Vague Labels for Pedagogical Methods Should Be Supplemented with Operational Definitions and Detailed Descriptions*

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O*perational definitions* and *detailed descriptions* of instructional methods such as those labeled *inquiry*, *active learning, discovery learning*, *cooperative learning, direct instruc*tion, *hands-on, minds-on,* and *constructivism* are required if research findings are to be meaningfully conveyed to the education community and the general public. For example, Klahr & Nigam (2004) 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 Kirschner, Sweller, & Clark (KSC) (2006) added to the confusion by arguably: (a) identifying *constructivist*, *discovery*, *problem-based*, *experiential*, and *inquiry-based* instructional methods as *all* "minimally guided"; and (b) proclaiming them *all* to be failures. In my judgment, KSC's conception of constructivist teaching is deficient – the "knowledge-based constructivism" of Resnick & Hall (1998) is *not* "minimally guided" and instructional methods consistent with it are *not* failures, as judged by the assessment literature referenced in this report. KSC's provocative use of vague labels spawned an entire book *Constructivist Instruction: Success or Failure?* [Tobias & Duffy (2009)] in which the contributors often used vague labels for instructional methods so as to talk past one another. Such communication problems might be reduced if education researchers did not [quoting Klahr and Li (2005)] "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."

Key Words: Constructivism, Discovery, Guided, Inquiry, Direct Instruction, Operational Definitions

I. Introduction

Education research attempts to apply the scientific method to 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 vague labels for pedagogical methods were supplemented by *operational definitions and detailed description* so that researchers in different disciplines could communicate with one another, with the education community, and with the general public. As explained by Holton & Brush [2001, Section 12.4, "Physical Concept: Measurement and Definition, pp. 161-163], *an operational definition of "X" is simply a specification for measuring "X."*† But after engaging in physics education research for several decades and attempting to monitor related research in a variety of fields, I have concluded that the education research suffers from vague labels that hinder its development and sometimes misrepresent its findings to both the education community and the general public. The difference in the language of education research between the physics and cognitive-science communities, as discussed below, is symptomatic of the problem.

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† "When we say force is the cause of motion we talk metaphysics, and this definition, if we were content with it, would be absolutely sterile. For a definition to be of any use, it must teach us to measure force; moreover, that suffices; it is not at all necessary that it teach us what force is in itself, nor whether it is the cause or the effect of motion." - Henri Poincaré (1905)

II. Abbreviations Used Repeatedly in This Article

DI: Direct Instruction
DL: Discovery Learning
IE: Interactive Engagement
KBC: Knowledge Based Constructivism
KN: Klahr & Nigam
KSC: Kirschner, Sweller, & Clark
LSTWM: Limitation of Short-Term Working Memory
PER: Physics Education Research
SKC: Sweller, Kirschner, & Clark
T: Traditional Instruction

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 classroom education research for over four 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://bit.ly/1ou64Mq>. In "One Physicist Experiments with Science Education," Robert Karplus (1964) wrote [**thenceforth I shall use indents and lower-case font size for quotes**]:

> 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" (IE) methods can produce a roughly two-standard-deviation superiority in average normalized pre-to-post-course learning gains <g> over traditional (T) passive-student lecture methods [Hake (1998a,b)]. As of 2008, similar differences in <g> between IE and T courses had been reported in at least 25 other peer reviewed publications, as listed in "Design-Based Research in Physics Education Research: A Review" [Hake (2008a)]. That research involves the measurement of pre-to-post-course learning gains on valid and consistently reliable *Concept Inventories* <http://en.wikipedia.org/wiki/Concept_inventory> 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 e.g., (a) "Lessons from the physics education reform effort" [Hake (2002a)], (b) "The Physics Education Reform Effort: A Possible Model for Higher Education" Hake (2005a)]; (c) *Adapting to a Changing World - Challenges and Opportunities in Undergraduate Physics Education* [NRC (2013)]; and (d) "Teaching and physics education research: bridging the gap" [Fraser et al. (2014)].

Some definitions [Hake (1998a,b)] are in order:

A. "Interactive engagement" (IE) methods are defined *operationally* as those designed at least in part to promote conceptual understanding through active engagement of students in heads-on (always) and hands-on (usually) activities which yield immediate feedback to both students and instructors through student discussion with peers and/or instructors. The feedback to instructors facilitates formative assessment in the sense used by Black & Wiliam (1998) and Shavelson (2008): "All those activities undertaken to provide information to be used as feedback so as to adapt the teaching to meet student needs."

B. "Traditional" (T) 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 <g>" is the average *actual* gain [<%post> - <%pre>], divided by the *maximum* possible average actual gain [100% - <%pre>], where the angle brackets <. . . > signify class averages. For a discussion of the rationale and half-century-old history of the "normalized gain" see "Design-Based Research in Physics Education Research: A Review" [Hake (2008a)].

But "people in glass houses should not throw stones." The definition of "interactive engagement" (IE) methods in "A" above suffers from, among other things, the ambiguity of the terms "heads-on" and "hands-on." Instead of "heads-on" Hake probably should have used Mayer's (2004) term "cognitively engaged." And "hands-on" is also poorly defined. Hake (2004) in "Direct Science Instruction Suffers a Setback in California - Or Does It?" 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).

So it may be worthwhile to supplement the operational definition of "interactive engagement" in "A" above with a *detailed description* of a fairly typical IE method - *Socratic Dialogue Inducing (SDI) Labs*, which have been shown [Hake (1998a, 1998b - Table Ic)] to be relatively effective in guiding students to construct a coherent understanding of Newtonian mechanics, even despite the markedly counterintuitive nature of its concepts. The SDI method might be characterized as "*guided construction*," rather than "guided discovery" or "inquiry." As indicated in "Design-Based Research in Physics Education Research: A Review" [Hake (2008a)], but slightly edited and with updated references:

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SDI laboratories emphasize hands- and minds-on experience with simple mechanics experiments and facilitate the interactive engagement of students with course material. They are designed to promote students' mental construction of concepts through:

(1) active engagement of students who are induced to think constructively about simple Newtonian experiments which produce conflict with their commonsense understandings;

(2) the Socratic method (e.g., Arons (1973, 1974, 1993, 1994, 1997); Collins & Stevens (1982); Rose et al. (2001); Hake (1992, 2002c, 2008a, 2012, 2014) 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 between students and instructors and thus a degree of individualized instruction;

(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.

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For detailed description of other IE 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) in his excellent survey "Introductory Physics Reform in the Traditional Format: An Intellectual Framework," the IE methods surveyed in Hake (1998a,b) are associated loosely with learning theories from cognitive science:

(a) "developmental theory" originating with Piaget [Inhelder & Piaget (1958); Gardner (1985); Inhelder, deCaprona, & Cornu–Wells (1987); Phillips & Soltis (2009)];

(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 (2009)].

Judging from the above description of the fairly typical IE method *Socratic Dialogue Inducing Labs*, IE 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, IE methods, shown by physics education researchers (PERs) to be far superior to what PERs define as "direct instruction," are – in a triumph of vague labels over effective communication – similar to *what cognitive scientists* Klahr & Nigam (2004) and Kirschner, Sweller, and Clark (2006) *define* as "direct instruction"!

An example of the confusion wrought by such language ambiguity is the following apparently conflicting expert views regarding the limitation of short-term working memory (LSTWM) <http://en.wikipedia.org/wiki/Working_memory>: expert "COG-SCI" pointing out that LSTWM accounts for the *superiority* of "direct instruction," and expert "PHYS" pointing out that LSTWM accounts for the *inferiority* of "direct instruction":

COG-SCI: Cognitive scientists Kirschner, Sweller, and Clark (KSC) (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.

PHYS: Physics education researcher (PER) Carl Wieman (2007), in his article "Why Not Try a Scientific Approach to Science Education?" writes ***[here and henceforth in this article my inserts into quotes will be indicated by double square brackets* ". . . .[[insert]]. . . ."**]:

> These results. . . .[[indicating the ineffectiveness of passive-student lectures – regarded by most PERs 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 . . . . . .[[to the beginning physics student unfamiliar technical terms such as *work*, *vector*, *displacement*, *velocity*, and *acceleration* are the analogues of Miller's "unidimensional stimuli" or Peterson and Peterson's (1959) "consonant syllables"]]. . . . 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 KSC and physics education researchers (PERs) attach totally different meanings to the term "direct instruction" – as indicated on p. 8:

> KSC (2006, p. 75): ". . . providing information that fully explains the concepts and procedures that 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."
>
> PERs: traditional *passive-student* lectures, recipe labs, and algorithmic problem sets.

But what is the education community and the general public to make of seemingly diametrically opposed statements from the experts?

IV. 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* and give *detailed descriptions* of their own very restricted meanings of "direct instruction" and "discovery learning," their paper [and its precursor Chen & Klahr (1999)] were 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), reacting to Chen & Klahr (1999), 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.

Cognitive scientists Klahr & Li (2005, p. 233-235), disturbed by the above reports, wrote:

> . . . 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. . . . . Because of. . . . [[media reports such Adelson (2004), the *AAAS EurekAlert* (1998), Begley (2004a), and Cavenaugh (2004)]]. . . .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. . . . . . *In hindsight 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)]*. . . . . [[my *italics*]]. . . . Only when we tuned in to the recent political debate in California about the permissible amounts of 'hands-on science' vs. 'direct instruction' . . . . . . [[Hake (2004, 2005b); Strauss (2004); 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 *emphasis*]] . . . . 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 *italics*]]. . . .

Independently of Klahr & Li (2005), cognitive scientist Michelene Chi (2009), in her paper "Active-Constructive-Interactive: A Conceptual Framework for Differentiating Learning Activities," has also emphasized the problems associated with the use of vague labels for instructional methods. Her abstract reads:

> Active, constructive, and interactive are terms that are commonly used in the cognitive and learning sciences. They describe activities that can be undertaken by learners. However, the literature is actually not explicit about how these terms can be defined; whether they are distinct; and whether they refer to overt manifestations, learning processes, or learning outcomes. . . . . . . Specifying distinct overt activities for active, constructive, and interactive also offers suggestions for how learning activities can be coded and how each kind of activity might be elicited.

The concern of Klahr and Li (2005) that research results can be misreported by the media was emphasized in "Will the No Child Left Behind Act Promote Direct Instruction of Science?" [Hake (2005b)]. There Hake 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 IVB 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 (2004, 2005b) of the California Curriculum Commission's anti-hands-on "Criteria For Evaluating K-8 Science Instructional Materials In Preparation for the 2006 Adoption," Hake 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, pp. 157-167)], 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 "Direct Science Instruction Suffers a Setback in California - Or Does It?" [Hake (2004)] indicated his own guesses as to what various groups have meant by "direct instruction" (slightly edited to include KSC):

(a) *Mathematically Correct Science Corner* [MCSC (2008)]: "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) KSC (2006, p. 75): "Direct instructional guidance is defined as providing information that fully explains the concepts and procedures that 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."

(d) *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 KN, 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 KN 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.

(e) *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, for example, 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 vague labels.

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:

> 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 Ausubel (1964), Bruner (1961), Klahr & Nigam (2004), Mayer (2004), Papert (1980/1993), Shulman & Keisler (1966), Steffe & Gale (1995), 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.

That KSC's brand of "direct instruction" (see directly above) is effective in promoting higher-order learning is inconsistent with the fact that 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)], Hake 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 for 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 above, judging from the abysmally low average pre-to-post-course 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 Bruner (1961), Jonassen (1991), Papert (1980/1993), 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 by KSC on pages 76-78]]. . . . , minimally guided instruction is likely to be ineffective. The past half-century of empirical research. . . .[[reviewed by KSC 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 judgment, *incorrect*. In their first paragraph KSC define 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, p. 80)]:

> 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) 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).

V. Knowledge-Based Constructivism

One of the "good" faces that Phillips (1995, 2000) does not explicitly mention is "Knowledge-based Constructivism" (KBC) [Resnick & Hall (1998)]. According to Resnick & Hall [*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" (KBC) [Resnick & Hall (1998)]. Henceforth I shall designate these as "KBC methods."

That KBC methods are more effective in promoting learning than "direct instruction" (in the *passive-student* sense) has been *argued* by e.g., AAAS (2014); Amaral et al. (2002); Anderson (2002); Berger et al. (1986); Brown & Campione (2004); Curren (2006); Duschl & Grandy (2008); Fraser et al. (2014); Hake (2008b, 2013); Hunt & Minstrell (2004); Lopez & Schultz (2001), Lowery (1997, 2011); McGilly (2004); Mintzes & Lenard (2006); Millis (2010); NRC (2011, 2013)]; Nelson (2010); Resnick (1989); Scardamalia et al. (2012); Wenger (2000); Wenger et al. (2002); Wieman & Perkins (2005); and Wieman (2007).

Aside from the above cited *arguments*, what's the *EVIDENCE* that KBC methods are more effective in promoting learning than "direct instruction"? Here are 21 reports of such evidence [in order of the first letter of the first author's name - reports published in or before the 2006 date of KSC (2006) are shown in **bold text**]:

1. “The Student-Centered Activities for Large Enrollment Undergraduate Programs (SCALE-UP) Project” [Beichner et al. (2007)].

2. “Active and Cooperative Learning in Signal Processing Courses” [Buck & Wage (**2005**)].

3. “A Student-Centered Approach to Teaching General Biology That Really Works: Lord's Constructivist Model Put to a Test” [Burrowes (**2003**)] .

4. “Peer Instruction: Ten years of experience and results” [Crouch & Mazur (**2001**)].

5. “Evaluating innovations in studio physics” [Cummings, Marx, Thornton, & Kuhl (**1999**)].

6. "Improved Learning in a Large-Enrollment Physics Class" [Deslauries, Schelew, & Wieman (2011)].

7. “How Does Technology-Enabled Active Learning Affect Undergraduate Students’ Understanding of Electromagnetism Concepts*?*” [Dori & Belcher (**2004)**].

8. “Overview of the Impact of Activity-Based Teaching Strategies on Learning Science” [Doss-Hammel (**2004**)].

9. “Evidence for the Efficacy of Student-active Learning Pedagogies” [Froyd (2007)]. Froyd lists 41 references, **24 of which do not appear in the present list and were published in or before 2006**:

10. “Interactive-engagement vs traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses” [Hake (**1998a)]** .

11. “Design-Based Research in Physics Education Research: A Review” [Hake (2008a)**]** .

12. “The initial knowledge state of college physics” [Halloun & Hestenes (**1985a**)],

13. “A direct comparison of conceptual learning and problem solving ability in traditional and studio style classrooms.” [Hoellwarth, Moelter & Knight (**2005**)].

14. “Cooperative Learning Returns to College: What Evidence Is There That It Works?” [Johnson, Johnson, & Smith (**1998**)];

15. “Teaching More by Lecturing Less” [Knight &Wood (**2005**].

16. “Promoting Active Learning Using the Results of Physics Education Research” [Laws, Sokoloff, & Thornton (**1999**)].

17. “Where‘s the evidence that active learning works?” [Michael (**2006**)].

18. “Inquiry-based science instruction. What is it and does it matter? Results from a research synthesis years 1984 to 2002” [Minner, Levy, & Century (2010)].

19. “Does Active Learning Work? A Review of the Research” [Prince (**2004**)].

20. “On the effectiveness of active-engagement microcomputer-based laboratories” [Redish, Saul, & Steinberg (**1997**)].

21. “Undergraduates in science, mathematics, engineering, and technology: a meta-analysis” [Springer, Stanne, & Donovan (**1999**)].

Kirshner, Sweller, & Clark (2006), in their referencing of "RESEARCH COMPARING GUIDED AND UNGUIDED INSTRUCTION" on pages 79-83, were either or (a) oblivious or dismissive of the evidence for the superiority of KBC to passive-student direct instruction in the above 40 reports [counting the 24 reports listed by Froyd (2007)] published in years (shown in **bold text**) in or before 2006; or (b) aware that what they regarded as "direct instruction" was similar to KBC with regard to the extensive guidance required.

It can be argued that: some (but not all) of the above cited evidence: (a) derives from non-randomized control trials [but see Hake's 2005 discussion-list post "Re: Should Randomized Control Trials Be the Gold Standard of Educational Research?" at <http://bit.ly/1qeY8jd>]; and (b) lacks the resolution of the pre/post testing methods of physics education research [Hake (1998a,b; 2002a,b; 2005a; 2008a.b)]. However, I don't think this mountain of evidence can be entirely dismissed. The fact that KBC methods are usually more successful than direct instruction passive-student methods 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:

> 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, Sweller, & Clark (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. 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. . . . .
> [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," since most constructivist teaching procedures are *not* 'minimally guided**]]. . . . . 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*"**]]. . . .

VI. The Ubiquitous But Vague Label "Inquiry"
The term "inquiry" (or its equivalent "enquiry") is often found in the education research literature, where it usually means "non-direct-instruction" (here "direct instruction" may have various meanings as indicated by Hake's guesses as to what various groups have meant by "direct instruction" in Section IVA above. The Wikipedia entry on "inquiry based learning" at <http://bit.ly/1jNqhLz> gives a more specific meaning (omitting the numbered references, my *italics*):

> Inquiry-based learning is primarily a pedagogical method, developed during the discovery learning movement of the 1960s as a response to traditional forms of instruction - where people were required to memorize information from instructional materials. The philosophy of inquiry based learning *finds its antecedents in constructivist learning theories* <http://bit.ly/1lbOue0>, such as the work of Piaget, Dewey, Vygotsky, and Freire among others and can be considered a constructivist philosophy.

Ronald Anderson (2002) in his report "Reforming Science Teaching: What Research says about Inquiry," has indicated some of the questions surrounding "Inquiry." He wrote [my *italics*]:

> Inquiry has a decades-long and persistent history as the central word used to characterize good science teaching and learning. Even at a time when *a new word, constructivism, had entered the general educational lexicon as the descriptor of good education* . . . . . [[but according to KSC (2006) "Constructivist Teaching" (along with "Discovery, Problem-Based, Experiential, and Inquiry-Based Teaching" is "minimally guided" and therefore a "failure"]]. . . . , the authors of the *National Science Education Standards* (NSES). . . . . .[[NRC (1996)]]. . . . . chose to stay with inquiry and totally ignore the new word.
>
> But in spite of its seemingly ubiquitous use, *many questions surround inquiry*. What does it mean to teach science as, through, or with inquiry? Is the emphasis on science as inquiry, learning as inquiry, teaching as inquiry or all of the above? Is it an approach to science education that can be realized in the classroom or is it an idealized approach that is more theoretical than practical? Is it something that the "average" teacher can do, or is it only possible in the hands and minds of the exceptional teacher? What are the goals of its use? Does it result in greater or better learning? How does one prepare a teacher to utilize this type of science education? What barriers must be overcome to initiate such science education in the schools? What dilemmas do teachers face as they move to this form of science education? The list of questions goes on.
>
> They are of particular importance to people committed to the NSES and wanting to see these standards put into greater practice. Reformers from all categories - teachers, teacher educators, administrators, policy makers and members of the general public want to know what answers research has for such questions. Given the central role of teacher education in the process of educational reform, however, these questions are of particular interest to science teacher educators.

In any case, the following 15 references in the ***References*** list below attest to the prevalence of the term **Inquiry**:

1. "Helping English Learners Increase Achievement Through **Inquiry**-Based Science Instruction" [Amaral et al. (2002)],

2. "Reforming Science Teaching: What Research says about **Inquiry**" [Anderson (2002)] 2002. Discusses various meanings of "inquiry."

3. "Guiding Insight and **Inquiry** in the Introductory Physics Laboratory" [Arons (1993)].

4. *Doing Science: The Process of Scientific* ***Inquiry*** [BSCS (2005)].

5. "Goals and methods for **inquiry** teachers" [Collins & Stevens (1982)].

6. *Philosophy of Education: An Anthology* [Curren (2006)]. Contains on pp. 389-422 four chapters on "**Inquiry**, Understanding, and Constructivism," including reprints of "The good, the bad, and the ugly: The many faces of constructivism" [Phillips (1995)] and "Constructivism and Objectivity: Disentangling Metaphysics from Pedagogy" [Grandy (1997)].

7. "Teaching Scientific **Inquiry**" [Duschl & Grandy (2008)].

8. *Scientific **Inquiry** and Nature of Science: Implications for Teaching* [Flick & Lederman (2004). An expurgated Google book preview at <http://bit.ly/1jO2pHF> contains most of Roger Bybee's Chapter 1, pp. 1-14, "Scientific **Inquiry** and Science Teaching."

9. "Direct Instruction rocks: Or does it?" [Hake (2013)], a response to "**Inquiry** Science rocks: Or does it?"

10. "The Arons Advocated Method" [Hake (2014)], accepted for publication in ***Inquiry**-Based Learning for Science, Technology, Engineering, and Math (STEM) Programs: A Conceptual and Practical Resource for Educators*.

11. "Scaffolding and Achievement in Problem-Based and **Inquiry** Learning: A Response to Kirschner, Sweller, and Clark (2006) [Hmelo-Silver, Duncan, & Chinn (2007)].

12. "Why Minimal Guidance During Instruction Does Not Work: An Analysis of the Failure of Constructivist, Discovery, Problem-Based, Experiential, and **Inquiry**-Based Teaching" [Kirschner, Sweller, & Clark (2006)].

13. "**Inquiry** Science rocks: Or does it?" [Klahr (2012)].

14. "**Inquiry**-based science instruction. What is it and does it matter? Results from a research synthesis years 1984 to 2002" [Minner, Levy, & Century (2010).

15. "***Inquiry** and the National Science Education Standards: A Guide for Teaching and Learning*" [NRC (2000)]

VII. Conclusions

Vague labels for pedagogical methods often impede the advancement of the learning sciences and sometimes misrepresent their findings to both the education community and the general public. In particular, Kirschner, Sweller, & Clark (KSC, 2006): (a) characterized constructivist, discovery, problem-based, experiential, and inquiry-based teaching methods as all "*minimally guided*," and (b) proclaimed them all to be *failures*. Assertions "a" and "b" are in direct contradiction to the fact that the operationally defined "interactive engagement" methods of physics education research are consistent with the tenets of Resnick & Hall's (1998) "knowledge-based constructivism" (KBC), 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)]. In addition, on pages 14-15 above I indicate 40 reports published in or before 2006 containing *EVIDENCE* for the superiority of KBC methods over passive-student direct instruction but not referenced in KSC (2006). 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'."

Acknowledgments

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AAAS EurekAlert. 1998. "Carnegie Mellon Researchers Say Direct Instruction, Rather Than 'Discovery Learning' Is Best Way To Teach Process Skills In Science," 13 February; online at <http://bit.ly/QoB9RX>. This is a report on Chen & Klahr (1999).

AAAS. 2014. *Project 2061*, online at <http://bit.ly/1gyTLHT>; especially:
(a) "Curriculum Materials" <http://bit.ly/1nCkvRN>,
(b) "Teaching and Learning" <http://bit.ly/1l21zKf>,
(c) "Testing and Assessment" <http://bit.ly/1mgmUjg>.

Adams, T. 2004. According to Strauss (2004):

> Thomas Adams, executive director of the [California] curriculum commission, said critics aremisrepresenting the panel's views. He said commission members are trying to balance theneed for a comprehensive science curriculum with the limited science background of manyK-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 andlimited 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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> Effective October 25, 2013 we will be closing the ADI office and dissolving the Association. We have explored many options to keep our doors open without success. During this period of time, we will be taking the necessary steps to ensure that you will have continued access to past issues of Direct Instruction News and the Journal of Direct Instruction as well as other professional resources. We are hopeful that another organization will step forward to run the 2014 Eugene conference.

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Ausubel, D.P. 2000. *The Acquisition and Retention of Knowledge: A Cognitive View*. Spinger, publisher's information at <http://bit.ly/HoHyqV>. Amazon.com information at <http://amzn.to/HktQSZ>, note the searchable "Look Inside" feature. In his "Preface" Ausubel <http://en.wikipedia.org/wiki/David_Ausubel> wrote:

> In 1963 an initial attempt was made in my *The Psychology of Meaningful Verbal Learning* to present a cognitive theory of meaningful as opposed to rote verbal learning. It was based on the proposition that the acquisition and retention of knowledge (particularly of verbal knowledge as, for example, in school, of subject-matter learning) is the product of an active, integrative, interactional process between instructional material (subject matter) and relevant ideas in the learner's cognitive structure to which the new ideas are relatable in particular ways. . . . . . . this new monograph was largely necessitated by the virtual collapse of the neobehavioristic theoretical orientation to learning during the previous forty years; and by the meteoric rise in the seventies and beyond of constructivist approaches to learning theory. . . . . .One possible weakness of the so-called "constructivist" position is that the [learner generates] new meanings which he purportedly "constructs" from the interaction between presented and related potential meanings in the latter's cognitive structure. This view seems to oversimplify and ignore somewhat the constraints and negative influences exerted by illusory relevances, misconceptions, subjective biases, motivational orientation to learning, cognitive style, and personality traits that enter involuntarily into the "constructive process.". . . . . eliminated from the present book was the chapter on discovery learning which is no longer the "hot issue" that it was in 1963. . . . . .Although glowing reports and theoretical articles on discovery learning continue to appear from time to time in the educational psychology and instructional research journals, the frequency of this occurrence has been steadily decreasing.

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> Discovery learning is often contrasted with didactic instruction. Both methods have their critics. On the one hand, there is considerable evidence that didactic teaching leads to passive learning. But, on the other hand, unguided discovery can be dangerous: children "discovering" in our classrooms are quite adept at inventing biological misconceptions (Brown 1992; Brown and Campione 1990; Brown and Palincsar 1989a). And the exact role of the teacher in discovery learning is still largely unchartered. We have argued in favor of a middle ground between didactic teaching and untrammeled discovery learning, that of "guided discovery" (Brown 1992; Brown and Palincsar 1989b) where the teacher acts as a facilitator, guiding the learning adventures of his or her charges. Guided discovery, however, is difficult to orchestrate. It takes sensitive clinical judgment to know when to intervene and when to leave well enough alone. To be successful, the guide must continually engage in on-line diagnosis of student understanding, and must be sensitive to the current "zone of proximal development" (Vygotsky 1978), the "region of sensitivity to instruction" (Wood and Middleton 1975), the "readiness arena," or "bandwidth of competence" (Brown 1979; Brown & Reeve (1987), where students are ripe for new learning. Guided discovery places a great deal of responsibility in the hands of the teacher, who must model, foster, and guide the "discovery" process into forms of disciplined inquiry that may not be reached without this expert guidance.

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> Physics faculty, experts in evidence-based research, often rely on anecdotal experience to guide their teaching practices. Adoption of research-based instructional strategies is surprisingly low, despite the large body of physics education research (PER) and strong dissemination effort of PER researchers and innovators. Evidence-based PER has validated specific non-traditional teaching practices, but many faculty raise valuable concerns toward their applicability. We address these concerns and identify future studies required to overcome the gap between research and practice. . . . . One of the most highly cited studies to compare student conceptual learning in traditionally taught environments to interactive classrooms was a meta-analysis conducted by Hake (1998a).

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Lave, J., and E. Wenger. 1991. *Situated Learning: Legitimate Peripheral Participation*. Cambridge University Press, publisher's information at <http://bit.ly/1eXrXAD>. Amazon.com information at <http://amzn.to/1e39FQs>, note the searchable "Look Inside" feature. See also Wenger (2000) and Wenger et al. (2002).

Laws, P., D. Sokoloff, & R. Thornton. 1999. "Promoting Active Learning Using the Results of Physics Education Research," *UniServe Science News* **13**, online at <http://bit.ly/1inppMF>.

Lipsey, M.W. & D.B. Wilson. 1993. "The Efficacy of Psychological, Educational, and Behavioral Treatment: Confirmation From Meta-Analysis," *American Psychologist* **48**(12): 1181-1209; online as a (3.4 MB) pdf at <http://bit.ly/1dRx81v>.

Note: The eleven K-12 science-education studies listed in Table 1, part 3.5.1: entries #3a,b, #4-7, #9-11, #13, #17 of Lipsey & Wilson (where the test group is characterized by reform methods) yield a total N = 888 students and average effect size <d> = 0.36 [Cohen (1988)]. Most of these studies include grades 4 or 6 to 12 with the effect size control group being traditional instruction) and the measurement unit being "achievement" or "learning" (presumably as measured by tests). What's the significance of <d> = 0.36? Cohen's (1988) rule of thumb, which is based on typical results in social science research, is that d = 0.2, 0.5, 0.8 implies respectively "small," "medium," and "large" effects. However, Cohen cautions that the adjectives " . . . . are relative, not only to each other, but to the area of behavioral science or even more particularly to the specific content and research method being employed in any given investigation."

Lopez, R.E. & T. Schultz. 2001. "Two Revolutions in K-8 Science Education," *Physics Today* **54**(9): 44-49; online at <http://bit.ly/1gHO0xC>.

Lowery, L.F. 1997. “The Nature of Learning,” FOSS Newsletter #10, online at <http://bit.ly/1hlk5M5>. Lowery wrote:

> A new consensus about the nature of learning has emerged. Its formation is stimulated by research in the field that has come to be known as cognitive science. The new conception of learning has a direct bearing on how science, and all other subjects, can be taught most effectively. The new view supports and provides a clearer understanding of the good things that foster learning and gives ideas for improving or changing those aspects that are ineffective or detrimental to learning. The view supports the intuition of our most thoughtful teachers, and it describes how learners best move from being novices to becoming experts. The view can be expressed quite simply:
> a. Learners construct understanding for themselves;
> b. Understanding is to know relationships;
> c. Knowing relationships depends upon prior knowledge.

Lowery, L.F. 2011. “Effective Teaching for Effective Learning,” a brief bio of Lawrence Lowery plus a video of his talk for the “How Students Learn Working Group” on 29 March 2011; online at <http://bit.ly/1gE2GIo>.

Mayer, R. 1987. “Learnable aspects of problem solving: some examples,” in *Applications of Cognitive Psychology: Problem Solving, Education, and Computing* [Berger, Pezdek, & Banks (1987, pp. 109–122)]. See also Mayer (1992).

Mayer, R. 1992. *Thinking, Problem Solving, Cognition*, 2nd ed. W.H. Freeman. Amazon.com information at <http://amzn.to/1gUOvPj>.

Mayer, R. 2004. “Should there be a three-strikes rule against pure discovery learning? The case for guided methods of instruction.” *American Psychologist* **59**: 14–19; online as a 52 kB pdf at <http://bit.ly/1fq6OfE>.

McDermott, L.C. 1991. “Millikan Lecture 1990: What we teach and what is learned - Closing the gap.” *Am. J. Phys*. 59 (4): 301-315; online as a 1.9 MB pdf at <http://bit.ly/1t1eAFV>.

McDermott L.C. & E.F. Redish. 1999. “RL-PER1: Resource letter on physics education Research,” *Am. J. Phys*. **67**(9): 755-767; online as a 127 kB pdf at <http://bit.ly/10hjC4R>.

McGilly, K. 1994. *Classroom Lessons: Integrating Cognitive Theory and Classroom Practice*. MIT Press, publisher’s information at <http://bit.ly/1l26kQr>. Amazon.com information at <http://amzn.to/1kXen5o>, not the searchable “Look Inside” feature. An expurgated Google book preview is online at <http://bit.ly/1ktLz1y>. Contains “Guided Discovery in a Community of Learners [Brown & Campione (1994) and “A Cognitive Approach to the Teaching of Physics” [Hunt & Minstrell (1994).

McKinnon, J.W. 1971. “Earth science, density, and the college freshman,” *J. Geol. Educ*. **19**(5): 218-220. An ERIC abstract, online at <http://1.usa.gov/1gzkCIV> states:

> Reports the results of testing 143 college freshmen on the meaning of density. Relates reasons for student inability to conceptualize density to the hierarchy of experiences which leads to the understanding of the density concept.

MCSC. 2008. Mathematically Correct Science Corner. The Mathematically Correct Science Corner went off-line several years ago but was archived at <http://bit.ly/1dUsfdO> by David Kline <http://bit.ly/ZIVIdN> of Cal State Northridge. This site features the opinions of direct instruction (in the passive-student sense) champion Stan Metzenberg (1998), a leader in the California Curriculum Commission’s attempt of enforce anti-hands-on science-education in K-8.

Metzenberg, S. 1998. Testimony before the U.S. House of Representatives. Stan Metzenberg was a leader in the California Curriculum Commission's attempt to enforce anti-hands-on science-education in K-8. Online at *Mathematically Correct Science Corner* – see MCSC. 2008 at <http://bit.ly/1dUsfdO> and (a) Click on "Stan Metzenberg at the House Science Committee" to bring up <http://bit.ly/1oyzI6C >, and (b) "Follow-Up Questions for Dr. Stan Metzenberg" to bring up <http://bit.ly/1lvwgFr>.

Meltzer, D.E. & R.K. Thornton. 2012. "Resource Letter ALIP-1: Active-Learning Instruction in Physics," *Am. J. Phys.* **80**(6): 478-496, the abstract, online at <http://bit.ly/O35gtB>, states:

> This Resource Letter provides a guide to the literature on research-based active-learning instruction in physics. These are instructional methods that are based on, assessed by, and validated through research on the teaching and learning of physics. They involve students in their own learning more deeply and more intensely than does traditional instruction, particularly during class time. The instructional methods and supporting body of research reviewed here offer potential for significantly improved learning in comparison to traditional lecture-based methods of college and university physics instruction. We begin with an introduction to the history of active learning in physics in the United States, and then discuss some methods for and outcomes of assessing pedagogical effectiveness. We enumerate and describe common characteristics of successful active-learning instructional strategies in physics. We then discuss a range of methods for introducing active-learning instruction in physics and provide references to those methods for which there is published documentation of student learning gains.

Michael, J. 2006. "Where's the evidence that active learning works?" *Advances in Physiology Education*, **30**: 159-167; online at <http://bit.ly/1eJPveD>.

Miller, G. A. 1956. "The magical number seven, plus or minus two: Some limits on our capacity for processing information," *Psychological Review* **63**: 81-97; online at <http://bit.ly/1lGbmWF>.

Millis, B.J. 2010. *Cooperative Learning in Higher Education: Across the Disciplines, Across the Academy*. Stylus, publisher's information at <http://bit.ly/cnftxU>. Amazon.com information at <http://amzn.to/9tXDQr>, note the searchable "Look Inside" feature. An expurgated Google book preview is online at <http://bit.ly/1kZr2R8>.

Minner, D.D., A.J. Levy, & J. Century. 2010. "Inquiry-based science instruction. What is it and does it matter? Results from a research synthesis years 1984 to 2002," *Journal of Research in Science Teaching* **47**: 474-496; online as a 197 kB pdf at <http://bit.ly/wdJq4R>. They wrote (my *italics*):

> Various findings across 138 analyzed studies *indicate a clear, positive trend favoring inquiry-based instructional practices*, particularly instruction that emphasizes student active thinking and drawing conclusions from data. . . . . . . We did not find, however, that overall high levels of inquiry saturation in instruction were associated with more positive learning outcomes for students. The only learning associations we found with the amount of inquiry saturation were modest.

I thank David Klahr for pointing out the latter "We did not find. . . " in a private communication of 25 October 2010.

Mintzes, J.J. J.H. Wandersee, & J.D. Novak. 2004. *Assessing Science Understanding: A Human Constructivist View*. Academic Press. Amazon.com information at <http://amzn.to/1fae27s>, note the searchable "Look Inside" feature/

Mintzes, J.J. & W.H. Lenard, eds. 2006. *Handbook of College Science Teaching*. NSTA Press. Amazon.com information at <http://amzn.to/nF67Cq>. An expurgated Google book preview is online at <http://bit.ly/1dddSkx>. The preview contains pages 119-120 of Novak's valuable Chapter 12 "Learning Science and the Science of Learning." See also Mintzes et al. (2004).

Nelson, C. 2010. "Want Brighter, Harder Working Working Students? Change Pedagogies!" Chapter 8 in *Cooperative Learning in Higher Education* [Millis (2010, pp. 119-139)]. Nelson wrote:

> Hake (1998a, 2002a) has assembled the most impressive data set assessing the effectiveness of alternate pedagogical strategies in science.

Newell, A. & H.A. Simon. 1972. *Human Problem Solving*. Prentice Hall. Amazon.com information at <http://amzn.to/1gZNVV6>. See also: (a) "Human Problem Solving: The State Of The Theory In 1970" online as a 1.5 MB pdf at <http://bit.ly/1nDVC8d>, based on the final chapter of *Human Problem Solving*; (b) Eugene Garfield's "This week's classic citation" at <http://bit.ly/1mRH6Zf>.

Novak, J. D. 1988. "Learning Science and the Science of Learning," *Studies in Science Education* **15**: 77–101. A first page preview is online at <http://bit.ly/1oBcqgD>. The abstract reads:

> In the past two decades, significant advances have occurred in two fields that have great importance for science education. Learning psychology dealing with humans has largely moved away for its seventy-five year dominance by behavioral psychology and toward a science of cognitive function that places emphasis on the role that concepts and conceptual and conceptual frameworks play in human construction of meaning. Epistemology, the field of philosophy dealing with the nature of knowledge and knowledge production, has moved away from earlier empiricist and positivist that centered on experiments designed for proof or falsification of hypotheses to establish 'truths' toward constructivist views that center attention on the complementation between concepts, principles, and theories we apply to observation of events and the resultant construction of knowledge claims. In the latter view we see science not as 'truth seeking' but rather as the construction of explanatory models that encompass wider ranges of phenomena, that is, models that are robust and parsimonious. Together, advances in these two domains of human endeavor are leading us rapidly toward a new science of learning with great import for the learning of science.

See also Mintzes & Lenard's (2006) chapter 12, "Learning Science and the Science of Learning," pp. 119-128 by Novak, which contains a recap of some of the key points of this article along with a discussion of more recent work.

NRC. 1996. *National Science Education Standards*. National Academies Press; online at <http://bit.ly/PEccFF>.

NRC. 1997. *Science Teaching Reconsidered: A Handbook*, National Academy Press; online at <http://bit.ly/1gZVQBV>. This is oriented towards postsecondary education. See especially Chapter 2, "How Teachers Teach: Specific Methods."

NRC. 1999. *Improving Student Learning: A Strategic Plan for Education Research and Its Utilization*, National Academies Press; online at <http://bit.ly/1mMgi9R>.

NRC. 2000. "*Inquiry and the National Science Education Standards: A Guide for Teaching and Learning*," National Academies Press; online in at <http://bit.ly/zM0tEP> (click on "Download"). See especially biologist Bruce Alberts' foreword: "A Scientists Perspective on Inquiry" for his characterization of "inquiry teaching":

> Teaching science through inquiry allows students to conceptualize a question and then seek possible explanations that respond to that question . . . . . Inquiry is in part a state of mind - that of inquisitiveness.

NRC. 2011. *Promising Practices in Undergraduate Science, Technology, Engineering, and Mathematics Education: Summary of Two Workshops*, online at <http://bit.ly/nCMLk7>. Natalie Nielsen, Rapporteur. Planning Committee on Evidence on Selected Innovations in Undergraduate STEM Education: Susan Singer (Chair), Melvin George, Kenneth Heller, David Mogk, & William B. Wood. The National Academies Press; online at <http://bit.ly/nCMLk7>.

NRC. 2013. *Adapting to a Changing World - Challenges and Opportunities in Undergraduate Physics Education*. National Academy Press, online at <http://bit.ly/126os6j>. On page 35 it's stated (slightly edited):

> One of the most robust findings from Physics Education Research is that traditional, lecture-style introductory courses have little long-lasting effect on students' erroneous notions about the physical world (McDermott, 1991; Hake, 1998a). . . . . .[["McDermott, 1991" was *not* referenced in NRC (2013), (probably due to an oversight) but the probably intended reference is given in the reference list below]]. . . . . . . This can be assessed by asking students simple questions such as making a prediction or drawing an inference about a physical situation. Memorization of formulas or even a relatively high level of skill at solving traditional end-of-chapter problems is inadequate for reasoning in these situation. . . . . Hake's (1998) seminal report on the effectiveness of interactive engagement methods remains an important contribution to undergraduate physics education. His article presents results from the Mechanics Diagnostic (MD) (Halloun and Hestenes, 1985a) and its successor, the Force Concept Inventory (FCI) (Hestenese et al., 1992), given before and after instruction on Newtonian mechanics in a variety of courses taught using different approaches. . . . . The plot reproduced in Figure 2.5. . . . [[same as Fig.1 of Hake (1998a)]]. . . . . shows the average gain in score (the percentage of correct answers on the posttest minus the percentage of correct answers on the pretest) against pretest score. Two main features of the plot are that (1) overall, scores are low and do not increase much as a result of instruction; and (2) in the courses in which the largest increases were reported, some sort of interactive technique was used.

NRC. 2014. *STEM Integration in K-12 Education: Status, Prospects, and an Agenda for Research*. National Academy Press, online at <http://bit.ly/1gEq3Tb>. The description reads, in part:

> [This book] examines current efforts to connect the STEM disciplines in K-12 education. This report identifies and characterizes existing approaches to integrated STEM education, both in formal and after- and out-of-school settings. The report reviews the evidence for the impact of integrated approaches on various student outcomes, and it proposes a set of priority research questions to advance the understanding of integrated STEM education. STEM Integration in K-12 Education proposes a framework to provide a common perspective and vocabulary for researchers, practitioners, and others to identify, discuss, and investigate specific integrated STEM initiatives within the K-12 education system of the United States.

Paas, F. & P. Ayres. 2014. "Cognitive Load Theory: A Broader View on the Role of Memory in Learning and Education," *Educational Psychology Review*, March, an abstract is online at <http://bit.ly/1jk0Qyc>.

Papert, S. 1993. *Mindstorms: Children, computers, and powerful ideas*. 2nd ed. Basic Books. Amazon.com information at <http://amzn.to/QmaV6k>, note the searchable "Look Inside" feature. First published in 1980. At the beginning of Chapter 1 "Computers and Computer Cultures," Papert wrote:

> The powerful image of child as epistemologist caught my imagination while I was working with Piaget. In 1964, after five years at Piaget's "Center for Genetic Epistemology" in Geneva, I came away impressed by his way of looking at children as active builders of their own intellectual structures. But to say that intellectual structures are built by the learner rather than the teacher does not mean that they are built from nothing. On the contrary: Like other builders, children appropriate to their own use materials they find about them, most saliently the models and metaphors suggested by the surrounding culture.

Peterson, L. & M. Peterson. 1959. "Short-term Retention of Individual Verbal Items," *Journal of Experimental Psychology* **58**: 193-198; online as a 434 kB pdf at <http://bit.ly/1gH0Pqx>.

Phillips, D. C. 1995. "The good, the bad, and the ugly: The many faces of constructivism," *Educational Researcher* **24**(7): 5-12; online to subscribers at <http://bit.ly/1nDYWQw>, Reprinted in Curren (2006). Also reprinted with some changes and additions as Chapter 1 of Phillips (2000). See also Taber's (2006) "Constructivism's New Clothes: The Trivial, the Contingent, and a Progressive Research Programme into the Learning of Science."

Phillips, D.C. 2000. *Expanded social scientist's bestiary: a guide to fabled threats to, and defenses of, naturalistic social science*. Rowman & Littlefield; publisher's information at <http://bit.ly/Jb1cXz>. Amazon.com information at <http://amzn.to/1dYCiya>, note the searchable "Look Inside feature. An expurgated Google book preview is online at <http://bit.ly/1dUZgqd>.

Phillips D.C. & N.C. Burbules. 2000. *Postpositivism and Educational Research*. Rowman & Littlefield; publisher's information at <http://bit.ly/Q33Wyf>. Amazon.com information at <http://amzn.to/1mJQTgT>, note the searchable "Look Inside feature. An expurgated Google book preview is online at <http://bit.ly/1gX1C7t>. See especially "Mistaken accounts of positivism," pp. 11-14.

Phillips, D.C., & J.F. Soltis. 2009. *Perspectives on Learning, 5th* ed. Teachers College Press, publisher's information at <http://bit.ly/1lLgc50>. Amazon.com information at <http://amzn.to/1e5bgoM>, note the searchable "Look Inside" feature. An expurgated Google book preview is online at <http://bit.ly/1mUzjHa>.

Poincaré, H. 1905. *Science and Hypothesis*, Walter Scott Publishing; online at <http://bit.ly/9hVfA8> thanks to the "Mead Project." A Wikipedia entry on Poincaré is at <http://bit.ly/b4jGVS>.

Prince, M. 2004. "Does Active Learning Work? A Review of the Research," *Journal of Engineering Education* **93**(3): 223–231; online as a 770 kB pdf at <http://bit.ly/rkiBjq>. The abstract reads:

> This study examines the evidence for the effectiveness of active learning. It defines the common forms of active learning most relevant for engineering faculty and critically examines the core element of each method. It is found that there is broad but uneven support for the core elements of active, collaborative, cooperative and problem-based learning.

Redish, E.F., J.M Saul, & R.N. Steinberg, 1997. "On the effectiveness of active-engagement microcomputer-based laboratories," *Am. J. Phys*. **65**(1); 45–54; online as a 123 kB pdf at <http://bit.ly/1ifiFzN>.

Resnick, L.B. 1987. *Education and Learning to Think*, National Academy Press, online at <http://bit.ly/1mKuL6e>.

Resnick, L.B., ed. 1989. *Knowing, learning, and instruction: Essays in honor of Robert Glaser*. Lawrence Erlbaum. Amazon.com information at <http://amzn.to/1n0o4gj>. An expurgated Google book preview is online at <http://bit.ly/1iONhX3>.

Resnick, L.B. and M.W. Hall. 1998. "Learning Organizations for Sustainable Education Reform," *Daedalus* **127**(4): 89-118; online at <http://bit.ly/1dVMV5h>, scroll down to the above title, then click on "Download."

Rose, C.P., J.D. Moore, K. VanLehn, & D. Allbritton. 2001. "A Comparative Evaluation of Socratic versus Didactic Tutoring," 23rd Annual Conference Cognitive Sciences Society, 1-4 August, Edinburgh, Scotland; online as a 152 kB pdf at <http://bit.ly/1lGHU2O>.

Ross, D.A. & N.M. Martin. 2006. Review of Geary (2005), *Am. J. Psychiatry* **163**: 1652-1653, September; online at <http://bit.ly/1hq37pZ>.

Ross, B.H., ed. 2003. *The Psychology Of Learning And Motivation,* Vol. 43, Academic Press. Amazon.com information at <http://amzn.to/1g4tKog>, note the searchable "Look Inside" feature. A Google book preview is online at <http://bit.ly/1n3NN7N>.

Scardamalia, M., J. Bransford, B. Kozma, E. Quellmalz. 2012. *New Assessments and Environments for Knowledge Building*. 2012. Springer, publisher's information at <http://bit.ly/1n5WZs5>, including 186 references. A pre-publication draft is online at <http://bit.ly/1i5kP6R>.

Schmidt, H.G., S.M.M. Loyens, T. van Gog, & F. Paas. 2007. “Problem-Based Learning is Compatible with Human Cognitive Architecture: Commentary on Kirschner, Sweller, and Clark (2006),” *Educational Psychologist* **42**(2): 91-97; online as a 72 kB pdf at <http://bit.ly/9uwVc8>.

SEF-GA. 2014. Science Education Foundation – General Atomics; online at <http://bit.ly/MNqnok>, thanks to Larry Woolf and his associates at General Atomics.

Shavelson, R.J. & L. Towne, eds. 2002. *Scientific Research in Education*, National Academy Press; online at <http://bit.ly/MgPHAk>.

Shavelson, R. 2004. According to Adelson’s (2004) report on Klahr & Nigam (2004):

> Psychologist Rich Shavelson . . . . notes that totally unguided discovery of the type used in the study is rarely used in the classroom.

Shavelson, R.J. 2008. “Formative Assessment,” Guest Editor's Introduction, special issue *Applied Measurement in Education*; online at <http://bit.ly/nn2Rcz>. Five articles on formative assessment/evaluation which appeared in *Applied Measurement in Education* are at this same site. Note that Shavelson and his collaborators: (1) are primarily concerned with K-12 education; and (2) use “formative assessment” (a) in the same sense as Black & Wiliam (1998): “All those activities undertaken to provide information to be used as feedback so as to adapt the teaching to meet student needs,” but (b) *not* in same sense as the “Joint Committee on Standards for Educational Evaluation” and “The Physics Education Reform Effort: A Possible Model for Higher Education” [Hake (2005a)]: “Evaluation designed and used to improve an object, especially when it is still being developed”– see Yarbrough et al. (2011]. See also Hake’s 2014 discussion-list post “Two Different Meanings of "Formative Evaluation #2” at <http://bit.ly/1e8Zhpr>.

Shulman, L. & E. Keisler, eds. 1966. *Learning by discovery: A critical appraisal*. Rand McNally. Amazon.com information at <http://amzn.to/QmlypK>. The first 2.5 paragraphs are online at <http://bit.ly/1l0dMM1> thanks to JSTOR. An ERIC abstract at <http://1.usa.gov/Q9J61p> reads:

> This volume is divided into five major sections. In the first section, Hawkins states that there are certain things which can only be learned by discovery. Glaser implies that when an object is described in behavioral terms, the behavior is teachable. In the second section, Wittrock reviews the literature of research. Cronbach presents a critical analysis of research on learning by discovery and on education. In the third section, Bruner describes the activities of classes engaged in some unique approaches to the social sciences. Davis discusses the ways in which learning by discovery has influenced the Madison Project. A hierarchical model of kinds of learning is used by Gagne as a tool for analyzing the relevance of discovery in learning. Kagan analyzes parapsychological variables. In the final section, Kendler and Morrisett review and analyze the preceding papers. Keislar and Shulman present a retrospective analysis of the conference and a prospectus for future research. A common bibliography is appended. This book is the proceedings of a conference on learning by discovery. . . . .

Spector, J.M., M.D. Merrill, J. vanMerrienboer, & M.P. Driscoll, eds. 2007. *Handbook of Research on Educational Communications and Technology*, 3rd ed., Lawrence Erlbaum. Amazon.com information at <http://amzn.to/R2YA87>, note the searchable “Look Inside” feature. An expurgated Google book preview is online at <http://bit.ly/1qzEIFS>. See also the more recent Spector et al. (2014)

Spector, J.M., M.D. Merrill, J. Elen, & M.J. Bishop, eds. 2014. *Handbook of Research on Educational Communications and Technology*, 4th ed., Springer, publisher’s information at <http://bit.ly/1g7mjcI>, including the Table of Contents, Preface, and Sample pages. Amazon.com information at <http://amzn.to/1hhc9dE>, note the searchable “Look Inside” feature.

Springer, L., M.E. Stanne, and S.D. Donovan. 1999. “Undergraduates in science, mathematics, engineering, and technology: a meta-analysis.” *Review of Educational Research* **69**(1): 21-51. online as a 164 kB pdf at <http://bit.ly/1lbJPZo>.

Steffe, L., & J. Gale, eds. 1995. *Constructivism in Education*. Lawrence Erlbaum. Amazon.com information at <http://amzn.to/1oBq8Qu>. According to the preface the core paradigms discussed in this book are "social constructivism, radical constructivism, social constructionism, information-processing constructivism, cybernetic systems, and sociocultural approaches to mediated action."

Strauss, V. 2004. "Back to Basics vs. Hands-On Instruction: California Rethinks Science Labs," *Washington Post*, Tuesday, 3 February, page A12; online at <http://bit.ly/1mMwkk8> thanks to *CENGAGE Learning* <http://www.cengage.com/us/>.

Sweller, J. & G.A. Cooper. 1985. "The use of worked examples as a substitute for problem solving in learning algebra," *Cognition and Instruction* **2**: 59–89; an abstract is online at <http://bit.ly/1hO4kfa>. See also Cooper (1998).

Sweller, J., J. Jeroen, G. van Merrienboer, & F.G.W.C. Paas. 1998. "Cognitive Architecture and Instructional Design," *Educational Psychology Review* ***10***(3); the abstract and the first two pages are online at <http://bit.ly/1oHoVav>. The abstract reads:

> Cognitive load theory has been designed to provide guidelines intended to assist in the presentation of information in a manner that encourages learner activities that optimize intellectual performance. The theory assumes a limited capacity working memory that includes partially independent subcomponents to deal with auditory/verbal material and visual/2- or 3-dimensional information as well as an effectively unlimited long-term memory, holding schemas that vary in their degree of automation. These structures and functions of human cognitive architecture have been used to design a variety of novel instructional procedures based on the assumption that working memory load should be reduced and schema construction encouraged. This paper reviews the theory and the instructional designs generated by it.

Richard Hake 4/7/14 11:19 AM
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Sweller, J. 2003. "Evolution Of Human Cognitive Architecture," in *The Psychology Of Learning And Motivation,* Vol. 43 [Ross (2003, pp. 215–266)]. See also Sweller et al. (1998), Sweller (2007), Sweller & Sweller (2006), and Sweller (2012).

Sweller, J., & S. Sweller. 2006. "Natural information processing systems," *Evolutionary Psychology* **4**: 434–458; online as a 156 kB pdf at <http://bit.ly/1qyDLeY>.

Sweller, J. 2007. "Human Cognitive Architecture" in *Handbook of Research on Educational Communications and Technology* Spector et al. (2007, pp. 369-381); online as a 184 kB pdf at <http://bit.ly/1jP5vvC>. Cognitive Load Theory (CLT) is discussed on pages 372-379. For interesting comments on CLT see:
(a) "Cognitive Load Theory: A Broader View on the Role of Memory in Learning and Education" [Paas & Ayres (2014)]; and
(b) learning technologist Doug Holton's "EdTechDev" blog entry "Cognitive Load Theory: Failure?" at <http://bit.ly/1sHJXoK>. Holton provides well-referenced discussions of "conceptual problems with CLT" and "methodological problems with CLT Research."

Sweller, J. , P.A. Kirschner, & R.E. Clark. 2007. "Why Minimally Guided Teaching Techniques Do Not Work: A Reply to Commentaries," *Educational Psychologist* **42**(2): 115-121; online as a 78 kB pdf at <http://bit.ly/p6wXB3>.

Sweller, J. 2012. "An Interview with John Sweller," YouTube talk; online at <http://bit.ly/1lAwVVX>. As of 26 April 2014 14:12-0800 this video had been viewed 1,095 times.

Taber, K.S. 2006. “Constructivism's New Clothes: The Trivial, the Contingent, and a Progressive Research Programme into the Learning of Science,” *Foundations of Chemistry* **8**(2): 1572-8463; in a special issue “Constructivism in Chemical Education,” the abstract and the first two pages are online at <http://bit.ly/1epDw0q> (click on the orange “Look Inside” sign).

Taber, K.S. 2007. Review of Geary (2007) in *Education Review: A Journal of Book Reviews*; online at <http://bit.ly/1hMhwNq>.

Taber, K.S. 2010a. “Constructivism and Direct Instruction as Competing Instructional Paradigms: An Essay Review of Tobias & Duffy (2009)” *Education Review* **13**(8); online at <http://bit.ly/9NlULx>. See also Taber (2010b).

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