physicists in the early twentieth century because it allowed them to ignore the concept of a conscious observer influencing the nature of reality beyond the level of microscopic entities. Others, as did Schrödinger, asserted that we should listen because nature is sending us a message: "The urge to find a way out of this impasse ought not to be dampened by the fear of incurring the wise rationalists' mockery" (Erwin Shrödinger, quoted in Rosenblum and Kuttner 2006, p. 202).

A Final Thought

Knowledge constructed through research is considered stronger when it is supported via multiple, independent lines of evidence. As researchers, we routinely demand that research include multiple, independent lines of evidence, and our skepticism diminishes only when empirical results from independent lines of evidence support theoretical explanations and predictions. Nearly a century and a half after Darwin first published his research, evolution remains the single unifying theoretical framework across the broad expanse of the life sciences because scientific evidence in several areas within the life sciences as well as from astrophysics, geology, physics, chemistry, and anthropology continues to provide support for evolution's explanations and predictions (National Academy of Sciences and Institute of Medicine 2008).

Competition between realism and constructivism hinges on three points: the purpose of experience; the subjectivity of experience; and the absence of lines of evidence independent of experience. Evolution tells us that we make meaning of experience to survive and thrive in our experiential world. Quantum mechanics reminds us that we have the capacity as conscious beings to create the reality that we observe. The root paradox and the problem of the criterion point out to us the absence of evidence that is independent of experience. Humans possess one and only one connection – experience – with a world external to, separate from, and independent of our consciousness. Whereas multiple lines of evidence within experience are the empirical foundation of strong scientific theories, constructivists continue to withhold judgment as to whether knowledge represents reality until knowledge completely independent of human experience can be cited in support of a knowledge claim. Given these three points, it seems rather ironic that such an argument occurs.

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