15 "To Every Thing There is a Season, and a Time to Every Purpose Under the Heavens"

What about Direct Instruction?*

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In this chapter, I address three questions that recur through this volume: (a) How does direct instruction differ from discovery learning? (b) When should direct instruction be used? and (c) What aspects of disciplinary practice should be included in early science education?

The first issue focuses on the features that distinguish direct instruction from discovery learning. Over the past 20 years or so, and culminating in the critique (Kirschner, Sweller, & Clark, 2006) and debate at the 2007 AERA meeting that motivated this volume, there have been extensive and heated exchanges among education researchers, learning scientists, and science educators about "discovery learning," "direct instruction," "authentic inquiry," and "hands-on science" (Adelson, 2004; Begley, 2004; EDC, 2006; Hmelo-Silver, Duncan, & Chinn, 2007; Janulaw, 2004; Klahr, Triona, & Williams, 2007; Kuhn, 2007; Ruby, 2001; Strauss, 2004; Tweed, 2004; Schmidt, Loyens, van Gog, & Paas, 2007). However, these arguments typically fail to establish a common vocabulary to define the essential aspects of the types of instruction being compared. I believe that in order to advance our ability to create effective instructional procedures, our field needs to become much more precise in the terminology it uses to describe instructional contexts and procedures, before moving on to advocacy about curriculum design. In the area of science education, more than others, it is particularly troubling—and ironic—that these debates often abandon one of the foundations of science: the operational definition. But a scientific field cannot advance without clear, unambiguous, and replicable procedures.

The second issue is about the place of direct instruction in the context of a constructivist perspective. Simply put: "When is it appropriate to use direct instruction?". The answer to the question is certainly not "never." Even the most zealous constructivist would acknowledge that there exist combinations of time, place, topic, learner, and context, when it is optimal to simply tell students something, or to show them something, or to give them explicit instruction about something. But how can we identify and characterize such instances?

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The third issue is about content. Should early science education include instruction—at any location on the direct to discovery dimension—about disciplinary practices? Advocates of constructivism believe that the answer is "yes." For example, Hmelo-Silver et al. (2007) claim that "In the case of science education in particular, a large body of research supports the importance of understanding the nature of scientific research and the practices involved as a critical part of scientific literacy" (p. 105). Although there are several aspects of constructivist approaches to science of which I am critical, on this point I tend to agree. However, my emphasis differs in two respects from what constructivist advocates usually mean by "disciplinary practice." One point of difference is about content: I propose that the aspect of disciplinary practice that should be included in the science curriculum is our knowledge about basic cognitive processes. More specifically, I will argue that students should be taught something about what the learning sciences have discovered regarding how people think, and how those thinking processes lead to scientific discovery. The other point of difference is that I believe that this topic should be taught as explicitly and directly as possible.

What is Direct Instruction in Science?

Because instructional methods are inextricably bound to specific learning goals, I will start by describing the context in which my colleagues and I have contrasted the different types of instruction described in this chapter. Our focal domain—the Control of Variables Strategy (CVS)—is a small but essential part of the middle school science instruction. Procedurally, CVS is a domain-general method for creating experiments in which a single contrast is made between experimental conditions so that the causal status of the contrasted variable on the outcome can be unambiguously determined. Mastery of CVS includes the ability to create unconfounded experiments, to make appropriate inferences from their outcomes, and to understand and articulate the indeterminacy of confounded experiments.

The experimental set up depicted in Figure 15.1 provides a referent for the following example. The aim of our initial instruction is to teach a set of conditional rules that enable students to (a) identify the focal variable in a simple experiment (e.g., ramp height); (b) establish two different, contrasting values for that variable (a high ramp and a low ramp); (c) ensure that all the other variables are the same in both conditions (e.g., ball type, ramp surface, length of run); (d) understand that if the two ramps produce different outcomes (distance the ball travels), then they can make the inference that height is a causal factor, but that this inference is only possible because the other potentially causal variables have identical values on each ramp. The specific experimental set up depicted in Figure 15.1 is, of course, completely confounded because each of the potentially causal variables is set at a different level.

The aim of the Chen and Klahr (1999) study was to determine the relative effectiveness of three levels of "directness" in teaching CVS. The three types of instruction are described in the next section. Before turning to that, it is impor-

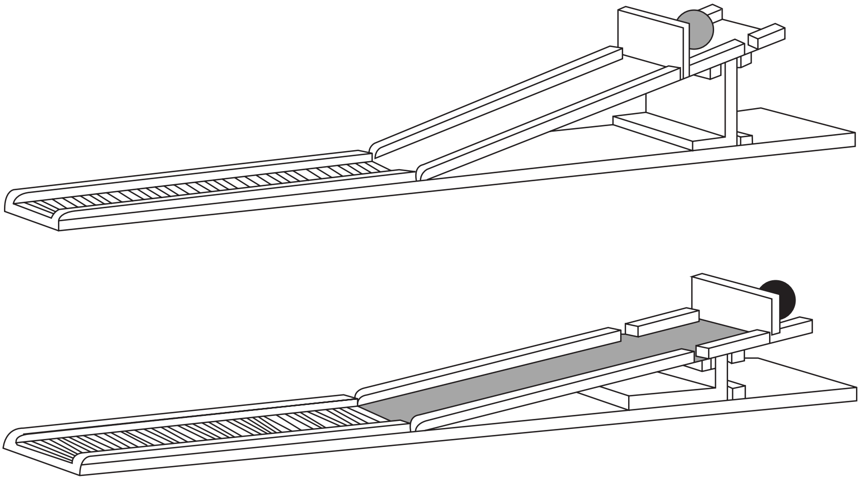

Figure 15.1 Ramps. One of several types of physical materials used in our CVS training studies. On each of the two ramps, children could vary the steepness, surface, and length of the ramp, as well as the type of ball. The confounded experiment depicted here contrasts (a) a golf ball on a steep, smooth, short ramp with (b) a rubber ball on a shallow, rough, long ramp.

tant to note that, in order to minimize potential effects of physical context, the study also used—as another between-subjects variable—three different sets of materials with the same underlying factorial structure: (a) slopes, as shown in Figure 15.1; (b) springs of varying length, width, wire size, and weight; and (c) sinking objects of different size, material, shape, and height above water. (See

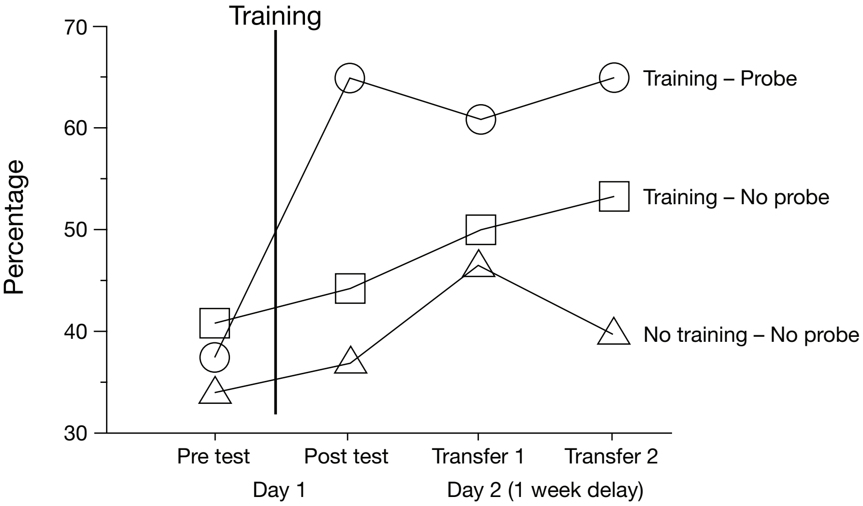

Figure 15.2 Percentage of trials with correct use of CVS by phase and training condition (source: adapted from Chen & Klahr, 1999, Figure 3).

Table 15.1 Materials used in Chen and Klahr (1999).

	Domain		
	Springs	*Slopes*	*Sinking*
Primary materials	Eight springs that vary on three variables A frame for hanging two springs Two sets of weights, a heavy pair and a light pair	Two ramps each with adjustable angle and "starting gate" location Two sets of two balls, golf and rubber (squash) Two two-sided surface inserts (for ramps) with different coefficients of friction	Two water-filled cylinders, with two drop heights indicated Eight objects that vary on three variables Scooper and magnet for retrieving sunken objects
To be determined	What factors determine how far a spring will stretch?	What factors determine how far a ball will roll down a ramp?	What factors determine how fast an object will sink in water?
Variable two independent values for each of four variables[a]	• length long, short • coil diameter wide, narrow • wire diameter thick, thin • weight size heavy, light	• angle high, low • starting gate short, long • surface smooth, rough • ball golf, rubber	• shape cube, sphere • material steel, Teflon • size large, small • height high, low
Dependent measure	Length of extension (for distance from base of rack when weight is added)	Distance ball rolls at end of ramp	Speed of sinking in water (for which reaches bottom first)
Subject activity			
Experimental design	From set of eight springs: • Select two springs • Hang spring on rack hooks • Select weights to go with each spring	For each of two ramps: • Select one or two angles • One of two surfaces • One of two starting positions • Select one of two balls to run	From set of eight objects: • Select two objects • For each object select one of two heights from which to drop object

Experiment execution	Hang weights on springs Observe amount of stretching (for distance from base)	Release gates (not necessarily simultaneously), allowing balls to roll Observe distance balls roll after leaving ramp	Simultaneously drop each object into water-filled cylinder Observe relative sink rates for arrival times at bottom of cylinder
Notable aspects of domain and procedure	All variables investigated are integral to selected spring Choice is from among pre-existing springs having a "cluster" of variable values Experiment is easy to set up and execute (no timing issues) Measurement is easy (stable outcome)	Variables are independent, object is constructed from choice of values for each variable Comparison objects are constructed; variable values are not clustered Outcome is evanescent (if based on speed), or stable (if based on final distance)	All variables investigated are integral to selected object Choice is among pre-existing objects having a "cluster" of variable values Easy to set up (simply choose two objects and heights) Simultaneity necessary at start of drop Outcome must be observed instantly, otherwise it is lost

Table 15.1 for details.) These three domains were also used to assess transfer of CVS knowledge elements beyond the physical domain in which they were acquired. Thus, children whose initial instruction occurred in the ramps domain were assessed on the transfer trials using springs and sinking objects. Children who had worked with springs during instruction were assessed with ramps and sinking objects on the transfer trials, and so on. This counterbalancing allowed Chen and Klahr (1999) to assess the extent to which the deep structure of CVS procedures and concepts had been generalized beyond the specific physical context in which they had been acquired.

Terminology Used to Describe Different Types of Instruction

Chen and Klahr (1999) did not use the terms “direct instruction” or “discovery learning” in describing their three contrasting instructional conditions. They called them “Training-Probe,” “No-Training Probe,” and “No-Training, No-Probe,” and defined them as follows:

> In the *Training–Probe* condition, children were given explicit instruction regarding CVS. Training ... included an explanation of the rationale behind controlling variables as well as examples of how to make unconfounded comparisons. ... A probe question before the test was executed asked children to explain why they designed the particular test they did. After the test was executed, children were asked if they could “tell for sure” from the test whether the variable they were testing made a difference and also why they were sure or not sure. In the *No-Training Probe* condition, children received no explicit training, but they did receive the same series of probe questions surrounding each comparison as were used in the *Training–Probe* condition. Children in the *No Training–No Probe* condition received neither training nor probes.
>
> (Chen & Klahr, 1999, p. 1101)

The results of the study were unambiguous. As shown in Figure 15.2, the Training-Probe condition, in which students received explicit instruction and were prompted to explain their reasoning, was by far the most effective, both immediately following training and after a one-week delay.

However, since I am arguing here that unambiguous definitions are essential to the advance of a science and the resolution of its controversies, it is embarrassing to admit that we used more conventional (and controversial) usage in other sections of that paper by discussing the contrast between “direct instruction” and “discovery learning.” In a subsequent paper on teaching CVS to third- and fourth-graders (Klahr & Nigam, 2004), we abandoned all caution and called the contrasting instructional procedures—in this study, only two types of instruction, rather than three as in Chen and Klahr (1999)—“Direct Instruction” (previously called “Training-Probe”) and “Discovery Learning” (previously called “No-Training, No-Probe”). We did attempt to clarify the way in which we defined these two types of instruction:

> The ... difference between Direct Instruction and Discovery Learning does not involve a difference between "active" and "passive" learning. In both conditions, students were actively engaged in the design of their experiments and the physical manipulation of the apparatus. The main distinction is that in Direct Instruction, the instructor provided good and bad examples of CVS, explained what the differences were between them, and told the students how and why CVS worked; whereas, in the discovery condition, there were no examples and no explanations, even though there was an equivalent amount of design and manipulation of materials.
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> (Klahr & Nigam, 2004, p. 663)

Interpretations of Our Procedures

Responses to our studies reveal the lack of a widely shared understanding of what a constructivist science curriculum entails, even among its advocates. The first type of critique was that our discovery-learning condition is not representative of what really transpires in discovery-oriented instruction because it provides so little guidance, motivation, and interactive engagement. Hake (2004) wrote that:

> Of course, neither "inquiry" nor "interactive engagement" methods should be confused with the extreme "discovery learning" mode, researched by Klahr and Nigam (2004). Their research suggests that, not surprisingly, an *extreme* mode of "discovery learning," in which there is almost no teacher guidance, is inferior to "direct instruction" for increasing third and fourth grade children's effective use of the control of variables strategy, a so-called "process skill".

But our discovery condition included hands-on instruction in which the teacher described the experimental apparatus and suggested a goal ("see if you can set up the ramps to see if the height of the ramp makes a difference"), and then the child was free to explore various kinds of arrangements, run the experiments, observe the results, and finally, under teacher suggestion, move on to another goal, such as "see if you can set up the ramps to see if the surface of the ramp makes a difference in how far the ball rolls." Rather than being a parody of the lack of structure in discovery learning, our discovery condition actually included more scaffolding than discovery learning as typically practiced.

The second type of critique took a diametrically opposite position to the first in its interpretation of the relation between our conditions and "authentic" discovery learning. It argued that our more effective procedure—our "Direct Instruction"—was, in fact, very close to what good constructivist pedagogy would recommend. In a personal letter that I received from a world-class scientist and ardent advocate of discovery learning, I was cautioned that:

> In California, and in many other places, the term "direct instruction" ... basically means telling, without any doing.... Your ... studies were of course all about guided inquiry.... The fact that you used the bare term "direct

> instruction" for your favored option must have delighted those who want to teach with no inquiry at all.

Note that, under this interpretation, our direct-instruction condition, criticized as being unfairly compared to a parody of discovery learning by the first type of critique, has become an instance of guided inquiry!

The third type of critique was that our findings might be used to "return to a traditional, fact-oriented, teacher-centered model" (Kohn & Janulaw, 2004, p. 41). Such a critique suggests that more attention was paid to our terminology than to our actual instructional procedures because our instructional objective was neither traditional nor fact-oriented. (Although it is hard to understand why, in science of all areas, "fact oriented" is used pejoratively.) Instead, the instructional goal was that children know how to design and interpret unconfounded experiments, that is, how to vary only one factor at a time, how to avoid varying multiple factors simultaneously, and why it is possible to make an unambiguous causal inference from the former type of experiment but not the latter. It is true that the teacher followed a very careful script, directed the child's attention to features of confounded and unconfounded experiments, asked questions, and corrected faulty causal reasoning. Is this being teacher-centered, or is it "scaffolding"?

In all of these studies, the immediate effect of the contrasting instructional methods consistently favored direct instruction. For example Klahr and Nigam (2004) found that 77% of the children in the direct-instruction condition, but only 23% of those in the "discovery" condition, reached the mastery criterion on CVS immediate post-tests. This finding is typical of our series of studies in three respects. First, many more children reach high levels of performance in our direct-instruction condition. Second, so do a non-trivial proportion of children in the "discovery" condition (see also Chen & Klahr, 1999; Triona & Klahr, 2003; Toth, Klahr, & Chen, 2000). Third, even in our direct-instruction condition another non-trivial proportion of children did not reach high performance levels, so direct instruction is certainly not perfect.

However, the primary goal of the Klahr and Nigam paper was not to compare the relative effectiveness of one form of instruction over another on an immediate, near-transfer assessment. Instead, the goal was to show that once students have mastered a procedure (such as how to design a simple, unconfounded experiment), then the *way* that they achieved that mastery—via one instructional method or another—does not matter on a "far-transfer task." Klahr and Nigam (2004) called this the "path independence hypothesis." More specifically, their assessment included a more "authentic" activity than simply designing unconfounded experiments: they asked children to judge the quality of other children's science fair posters and they found that "the many children who learned about experimental design from direct instruction performed as well as those few children who discovered the method on their own" (Klahr & Nigam, 2004, p. 661).

Another important finding from our first study (Chen & Klahr, 1999)—and one that should be viewed favorably by discovery-learning advocates—is that children showed increases in their knowledge about different factors, even though they had not been taught anything directly about them (that is, they learned that the ball rolls further on a smooth ramp than on a rough ramp, even though there was no explicit instruction about the effect of different factors levels on the outcome of an experiment). As Chen and Klahr (1999) put it, "direct instruction about a process skill facilitated discovery learning about domain knowledge" (p. 1116). Although we did not emphasize this aspect of our study, it is directly relevant to Kuhn's (2007) response to the initial Kirschner et al. (2006) paper.

> But note the anomaly that confronts us at this point. If we agree that development of inquiry skills is a worthwhile educational goal,… and we also accept Kirschner et al.'s claims regarding the desirability of direct over inquiry methods of instruction, the following conclusion is unavoidable: Students should learn inquiry skills but they should not be involved in inquiry as an instructional method for mastering these skills.
>
> (Kuhn, 2007, p. 112)

But, as our results demonstrate, there is no paradox; by using direct instruction to teach children how to construct and interpret unconfounded experiments, we enabled them to use CVS to discover—via the very inquiry skill that we taught them—the effects of different levels of each causal variable.

Replication, Extension, and Improved Operational Definitions of Contrasting Instructional Methods

Given the extensive controversy about the benefits and costs of instruction located at different points along the "discovery to direct spectrum" (e.g., Adelson, 2004; Begley, 2004; Cavanagh, 2004; Kirschner et al., 2006; Tweed, 2004), and the idea that results can change drastically with different operationalizations of both instruction and assessment procedures, Strand-Cary and Klahr (in press) replicated and extended several features of the Klahr and Nigam (2004) study using the ramps apparatus described above, the same contrasting training conditions (here called "Explicit Instruction" and "Exploration"), and several assessments of near and far transfer, as well as delays of 3 and 36 months between instruction and assessment.

As noted above, the controversy about the defining properties of instructional procedures such as "hands-on science," "direct instruction," "discovery learning," and "inquiry based science instruction" makes it important to articulate both the common and the distinct features of the contrasting instructional procedures. Table 15.2 (taken from Strand-Cary and Klahr, in press) shows how the two types of instruction differed along several dimensions. Several of the typical direct/discovery dichotomies do not map cleanly onto the contrasts used here. Consider first the common features of both types of instruction. Children in *both* conditions were engaged in physical manipulation of the apparatus involving "hands-on" experiences. During the ramps pre- and post-tests children in both

Table 15.2 Common and Distinct Features of Explicit Instruction Condition and Exploration Condition in Phase 1b

	Aspect	*Training condition*	
		Explicit Instruction	*Exploration*
Common features	Materials	Pair of ramps and balls apparatus	Pair of ramps and balls apparatus
	Goal setting	By Experimenter: "can you find out whether X makes a difference in how far the ball rolls?"	By Experimenter: "can you find out whether X makes a difference in how far the ball rolls?"
Distinct features	Physical manipulation of materials by child	Child assisted in taking down ramps after each set up by experimenter	Child set up ramps, rolled ball, and took down ramps from self-designed experiments
	Number of experiments designed	Four	Eight
	Focal dimensions	Steepness (two experiments) Run length (two experiments)	Steepness (two experiments) Run length (four experiments) Surface (two experiments)
	Design of each experiment	By Experimenter: one "good" (unconfounded) and one "bad" (confounded) experiment for each variable under consideration	By child: child designed experiment to determine effect of focal variable chosen by experimenter
	Probe questions	Experimenter asked about whether experiment was "smart" or not, and whether (hypothetical) outcome of experiment would "let you know for sure" about causal variable	No probe questions
	Explanations	Experimenter explained why an experiment was good or bad and how it could be corrected	No explanation
	Summary	Experimenter summarized CVS logic	No summary
	Execution of experiments	None	By child
	Observation of outcomes	None: child only observed and discussed set up and a possible outcome	Child observed outcome of each experiment
	Exposure to good and bad experiments	One good and one bad experiment (identified as such by Experimenter) for each focal variable	Varied according to child (because there was no feedback from Experimenter as to good or bad design)

conditions set up the ramps, rolled the balls, and took apart the ramps. Also, in both conditions the experimenter challenged the children with an explicit goal and children participated in goal-directed investigations in which the aim—to find out about the effect of a single causal variable—was generated by the experimenter, not the child. In *neither* condition were children unguided with respect to the purpose of the activity.

The many differences between the two types of instruction are also listed in Table 15.2. Some of these were motivated by the underlying theoretical issue being investigated: who designed each experiment, whether or not there were probe questions and explanations, systematic exposure to good and bad experiments. Others were engineering compromises imposed by pragmatic concerns: number of experiments designed (varied to compensate for extra time taken by explanations and probes), number of different factors used as focal dimensions for an experiment.

Knowing *which* one(s) of these differences between the Explicit and Exploration conditions are responsible for differences in children's learning about CVS is not possible in this particular study. Given that the goal was to compare two educationally realistic instructional strategies, it is necessary to take the conditions in their entirety as the experimental contrast. However, by carefully describing these differences, we are able to provide a reasonably detailed operational definition of what we mean, in this study, by Explicit Instruction and Exploration, and this operational definition facilitates future analysis of the effects of any of the specific features that differ between the two types of instruction.

When to Use Direct Instruction?

Decisions about instructional methods, procedures, and sequences—aka "curricula"—are acts of engineering. They involve theoretically motivated, but ultimately pragmatic, tradeoffs among a complex mixture of potentially causal factors. Suggestions about when to use direct instruction must therefore consider many characteristics of the overall curriculum. In this section, I will describe four particularly important features that argue in favor of direct instruction in the science curriculum: duration, feedback, sequencing, and consistency of implementation.

Duration of Instruction

Direct instruction is fast. In our experimental studies, the training condition took about 25 minutes, and consistently produced significant increases in the proportion of children who master CVS. In our classroom studies in middle class schools, in which regular science teachers adapted our experiment "script" into a lesson plan, we achieved similarly high levels of mastery over the course of three or four 45-minute science classes (Toth et al., 2000). In contrast, discovery approaches to teaching CVS have been proven to take substantially more time to reach much lower levels of performance. For example, Kuhn and Dean (2005), employed a microgenetic approach in which they provided no explicit instruction at all as children attempted to isolate causal factors in a simple context employing five binary variables, very similar, structurally, to our materials. They found that even after a dozen 45-minute "discovery" sessions, spread over 8 weeks, only 75% of the children in their discovery condition met their lenient criterion of "mostly or exclusively" making valid inferences.

Feedback

Instructional contexts vary widely in the extent to which they provide feedback that is inherently self-correcting. For example, in the classic balance-scale tasks studied by Siegler (1976), trial-to-trial performance of the balance scale provides clear feedback about whether or not the child's prediction is correct. "Minimally guided instruction" with these materials could be quite effective, because the materials, in effect, provide the instruction. In contrast, the CVS context provides no such consistent, self-correcting feedback about a confounded experimental set up. In our studies, only explicit training focusing on the confound was effective in enabling children to master CVS.

Sequencing

In our most recent study (Strand-Cary & Klahr, in press), we assessed CVS performance immediately following the training condition, and 3 months later. Figure 15.3 shows that, as in our other studies, the immediate effect of the two types of instruction was that children in the Explicit-Instruction condition produced significantly higher CVS scores than children in the Exploration condition. However, after a 3-month interval, and without any further instruction, the

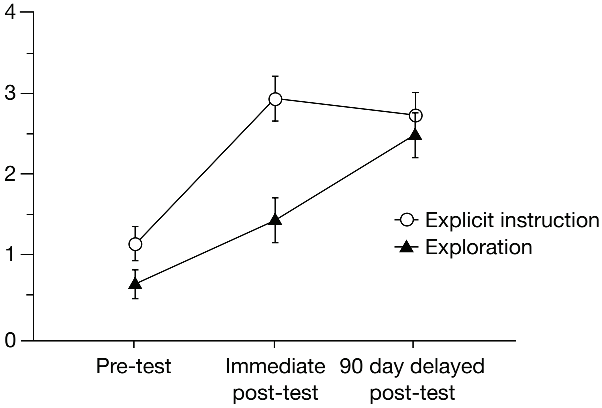

Figure 15.3 Mean CVS score showing the mean number of unconfounded experiments (out of 4) for children in Exploration condition and Explicit condition at three different points: (i) at pre-test, (ii) on an immediate post-test following training on the same day as pretest and training, and (iii) after a 90 day delay (source: from Strand-Cary & Klahr, in press).

Exploration group performance rose to the same level as the Explicit group. The possible explanations for this "spontaneous" improvement are addressed in Strand-Cary and Klahr, but here I will focus only on the sequencing implications of this finding. If two different instructional methods are equally effective in the long run, but one of them gets students to a high performance level very quickly, then the method containing the "fast acting ingredient" should be preferred. Thus, the argument for Explicit Instruction is that it allows curriculum designers to teach CVS early rather than waiting for it to appear 3 months down the road. Given its position at the core of experimental science, CVS is clearly a prerequisite for much of the science curriculum, and the method of instruction should be one that maximizes the level of student performance in the minimum amount of time. One common critique of Explicit Instruction is that it provides only a temporary and somewhat narrow learning context. However, if CVS is taught early in the science curriculum, then there will be many opportunities for students to apply it to different contexts, later in the curriculum, thereby solidifying that knowledge.

Implementation Fidelity

Discovery-learning approaches are inherently vague about the sorts of learning events that should or might occur during the child's exploration and inquiry about the domain to be learned. While our particular implementation of the exploration condition in Strand-Cary and Klahr (in press), or the discovery-learning condition in Klahr and Nigam (2004), included a pre-specified number of trials and explicit goal-setting by the experimenter (see Table 15.2), this is rarely the way that discovery learning is implemented in the classroom. Instead, discovery-learning episodes in real classrooms are delimited more by inputs (time and effort) than by outputs (specific activities of the learner) because the method is inherently unstructured and minimally constrained. As the recent National Research Council volume on early science instruction notes:

> While ... intervention studies suggest that students can learn science ... through highly scaffolded and carefully structured experiences designing and conducting investigations, we also note that having students design and conduct investigations may be particularly difficult and *require a very high level of teacher knowledge and skill* in order for students to master content across the strands.
>
> (Duschl, Schweingruber, & Shouse, 2007, p. 257; emphasis added)

Put more boldly, the absence of an "instructional cook book" leads to extremely wide variability in what actually transpires in a constructivist curriculum. Thus, such an approach depends much more heavily on the skill, knowledge, and pedagogical acumen of the teacher than does direct instruction. While one can point to a handful of exquisitely sensitive and skilled examples of constructivist-based science instruction (Hennessey, 2002; Lehrer & Schauble, 2004; Smith, Maclin, Houghton, & Hennessey, 2000), there is no evidence that the majority of science teachers have the pedagogical skills, the time needed for preparation and analysis, or the deep science content knowledge to emulate these exemplary cases. Even if there were evidence that the best forms of discovery learning are more effective than pedestrian implementations of direct instruction, the best is too rare to provide a sound basis for curriculum policy.

Adding Cognitive Psychology to the Science Curriculum

One consistent theme in constructivist approaches to science education is that in addition to learning a rich and varied sample of the *content* of scientific knowledge, students need to understand and experience the *processes* that produced that knowledge. "In a word, students need to learn what it is scientists do and why they bother to do it. Students can develop that understanding only by engaging, in however rudimentary a way, in the practice of science" (Kuhn, 2007, p. 114). This is usually taken to mean that science instruction should include many features of scientific practice, including group projects, participation in appropriate modes of argumentation and communication, processes of notation and representation, and so on. Kirschner et al. (2006) challenge this perspective by noting that

> The major fallacy of this rationale is that it makes no distinction between the behaviors and methods of a researcher who is an expert practicing a profession and those students who are new to the discipline and who are, thus, essentially novices.
>
> (p. 79)

But there is a grain of truth to the constructivist claim that we should teach budding scientists about how scientists think. In particular, we should teach them that they think like everyone else: that they have at their disposal the same cognitive processes that have been discovered, studied, and refined by cognitive scientists for the past 50 years.

Although the "science as problem solving" perspective has been useful for those of us who study the psychology of scientific reasoning (Klahr, 2000; Kuhn, Garcia-Mila, Zohar, & Andersen, 1995; Mynatt, Doherty, & Tweney, 1977, 1978; Schauble, 1990; Klahr, Fay, & Dunbar, 1993), it has never been explicitly conveyed to children. For example, consider just one of the methods that are part of every working scientist's portfolio of problem-solving methods: analogy. Analogy-based instruction in science and mathematics has been proven to enhance learning (Clement & Steinberg, 2002; Dagher, 1995; Else, Clement, & Ramirez, 2003; Glynn, Britton, Semrud-Clikeman, & Muth, 1989; Paris & Glynn, 2004; Richland, Holyoak, & Stigler, 2004; Stephens & Clement, 2006) and such studies use the theoretical constructs associated with analogical reasoning to design different types of analogies, to identify different ways that teachers use them, and to assess the impact of different types of analogical reasoning on student (and teacher) performance. However, those constructs are, in effect, reserved for the analyst. But students are never explicitly instructed about what cognitive science knows about analogical reasoning: its forms, types, and associated processes.

In effect, the very knowledge that psychologists use to design studies of analogy or problem solving has been kept as a kind of "secret" from the children involved in those studies. That is, in none of the cited work were children explicitly instructed about the fact that they—or the scientists they were learning about—were working in multiple spaces, solving problems, using means–ends analysis, or pattern detection or analogy. They were not informed that the challenge of coming up with a discriminating experiment or an informative and consistent way to represent the results of a series of experiments was itself a problem to be solved, or that analogies have both surface similarity, structural similarity, and a set of mappings between the source and the target. I am suggesting that we make these ideas an integral part of the science curriculum—that we "let students in" on what is known about analogical reasoning—both as an account of fundamental disciplinary practice and as a set of heuristics that children can use in their own scientific endeavors. The goal here is to ensure that rather than just acting like scientists, students are thinking like scientists.

Direct Instruction on a Constructivist Knowledge Element?

I view this suggestion as a partial rapprochement between the two "warring" perspectives on science education that motivated this book: (a) the constructivist approach emphasizing discovery learning about the nature of disciplinary practice in science, and (b) the information-processing approach focusing on direct instruction about higher-order problem solving. In summary, although many of the constructivist methods aim to teach science by embedding young children in the methods and processes of scientists, none of them yet adequately address an essential feature of the scientific method: utilization of a powerful set of general problem-solving heuristics.

Kuhn (2001) and her colleagues have made a convincing case for the importance of metacognition—thinking about thinking—in the development of children's scientific-reasoning capacity. Most of the focus in that work is on having children understand the difference between theory and evidence and, in some studies, children have been encouraged to use a specific type of metacognitive knowledge, by being trained in methods of argumentation (Kuhn & Udell, 2003; Kuhn & Pearsall, 1998). As Kuhn and Dean (2004) note: "studies of people reasoning scientifically have something to tell us about thinking in the less rarefied contexts of everyday life outside of science" (p. 286). My suggestion turns that argument around: by instructing children in the range of everyday thinking processes that have been identified by cognitive psychology, we can enhance their ability to understand and to do science.

Conclusion

Like all of the venerable "isms" in education, constructivism has many faces and facets. In this essay, I have attempted to address only a few: what distinguishes direct instruction from discovery learning; when should we use direct instruction; and which aspects of scientific practice might be both teachable and useful for young science students? My answer to the first question is that there is no universally agreed upon definition of something as broad as an "approach," so we need to be as explicit as possible about our instructional procedures, striving for operational definitions that will facilitate unambiguous comparisons. My answer to the second question is that direct instruction should be used whenever we have evidence that it is both efficient and effective in the short and long term. This is most likely to occur in situations where corrective feedback on misconceptions and errors is unlikely to be systematically generated by the instructional context. My answer to the third question is that an important part of scientific practice is the use of general "weak methods" (Newell & Simon, 1972), and that we should begin to integrate such cognitive psychology topics into the early science curriculum. That is, students should not just be asked to *use* analogies that they or others have generated in approaching a scientific problem. Nor should they be told simply to "look for patterns" in their data. Instead, they should receive explicit instruction about the nature of human problem-solving processes, and how scientists have used them in the past and will inevitably use them in the future.

Question: Schwartz et al. *This was a useful and clarifying review of your work on children's learning "the control of variable" strategy. With respect to the "constructivism debate," you highlighted the critical role of operationalization in science. Do you have any thoughts on the role of circumscribing generalizations based on a singular operationalization? The claims in this chapter mostly arise from studies that operationalize instructional terms in the context of young children learning one particular scientific strategy. There are many other aspects of inquiry, for example generating important and tractable questions, deciding what and how to measure, consulting relevant prior research, deploying representational tools, postulating models, and knowing the assumptions that warrant generalization. It would be nice to have your explicit thoughts, given the possibility that your findings have been over-generalized by the greater education community.*

Reply: Klahr. Good question. First, let me disavow any personal responsibility for anything attributed to the "greater education community," because I don't know exactly who that includes, and I can't grapple with a bag of feathers. Let me respond to your more fundamental point about "circumscribing generalizations based on a singular operationalization" (which, I duly acknowledge, is the most eloquently phrased critique of my claims for direct instruction (DI) that I have yet encountered!). With respect to the universality of DI, I tried to be careful in my chapter about delineating some of the considerations that might favor DI: constraints on available instructional time, lack of explicit feedback from the instructional context, early location of the to-be-learned material in a sequence of topics, and likelihood that teachers could consistently and competently use direct vs. discovery instructional methods. It turns out that the particular domain that I have studied for several years—the control-of-variables strategy (CVS), favors DI on all of these, but I would be quite surprised if DI was ever the only game in town. In fact, my extensive work on scientific reasoning (Klahr, 2000) was derived from some earlier research on what we called "instructionless learning," in which we identified some of the processes that people use when they have absolutely no instruction whatsoever. Indeed, they can learn. But the fact that they can learn doesn't mean that they wouldn't have learned even more in less time if they had received some instruction.

Question: Schwartz et al. *You suggest that students should learn principles of human learning, because this will improve their own learning. We are very sympathetic to this point. When we have similar thoughts, which we do, we fear that we may be falling into a common trap. The trap is thinking that everybody needs to know what we know, and that the most effective way to learn is to do what we do. It is pretty obvious that just because we study cognition we are not any better at learning than the sociologists down the hall. Do you think the literature on metacognition, as it stands, justifies teaching scientific knowledge about cognition as a way to improve learning in general? Maybe just telling people what to do and having them practice with variable reinforcement would be more effective.*

Reply: Klahr. This is speculative at this point. We do know that young children can be instructed in how to use rehearsal and other processes—discovered by lab psychologists—to improve their short-term memory, so there is at least an existence of proof that the stuff that we know is worth disseminating. I am not proposing that we add a course in general problem-solving methods to early science instruction, just because my colleagues and I think it's cool stuff. Indeed, the evidence thus far is that attempts to teach general problem-solving skills, applicable over a wide range of domains, have not been very successful. The proposal in my chapter is that we teach a much more focused set of problem-solving skills related to science. Rather than teach about, say, pattern detection or analogical problem solving in general, I am suggesting teaching how those cognitive processes have worked in the sciences. And I would then have students apply that to the science content they are learning in a variety of substantive domains. I would not expect students to automatically generalize such skills to pattern detection or analogical problem solving in the economy, personal development, or historical trends.

Question: Gresalfi and Lester. *What is direct instruction, anyway? The discussion of the series of studies that you conducted contrasts two different instructional practices, one which you call direct instruction, and the other which you call discovery. What I began to wonder was why you chose to call your "instruction-first" method "direct instruction." Indeed, with respect to the history and particular definitions of direct instruction (see in particular Rosenshine, Chapter 11, this volume), the* *instructional method outlined in this chapter is not well-aligned. What is your rationale for continuing to refer to this method as direct instruction?*

Reply: Klahr. Questions about labels miss the point of my chapter. It matters not what one calls the instructional method that I devote at least one-third of my chapter to: "direct instruction," "explicit instruction," "training with probes," etc. etc. What does matter is the effectiveness of the combination of features associated with type of instruction when contrasted with methods that lack some or all of those features described. This kind of instruction is clearly distinct from the broad family of instructional methods associated with constructivist views of learning, so the scientific question is what the evidential base is for the relative effectiveness of each type of teaching in different contexts.

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