

Language Ambiguities in Education Research*†

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Language ambiguities hinder development of education research and sometimes misrepresent its findings to both the education community and the general public. For example, in 2004 Klahr & Nigam demonstrated the superiority of what *they defined* as “direct instruction” over what *they defined* as “discovery learning.” But their research was widely misinterpreted as showing that “direct instruction” *in all its various forms* was superior to “discovery learning” *in all its various forms*. Then, in 2006, Kirschner, Sweller, & Clark (KSC) not only reinforced that misconception, but also added to the general misunderstanding by identifying constructivist, discovery, problem-based, experiential, and inquiry-based teaching methods as all “minimally guided,” and proclaiming all of them to be failures. But KSC’s conception of constructivist teaching appears limited – the “knowledge-based constructivism” of Resnick & Hall is *not* “minimally guided” and instructional methods consistent with it are *not* failures, as judged by the assessment literature. Nevertheless, KSC make strong arguments against the “minimally guided” instruction of “pure discovery learning,” even if language ambiguities may impede transmission of their arguments across interdisciplinary barriers. Such communication problems might be reduced if (quoting Klahr and Li) “those engaged in discussions about implications and applications of educational research focus on clearly defined instructional methods and procedures, rather than vague labels and outmoded ‘-isms.’ ”

I. Introduction

Education researchers attempt to apply the scientific method to teaching and learning in a large number of different disciplines. According to Shavelson & Towne (2002), among six guiding principles of scientific inquiry are #5 “Replicate and Generalize Across Studies, and #6 “Disclose Research to Encourage Professional Scrutiny and Critique.” Both these principles would be more easily facilitated if non-ambiguous language were utilized so that researchers concerned with different disciplines could communicate with one another, with the education community, and with the general public.

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An example of the confusion wrought by language ambiguity are the following apparently conflicting expert views regarding the limitation of short-term working memory (LSTWM): experts “A” pointing out that LSTWM accounts for the *superiority* of “direct instruction,” and expert “B” pointing out that LSTWM accounts for the *inferiority* of “direct instruction”:

(A) Cognitive scientists Kirschner, Sweller, and Clark (2006), in providing the rationale *for what they call* “direct instruction” write on page 77:

Working memory has two well-known characteristics: When processing novel information, it is very limited in duration and in capacity. We have known at least since Peterson and Peterson (1959) that almost all information stored in working memory and not rehearsed is lost within 30 sec and have known at least since Miller (1956) that the capacity of working memory is limited to only a very small number of elements. That number is about seven according to Miller, but may be as low as four, plus or minus one [see, e.g., Cowan (2001)]. Furthermore, when processing rather than merely storing information, it may be reasonable to conjecture that the number of items that can be processed may only be two or three, depending on the nature of the processing required.

(B) Physics education researcher Carl Wieman (2007), in his article “Why Not Try a Scientific Approach to Science Education?” writes [my insert at “. . . [insert]. . .”]

These results. . . [indicating the ineffectiveness of passive-student lectures – regarded by most PER’s as the exemplar of “direct instruction”]: . . . do indeed make a lot of sense and probably are generic, based on one of the most well-established - yet widely ignored-results of cognitive science: the extremely limited capacity of the short-term working memory. The research tells us that the human brain can hold a maximum of about seven different items in its short-term working memory and can process no more than about four ideas at once. Exactly what an “item” means when translated from the cognitive science lab into the classroom is a bit fuzzy. But the number of new items that students are expected to remember and process in the typical hour-long science lecture is vastly greater. So we should not be surprised to find that students are able to take away only a small fraction of what is presented to them in that format.

Of course, the above apparent conflict is resolved when it is realized that cognitive scientists Kirschner, Sweller, and Clark attach a totally different meaning to “direct instruction” – see Section IIB below - than does physics education researcher Carl Wieman – see Section III below. But what is the education community and the general public to make of seemingly diametrically opposed statements from the experts?

II. The Language of Education Research in Cognitive Science

A. Klahr & Nigam (2004)

In 2004, cognitive scientists David Klahr and Milena Nigam demonstrated the superiority of what *they defined* as “direct instruction” to what *they defined* as “discovery learning” in a widely publicized article titled “The equivalence of learning paths in early science instruction: effects of direct instruction and discovery learning” [Klahr & Nigam (2004)]. Although Klahr and Nigam were careful to operationally define their own very restricted meanings of “direct instruction” and “discovery learning,” their paper was widely presented in the media in ways that could be interpreted to imply that “direct instruction” *in all its various forms* was superior to “discovery learning” *in all its various forms*. For example:

- a. Rachel Adelson (2004) wrote in the American Psychological Association’s *Monitor On Psychology*:

In science, how is critical thinking best taught? This question may be answered. . . . [by Klahr & Nigam, who]. . . . have new evidence that “direct instruction”- explicit teaching about how to design unconfounded experiments - most effectively helps elementary school students transfer their mastery of this important aspect of the scientific method from one experiment to another.

- b. The American Association for the Advancement of Science in their *AAAS EurekAlert* (1998) stated:

Direct instruction using the Control of Variables Strategy, rather than discovery learning, may be the best way to teach young children about science, says a Carnegie Mellon psychologist who is conducting a four-year field study in public schools in Pittsburgh, Pa. The field study could lead to a new kind of science curriculum for elementary schools.

- c. Sharon Begley (2004a) wrote in the *Wall Street Journal*:

It is conventional wisdom in science education. . . . that the best way to give K-12 students a deep and enduring understanding is through “discovery learning” the teacher gives the kids a goal and the requisite materials and then tells them to go to it, with the hope that they will uncover principles such as Newton’s laws of motion. In contrast, using “direct instruction,” teachers explicitly present information to students. “The idea is that students who acquire knowledge on their own can apply it more broadly and extend it better than if they are told or shown that same knowledge,” says David Klahr of Carnegie Mellon University in Pittsburgh. To test this claim, he and a colleague compared how well the approaches taught 112 third- and fourth-graders a core scientific concept: To discover how one thing affects another, change only one variable at a time. . . . Students receiving direct instruction were explicitly told to change one property at a time and were given explanations. The discovery learners got neither. In both cases, the kids worked with ramps and balls, so everyone did hands-on science. The result: Not only did more kids master the control-of-variables lesson from direct instruction, but -- and this strikes at the heart of the claims for discovery learning -- the latter approach did not give kids a deeper, more enduring knowledge.

d. Sean Cavanagh (2004) wrote in *Education Week*:

The National Research Council is conducting a series of studies aimed at exploring topics such as the role of the laboratory in science classrooms and how states should assess students' knowledge in the subject. That renewed interest was also obvious with the release of a widely distributed study conducted by researchers at Carnegie Mellon University and the University of Pittsburgh, which was detailed at a national science “summit” sponsored by the U.S. Department of Education earlier this year. The study found that students taught through direct instruction were more likely on average to become “experts” in designing scientific experiments—an important step in the development of scientific-reasoning skills—than those taught through what is often called discovery learning. Moreover, the students who showed expertise in designing those experiments through direct instruction performed just as well as those who developed similar expertise through discovery paths on a separate test of their broader scientific judgment—countering some previous claims that direct instruction produces weaknesses in that area.

It is ironic that the sensational heading “Carnegie Mellon Researchers Say Direct Instruction, Rather Than ‘Discovery Learning’ Is Best Way To Teach Process Skills In Science” of the AAAS announcement “b” above, trumpeting the research of the *pro*-hands-on Klahr & Nigam (2004), merited a link on the virulently anti-reform *Mathematically Correct Science Center* website [MCSC (2008)], next to a link to the *anti*-hands-on testimony of California Curriculum Committee leader Stan Metzenberg (1998) before the U.S. House of Representatives.

Klahr & Li (2005), disturbed by the above reports, wrote [my insert at “. . . . [insert]. . . .”]:

Because of. . . [media reports such as the above]. . . others are concerned that our findings may be used to “conclude that direct instruction is the best way to teach science” [Tweed (2004)], to promote lecture-based passive learning [“Stand and deliver . . . or let them discover?” . . . [District Administration (2004)]. . . , and to equate our specification of discovery learning with the more moderate (and presumably, more often used) versions of guided or scaffolded inquiry. . . . we share the concern that our findings may be misinterpreted as evidence to promote one method over another for science education as a whole. . . we are (now!) mindful of the way in which our results can be used to support or attack specific aspects of science education practice and policy. . . . we may have muddied the interpretation of our findings by incorporating popular terminology like “direct instruction” and “discovery learning” into articles and public presentations of [Klahr & Nigam (2004)]. Only when we tuned in to the recent political debate in California about the permissible amounts of “hands-on science” vs. “direct instruction” [Strauss (2004); Hake (2004a, 2005b); Woolf (2005)]. . . . did we become fully aware of how easy it is for someone to pick up a terminology, and imbue it with whatever meaning suits the purpose of an argument. . . . One thing is clear from all of this: *it is essential for the field of education to make much more precise use of terminology before moving on to public debates and policy decisions.* [My italics.] Indeed, it is surprising that when education researchers and science educators join in heated debates about discovery learning, direct instruction, inquiry, hands-on, or minds-on, they usually abandon one of the foundations of science—the operational definition. ***The field of science cannot advance without clear, unambiguous, operationally defined, and replicable procedures. Education science is no exception.*** [My emphasis.]

The above concern of Klahr and Li was emphasized in “Will the No Child Left Behind Act Promote Direct Instruction of Science?” [Hake (2005b)]. There I listed the widespread misinterpretation of Klahr & Nigam (2004), as one of the seven reasons why direct science instruction (in the passive-student sense) might dominate K-12 science education under the aegis of the “No Child Left Behind Act.” More recently, Kirschner, Sweller, and Clark (2006) – Section IIB below - have added to the chorus proclaiming Klahr & Nigam’s endorsement of “direct instruction.”

BUT WAIT! What do Klahr & Nigam; Kirschner, Sweller, and Clark; and other education researchers, instructors, administrators, activists, and policy makers *mean* by “discovery learning,” and what do they *mean* by “direct instruction”? In criticisms [Hake (2004a, 2005b) of the California Curriculum Commission’s anti-hands-on “Criteria For Evaluating K-8 Science Instructional Materials In Preparation for the 2006 Adoption,” I opined that popular pedagogic terms such as “discovery learning,” “direct instruction,” “hands-on activities,” “active learning,” “cooperative learning,” “inquiry,” and “interactive engagement,” should be *operationally defined* [see, e.g. Holton & Brush (2001), Phillips (2000)], even despite the “antipositivistic vigilantes” [Phillips (2000), Phillips & Burbules (2000)]. More generally, rigorous operations should be defined for distinguishing pedagogic method X from other methods Y, Z, A, B, C, . . .

Although operational definitions are uncommon in the educational literature, in Hake (2004a) I indicated my own guesses as to what various groups have meant by “direct instruction”:

(a) *Mathematically Correct Science Corner*

<<http://mathematicallycorrect.com/science.htm>> : “drill and practice,” “non-hands-on,” “teach 'em the facts” [Metzenberg (1998)], and “non-discovery-learning,” where “discovery learning” means setting students adrift either in aimless play or ostensibly to discover on their own, say, Archimedes’ principle or Newton’s Second Law.

(b) *Physics Education Researchers*: traditional *passive-student* lectures, recipe labs, and algorithmic problem sets.

(c) *Klahr & Nigam* (2004): . . . instruction in which “the goals, the materials, the examples, the explanations, and the pace or instruction are all teacher controlled,” but in which *hands-on activities are featured*. At least this is Klahr & Nigam’s (KN’s) definition of what they call “*extreme* direct instruction” (extreme DI), possibly having in mind the reasonable idea of a continuum of methods from extreme DI to extreme “discovery learning” (DL). In extreme DL, according to Klahr & Nigam, there is “no teacher intervention beyond the suggestion of a learning objective: no guiding questions, and no feedback about the quality of the child’s selection of materials, explorations, or self assessments.” I suspect that Klahr & Nigam might classify “interactive engagement” methods (Hake (1998a,b; 2002b) and “inquiry methods” [NRC (1996, 1997, 1999, 2000), Donovan et al. (1999), Bransford et al. (2000), Donovan & Bransford (2005), Duschl et al. (2007)] as somewhere along a continuum ranging from extreme DI to extreme DL, since “interactive engagement” and “inquiry” methods both involve various degrees of judicious teacher intervention so as to guide students’ conceptual understanding, problem solving abilities, and process skills towards those of professionals in the field.

(d) *Association of Direct Instruction* [ADI (2004)]:

- (1) teaching by telling (as contrasted by teaching by implying), or
- (2) instructional techniques based on choral responses, homogeneous grouping, signals, and other proven instructional techniques, or
- (3) specific programs designed by Siegfried Engelmann and his staff.

Direct Instruction programs incorporate the above “2” coupled with carefully designed sequences, lesson scripting, as well as responses to anticipated children's questions as expounded in Englemann & Carnine (1982).

Thus the *interpretation* of Klahr and Nigam (2004) that “direct instruction” (*as defined by them*) is superior to “discovery learning” (*as defined by them*), while consistent with their research, appears to be a *misinterpretation* to physics education researchers (PER’s) if they use the PER definition of “direct instruction,” and are unaware of the Klahr and Nigam definitions of “direct instruction” and “discovery learning.” Thus there may be a *communication failure* due to language ambiguities.

B. Kirschner, Sweller, & Clark (2006)

Another example of ambiguous language in education research is provided by the previously mentioned paper of cognitive scientists Kirschner, Sweller, & Clark (KSC) (2006) with its seemingly non-sequitur title “Why Minimal Guidance During Instruction Does Not Work: An Analysis of the Failure of Constructivist, Discovery, Problem-Based, Experiential, and Inquiry-Based Teaching.” KSC reinforce the misinterpretation of Klahr & Nigam (2004) as demonstrating that “direct instruction” *in all its various forms* was superior to “discovery learning” *in all its various forms* with this passage (p. 79, lower right-hand column):

Klahr and Nigam (2004) in a very important study, not only tested whether science learners learned more via a discovery versus direct instruction route but also, once learning had occurred, whether the quality of learning differed. Specifically, they tested whether those who had learned through discovery were better able to transfer their learning to new contexts. The findings were unambiguous. Direct instruction involving considerable guidance, including examples, resulted in vastly more learning than discovery. Those relatively few students who learned via discovery showed no signs of superior quality of learning.

Here again, as with Klahr and Nigam (2004), “direct instruction” appears to mean to Kirschner, Sweller, & Clark (KSC) pedagogy rather similar in some respects to the “interactive engagement” methods shown to be relatively effective by physics education researchers, as can be seen from the KSC’s abstract [my insert at “. . . [insert]. . .”]:

Evidence for the superiority of guided instruction. . . [such as “interactive engagement”]. . . is explained in the context of our knowledge of human cognitive architecture, expert–novice differences, and cognitive load. Although unguided or minimally guided instructional approaches are very popular and intuitively appealing, the point is made that these approaches ignore both the structures that constitute human cognitive architecture and evidence from empirical studies over the past half-century that consistently indicate that minimally guided instruction is less effective and less efficient than instructional approaches that place a strong emphasis on guidance of the student learning process. The advantage of guidance begins to recede only when learners have sufficiently high prior knowledge to provide “internal” guidance.

On the other hand, KSC, in the first paragraph of KSC (2006), indicate that their brand of “direct instruction” is more than just “guidance.” It involves explicitly “telling it like it is” and conveying a learning strategy. It is therefore not entirely the same as the less direct “direct instruction” of Klahr and Nigam (see above). KSC write [see their online article for references other than Klahr & Nigam (2004), Steffe & Gale (1995), Mayer (2004), and Sweller (2003); my *italics*]:

Disputes about the impact of instructional guidance during teaching have been ongoing for at least the past half-century (Ausubel, 1964; Craig, 1956; Mayer, 2004; Shulman & Keisler, 1966). On one side of this argument are those advocating the hypothesis that people learn best in an unguided or minimally guided environment, *generally defined as one in which learners, rather than being presented with essential information, must discover or construct essential information for themselves* (e.g., Bruner, 1961; Papert, 1980; Steffe & Gale, 1995). On the other side are those suggesting that novice learners should be provided with direct instructional guidance on the concepts and procedures required by a particular discipline and should not be left to discover those procedures by themselves (e.g., Cronbach & Snow, 1977; Klahr & Nigam, 2004; Mayer, 2004; Shulman & Keisler, 1966; Sweller, 2003). *Direct instructional guidance is defined as providing information that fully explains the concepts and procedures students are required to learn as well as learning strategy support that is compatible with human cognitive architecture.* Learning, in turn, is defined as a change in long-term memory.

Generations of physics teachers, attempting to bring students into the Newtonian World, have provided “information that fully explains the concepts and procedures students are required to learn” through the traditional passive-student lecture method. In “Socratic Pedagogy in the Introductory Physics Laboratory” [Hake (1992)], I wrote:

Aside from exposing students’ preconceptions, how can such elementary and non-analytical activities [as in Socratic Dialogue Inducing Labs] be of any value? Shouldn’t someone just give these students the Newtonian “WORD”? Unfortunately, most research has shown that the usual bombardment of passive students with a formidable flux of physics “factons,” formulas, and problem-solving assignments fails to implant conceptual understanding, while there have been several recent studies demonstrating the relative success of active-engagement methods. . . .

As far as providing “learning strategy support,” the time-honored advice given by physics instructors to their students has been to:

- (a) study the traditional 1000+ page text (*replete with “worked problems”*);
- (b) attend recipe labs where various relationships, theories, or laws are “verified” by following explicit instructions (usually under severe time pressure);
- (c) attend “discussions” or “recitations” to watch teaching assistants work through back-of-chapter problems, and
- (d) work through many such problems by themselves - an evidently failed tactic since “Students do not overcome conceptual difficulties after solving 1000 traditional problems” [Kim & Pak (2002)].

As discussed below in Section III, judging from the abysmally low average normalized gains on conceptual tests, such traditional “full explanation of concepts and procedures” and traditional “learning strategy support” may be necessary, but are certainly not sufficient to provide a rudimentary conceptual understanding of Newtonian mechanics.

What is the rationale for Kirschner, Sweller, & Clark’s (KSC’s) (2006) classification of constructivist, discovery, problem-based, experiential, and inquiry-based teaching as “minimally guided,” and their astonishing proclamation of the “failure” of those methods? On pages 75-76, KSC write [see that article for references other than Jonassen (1991) and Steffe & Gale (1995)]:

The minimally guided approach has been called by various names including discovery learning (Anthony, 1973; Bruner, 1961); problem-based learning (PBL; Barrows & Tamblyn, 1980; Schmidt, 1983), inquiry learning (Papert, 1980; Rutherford, 1964), experiential learning (Boud, Keogh, & Walker, 1985; Kolb & Fry, 1975), and constructivist learning (Jonassen, 1991; Steffe & Gale, 1995). Examples of applications of these differently named but essentially pedagogically equivalent approaches include science instruction in which students are placed in inquiry learning contexts and asked to discover the fundamental and well-known principles of science by modeling the investigatory activities of professional researchers (Van Joolingen, de Jong, Lazonder, Savelsbergh, & Manlove, 2005). Similarly, medical students in problem-based teaching courses are required to discover medical solutions for common patient problems using problem-solving techniques (Schmidt, 1998, 2000). The goal of this article is to suggest that based on our current knowledge of human cognitive architecture. . . [reviewed on pages 76-78]. . . , minimally guided instruction is likely to be ineffective. The past half-century of empirical research. . . [reviewed on pages 79-83]. . . on this issue has provided overwhelming and unambiguous evidence that minimal guidance during instruction is significantly less effective and efficient than guidance specifically designed to support the cognitive processing necessary for learning.

That *all* forms of “discovery,” “problem-based,” “experiential,” “inquiry,” and “constructivist” approaches to learning are “minimally guided” is, in my view, debatable. In their first paragraph KSC define an unguided or minimally guided environment “*as one in which learners, rather than being presented with essential information, must discover or construct essential information for themselves.*” But aside from extreme discovery teaching, I know of no “problem-based,” “inquiry,” or “constructivist” teaching method that is without coaching and scaffolding to assist students in “discovering or constructing essential information.” Similarly, I think it is incorrect to state that all these methods place students “in inquiry learning contexts and ask them to discover the fundamental and well-known principles of science by modeling the investigatory activities of professional researchers.”

That instructional methods are *not* “minimally guided” has been argued for the case of problem-based and inquiry teaching by Hmelo-Silver et al. (2007), and for the case of problem-based teaching by Schmidt et al. (2007). In response, Sweller, Kirchner, & Clark (2007) did not refute the claims of those two groups regarding the copious guidance offered by problem-based and inquiry teaching, but sidestepped the issue by contesting the arguments of Hmelo-Silver et al. and Schmidt et al. on grounds that: (1) the studies cited by these two groups failed to provide a valid test of the Kirschner, Sweller, Clark (KSC) version of “direct instruction” vs problem-based or inquiry teaching; and (2) the guidance given in problem-based and inquiry instruction (a) falls short of the what KSC deem to be “direct instruction,” i.e., “providing information that fully explains the concepts and procedures students are required to learn”; and (b) fails to take advantage of the “worked example” effect.

According to Kirschner, Sweller, & Clark (KSC) (2006) [my insert at “. . . [insert]. . .”]:

The worked-example effect. . . [http://en.wikipedia.org/wiki/Worked-example_effect]. . . . , which is based on cognitive load theory. . . . [http://en.wikipedia.org/wiki/Cognitive_load]. . . . , occurs when learners required to solve problems perform worse on subsequent test problems than learners who study the equivalent worked examples. Accordingly, the worked-example effect, which has been replicated a number of times, provides some of the strongest evidence for the superiority of Directly guided instruction over minimal guidance. The fact that the effect relies on controlled experiments adds to its importance. The worked-example effect was first demonstrated by Sweller and Cooper (1985) and Cooper and Sweller (1987), who found that algebra students learned more studying algebra worked examples than solving the equivalent problems.

And on what grounds do KSC contend that *all* forms of constructivist teaching are “minimally guided”? Their justification appears to rely on two sources: *Constructivism in Education* [Steffe & Gale (1995)] and “Objectivism vs. constructivism: Do we need a new paradigm?” [Jonassen (1991)]. From a different vantage point, Denis Phillips (1995, 2000) has discussed the “many faces of constructivism: the good, the bad, and the ugly.” Phillips identifies the *ugly* as the quasi-religious or ideological aspects of constructivism and then writes:

The *good*. . . is the emphasis that various constructivist sects place on the necessity for active participation by the learner, together with the recognition (by most of them) of the social nature of learning; it seems clear that, with respect to their stance on education, most types of constructivism are modern forms of progressivism. Constructivism also deserves praise for bringing epistemological issues to the fore in the discussion of learning and the curriculum. . . . The *bad*are constructivist epistemologies that tend (despite their occasional protestations to the contrary) toward relativism and make the justification of our knowledge-claims pretty much entirely a matter of sociopolitical processes or consensus, or that jettison any justification or warrant at all (as arguably the case with radical social constructivism).

One of the “good” faces that Phillips does not explicitly mention is “Knowledge-based Constructivism” [Resnick & Hall (1998)]. According to Hall & Resnick [*emphasis* in the original except where indicated]:

Since about 1960, beginning with the publication of Newell and Simon's (1972) landmark studies of human problem solving, a body of cognitive-science research has focused on the nature of the mental processes involved in thinking and learning. Hundreds of scholars have been involved, using varied methods and examining cognitive processes in people of all ages and social conditions. Despite the variety of approaches and the many theoretical differences among cognitive scientists, it is possible to outline a few important points of fundamental agreement that we can take as the new core theory of learning [Resnick (1987), Bruer (1993)].

Broadly speaking, cognitive science confirms Piaget's claim that people must *construct* their understanding; they do not simply register what the world shows or tells them, as a camera or a tape recorder does. To “know” something, indeed even to memorize effectively, people must build a mental representation that imposes order and coherence on experience and information. Learning is interpretive and inferential; it involves active processes of reasoning and a kind of “talking back” to the world - not just taking it as it comes. Competent learners engage, furthermore, in a great deal of self-management of their cognitive processes, that is, in forms of cognition known as *metacognitive* and *self monitoring*.

This much sounds like the child-centered, process theories of education. Early on, however, cognitive scientists found that they could not account for problem solving and learning without attending to what people already *knew*. Vast knowledge of possible positions in a chess game, they found – not a superior ability to “think ahead” – was what distinguished chess masters from merely good chess players. In every field of thought, cognitive scientists found that knowledge is essential to thinking and acquiring new knowledge - in other words to learning. . . These repeated findings about the centrality of knowledge in learning make perfect sense for a constructivist theory of learning, because one has to have something with which to construct. But they turn out to be almost as much of a challenge to Piagetian or Deweyan theories of pedagogy as to Thorndikean ones. This is because they insist that knowledge - *correct* knowledge - is essential at every point in learning. And they make it impossible to suggest that education for the information age should not trouble itself with facts and information, but only with processes of learning and thinking. What we know now is that just facts alone do not constitute true knowledge and thinking power, so thinking processes cannot proceed without something to think about. Knowledge is in again, but alongside thinking, indeed, intertwined with it, not instead of thinking. So although it is essential for children to have the experience of discovering and inventing, their experience must be of one of disciplined invention, that is, by established processes of reasoning and logic.

[The above advocated] *Knowledge-based Constructivism*, taken seriously, *points to a position that can moderate the century-long polarity between passive drill pedagogies and child-centered discovery pedagogies.* [My italics.]

I submit that the teaching methods advocated by Donovan et al. (1999), Bransford et al. (2000), Donovan & Bransford (2005), Duschl et al. (2007), as well as the “interactive engagement” methods surveyed in Hake (1998a,b) are all consistent with the tenets of “knowledge-based constructivism.” Evidence for the relative effectiveness of those methods has been advanced by e.g.: Lipsey & Wilson (1993), AAAS (1993, 2008), Hake (1998a,b), Springer et al. (1999), Lopez & Schultz (2001), Anderson (2002), Amaral et al. (2002), Doss-Hammel (2004), Minner et al. (2008), & Minner (2008). All the pre-2006 sources were ignored in the referencing of empirical research on pages 79-83 of KSC (2006).

Although it can be argued that some (but not all) of the above cited evidence derives from non-randomized control trials [but see “Re: Should Randomized Control Trials Be the Gold Standard of Educational Research?” (Hake, 2005c)], and some (but not all) lacks the resolution of the pre/post testing methods of physics education research [Hake (2008b)], I don’t think this mountain of evidence can be entirely dismissed. The fact that these methods are at least sometimes relatively successful conflicts with KSC’s claim that constructivist teaching is a failure.

Nevertheless, Kirschner, Sweller, & Clark (2006), despite their arguable characterization of “constructivist teaching” as “minimally guided,” *do* make a strong case against the minimally guided instruction of “pure discovery learning.” Their arguments are reinforced by Sweller, Kirschner, & Clark (SKC) (2007), in response to criticisms by psychologists Hmelo-Silver et al. (2007), Schmidt et al. (2007), and Kuhn (2007). In the last section of SKC (2007), titled “A New Educational Psychology is Emerging,” SKC invoke “evolutionary educational psychology,” to explain the failure of discovery or “immersion” teaching methods to promote learning of “biologically secondary information.” SKC write [my insert at “. . . . [insert]. . . .”]:

For several decades, educational psychology has been dominated by the view that direct explicit instruction is inferior to various combinations of discovery learning or “immersion” in the procedures of a discipline. This view was both attractive and plausible on the grounds that the bulk of what we learn outside of educational institutions is learned either by discovery or immersion. Extending this argument further, it seemed reasonable to expect that we should base the pedagogy for teaching and learning in the natural sciences on the epistemology of the natural scientist (Kirschner, 1992; Kirschner et al., 2006).

This view, in spite of the questions raised in the 1980s. . . .[SKC reference Wellington (1981), Mayer (1987), Novak (1988)]. . . . , was sufficiently attractive to be impervious to the near total lack of supporting evidence from randomized, controlled experiments. Theories such as cognitive load theory argued that the failure to find empirical evidence for the superiority of indirect instruction was because without direct, explicit instruction, working memory was overwhelmed by the need to engage in search through a wilderness of possibilities. But while cognitive load theory could point to the empirical evidence from controlled studies supporting this view, it was unable to explain why in some basic areas not taught in educational institutions, immense amounts could be learned without explicit instruction.

Recent work by Geary (2002, 2005, 2007) provides some of the missing pieces of the scientific jigsaw.[Evolutionary psychologists have also weighed in on the “fact” side of the controversial issue “Sex Differences in Mathematical Ability: Fact or Artifact?” - see Section M of Part 2 of Hake & Mallow (2008)]. Some knowledge, that Geary called biologically primary knowledge, is not learned consciously because we have evolved to acquire that knowledge easily and automatically. Huge amounts of such knowledge can be learned and stored directly in long-term memory without the restrictions imposed by a limited working memory.

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[But]. . . there is no theoretical reason to suppose or empirical evidence to support the notion that constructivist teaching procedures[*more accurately, in my view, “minimally guided procedures”*]. . . . based on the manner in which humans acquire biologically primary information will be effective in acquiring the biologically secondary information required by the citizens of an intellectually advanced society. That information requires direct, explicit instruction. [*more accurately, in my view” methods consistent with “knowledge-based constructivism”*]. . . .

III. The Language of Education Research in Physics

Little known to those outside (and even inside) the physics community, some physicists have been engaged in education research for about three decades. In Section IV, “Empirical Studies,” of McDermott & Redish’s (1999) “Resource letter on physics education research,” I count over 80 articles, dating from McKinnon (1971), that feature empirical research.

As far as I know, one of the earliest examples of such research in physics education, was the effort involved in the development of the *Science Curriculum Improvement Study* (SCIS), now available through Delta Education <<http://www.delta-education.com/>>. In “One Physicist Experiments with Science Education,” Robert Karplus (1964) wrote:

The experimentation with science teaching that I have described is being carried out by the Science Curriculum Improvement Study at the University of California in Berkeley. The parts of the science program which have been constructed by SCIS staff members over the past three years are now ready for classroom trial. The kindergarten and first grade teachers in several schools are working with a unit called *Material Objects*, while the second and third grade teachers are working with a unit called *Interaction and Systems* with their classes. Staff members and consultants are available to evaluate the effectiveness of the teaching program and to help participating teachers in using the materials. Reactions and suggestions from the teachers and the results of observations of the pupils’ behavior will help determine what revisions in the teaching plans are necessary.

More recently, for Newtonian mechanics, physics education researchers have demonstrated that “interactive engagement” methods can produce a roughly two-standard-deviation superiority in average normalized learning gains $\langle g \rangle$ over traditional passive-student lecture methods [Hake (1998a,b)]. Similar differences in $\langle g \rangle$ between “interactive engagement” and “traditional” courses have now been reported in at least 25 other peer reviewed publications, as listed in “Design-Based Research in Physics Education Research: A Review” [Hake (2008a)]. This research involves the measurement of pre-to-posttest gains on valid and consistently reliable tests of conceptual understanding developed by disciplinary experts [Halloun & Hestenes (1985a,b); Hestenes et al. (1992), Thornton & Sokoloff (1998)], and the use of reasonably well-matched control groups provided by traditional introductory courses. For reviews see Hake (2002a; 2005a; 2007a,b; 2008a,b). Some definitions [Hake (1998a,b)] are in order:

(A) “Interactive engagement” methods are defined *operationally* as those designed at least in part to promote conceptual understanding through interactive engagement of students in heads-on (always) and hands-on (usually) activities which yield immediate feedback through discussion with peers and/or instructors.

(B) “Traditional methods” are defined *operationally* as those which make little or no use of “interactive engagement” methods, relying primarily on passive-student lectures, recipe laboratories (in which detailed and explicit procedures must be followed), and algorithmic problem examinations – *this is what’s known to most physicists (but not to most cognitive scientists) as “direct instruction.”*

(C) The “average normalized gain $\langle g \rangle$ ” is the average *actual* gain [$\langle \%post \rangle - \langle \%pre \rangle$], divided by the *maximum* possible average actual gain [$100\% - \langle \%pre \rangle$], where the angle brackets $\langle . . . \rangle$ signify class averages. For a discussion of the rationale and history of the half-century-old normalized gain see “Should We Measure Change? Yes!” [Hake (2007a)].

But education researchers in glass houses should not throw stones. I am aware that the definition of “interactive engagement” methods in “A” above suffers from, among other things, the ambiguity of the terms “heads-on” and “hands-on.” Instead of “heads-on” I probably should have used Mayer’s (2004) term “cognitively engaged.” And “hands-on” is also poorly defined. Considering the various meanings of that term as used during the recent K-8 California science-education wars, in “Direct Science Instruction Suffers a Setback in California - Or Does It?” [Hake (2004a)] I wrote [using the physics-education-research meaning of the term “direct instruction,” i.e., traditional *passive-student* lectures, recipe labs, and algorithmic problem sets]:

I suspect that “hands-on activity” means to:

- (a) California Curriculum Commission’s (CCC’s) Stan Metzenberg (1998): “non-direct-instruction,”
- (b) Thomas Adams (2004), executive director of the CCC: “discovery learning,”
- (c) most members of the CCC: either “discovery learning,” or “non-direct-instruction,”
- (d) most physics education researchers: “interactive engagement” or “inquiry” or - “hands-on guided inquiry,”
- (e) literalists: placing hands on *any* object (e.g., pencil, paper, book, candy).

So it may be worthwhile to supplement the operational definition of “interactive engagement” in “A” above with a description of a fairly typical “interactive engagement” method - Socratic Dialogue Inducing Labs – as indicated in Hake (1992, 1998c), but slightly edited and with updated references:

Socratic Dialogue Inducing (SDI) labs have been shown [Hake (1998a, 1998b - Table Ic)] to be relatively effective in guiding students to construct a coherent conceptual understanding of Newtonian mechanics. The SDI method might be characterized as “*guided construction*,” rather than “guided discovery” or “inquiry.” We think the efficacy of SDI labs is primarily due to the following essential features:

- (1) active participation of students who are induced to think constructively about simple Newtonian experiments that produce conflict with their commonsense understandings;
- (2) the Socratic method [e.g., Arons (1973, 1974, 1993, 1997); Collins & Stevens (1982); Rose et al. (2001); Hake (1992, 2002c, 2004b, 2007c) of the *historical* Socrates [Vlastos (1990, 1991, 1994)] (not Plato’s alter ego in the *Meno*, as mistakenly assumed by many - even some physicists), utilized by experienced instructors who have a good understanding of the material and are aware of common student preconceptions and failings;
- (3) considerable interaction with, and feedback from, students and instructors; thus a degree of individualized instruction along with constant *formative assessment* by instructors [Black & Wiliam (1998), Shavelson (2008)];
- (4) extensive use of multiple representations (verbal, written, pictorial, diagrammatic, graphical, and mathematical) to model physical systems;
- (5) real world situations and kinesthetic sensations (which promote student interest and intensify cognitive conflict when students’ direct sensory experience does not conform to their conceptions);

- (6) cooperative group effort and peer discussions;
- (7) repeated exposure to the coherent Newtonian explanation in many different contexts;
- (8) enhancement of students': (a) understanding of the nature of science, (b) use of effective strategies for scientific thinking and problem-solving, and (c) research skills such as collaborative effort, drawing, written description, thought experiments, modeling, consideration of limiting conditions, experimental design, control of variables, dimensional analysis, and solution of real-world problems.

For detailed description of other interactive engagement methods surveyed in Hake (1998a,b): e.g., *Collaborative Peer Instruction*, *Microcomputer-Based Laboratories*, *Concept Tests*, *Modeling*, *Active Learning Problem Sets*, & *Overview Case Studies*, I refer the reader to the developers' descriptions of those methods as referenced in Hake (1998a,b).

As indicated by Kenneth Heller (1999), the “interactive engagement” methods surveyed in Hake (1998a,b) are associated loosely with learning theories from cognitive science – for the references see the online “Lessons from the physics education reform effort” [Hake (2002a)]:

- (a) “developmental theory” originating with Piaget [Inhelder & Piaget (1958); Gardner (1985); Inhelder, deCaprona, & Cornu–Wells (1987); Phillips & Soltis (1998)];
- (b) “cognitive apprenticeship” [Collins, Brown, & Newman (1989); Brown, Collins, & Duguid (1989)];
- (c) in addition, all the methods recognize the important role of social interactions in learning [Vygotsky (1978); Lave & Wenger (1991); Dewey (1938/1997); Phillips & Soltis (1998)].

As is apparent from the above description of Socratic Dialogue Inducing Labs, “interactive engagement” methods *involve considerable guidance* and bear near zero resemblance to the extreme “discovery learning” methods researched by Klahr & Nigam (2004), rarely used in the classroom [Shavelson (2004)], and criticized by Mayer (2004) as having “struck out.” In fact, “interactive engagement” methods, shown by physics education researchers (PER’s) to be far superior to what *PER’s define* as “direct instruction,” are – in a triumph of ambiguity over effective communication - close to *what cognitive scientists* Klahr & Nigam (2004) and Kirschner, Sweller, and Clark (2006) *define* as “direct instruction”!

IV. Conclusions

Language ambiguities often impede the advancement of the education research and sometimes misrepresent its findings to both the education community and the general public. In particular, Kirschner, Sweller, & Clark (2006): (a) characterized constructivist, discovery, problem-based, experiential, and inquiry-based teaching methods as all “minimally guided,” and (b) proclaimed all of them to be failures. Assertions “a” and “b” are in direct contradiction to the fact that, for example, the operationally defined “interactive engagement” methods of physics education research are consistent with the tenets of Resnick & Hall’s “knowledge-based constructivism,” are *not* minimally guided, and have been shown by many different research groups to be relatively effective in hundreds of courses with hundreds of different instructors in widely varying classroom circumstances [Hake (2008a)]. I concur with the antidote for ambiguity suggested by Klahr and Li (2005): “those engaged in discussions about implications and applications of educational research focus on clearly defined instructional methods and procedures, rather than vague labels and outmoded ‘-isms’.”

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- (a) "Curriculum Materials" <<http://www.project2061.org/research/curriculum.htm>>,
- (b) "Teaching and Learning" <<http://www.project2061.org/research/learning.htm>>,
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Thomas Adams, executive director of the curriculum commission, said critics are misrepresenting the panel's views. He said commission members are trying to balance the need for a comprehensive science curriculum with the limited science background of many K-8 teachers. Twenty to 25 percent of hands-on instruction seemed like the like "the most reasonable amount of time for someone faced with the challenges of limited facilities and limited time," he said. "What we want are materials that all teachers can use," Adams said. ". . . *There are some people who are convinced that the only way that students learn is in a discovery method.*" [My italics.]

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