# Education and a Civil Society: Teaching Evidence-Based Decision Making


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American Academy of Arts & Sciences

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AMERICAN ACADEMY OF ARTS & SCIENCES

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# Acknowledgments

This collection is part of an American Academy of Arts and Sciences project that explores evidence-based thinking in K-16 education. The project proposes that the educational system of the United States should consider how to prepare young people more effectively for the kind of decision-making that is required to understand change, to advocate, and to vote with knowledge about public policy. Citizens who value and know how to use evidence, the project hypothesizes, will be better prepared to participate in the democratic process as informed thinkers. Evidence-based thinking is part of legal and medical training, and the case study method is the foundation of many American business schools. Clearly, this kind of reasoning is considered valuable to the professions, as it is intended to enhance a student's ability to understand and scrutinize causal claims; to assess and draw inferences from evidence; and to develop or modify appropriate beliefs in the validity of assertions. The wider public would benefit from systematic training in this type of critical thinking.

To explore this topic, the Academy brought together educators, textbook editors, curriculum designers, experts on educational assessment and policy, experts on developmental psychology and the philosophy of science, and social scientists with knowledge of the public's understanding of complex policy issues. During a series of discussions, chaired by Paul Brest, President of the William and Flora Hewlett Foundation, several topics were identified for this collection. As each essay reveals, more work needs to be done in the schools, but determining what should be done and how to do it raises additional complex issues. This volume is intended to encourage further conversation about critical thinking and its importance.

The Academy gratefully acknowledges the essayists and other workshop participants whose insights contributed to this volume: Joseph Blatt (Harvard University), Eamonn Callan (Stanford University), Joel Cohen (Rockefeller and Columbia Universities), Tina Grotzer (Harvard University), Eric Hanushek (Hoover Institution), Jerome Kagan (Harvard University), Mark Lepper (Stanford University), Roy Pea (Stanford University), David Perkins (Harvard University), Jason Puskar (Boston College), Michael Ranney (University of California, Berkeley), Lee Ross (Stanford University), Richard Rothstein (Economic Policy Institute), Lee Shulman (Carnegie Foundation for the Advancement of Teaching), Laura Schulz (Massachusetts Institute of Technology), Claude Steele (Stanford University), and Daniel Yankelovich (Viewpoint Learning, Inc.). The Academy also expresses its gratitude to Professors Michael Ranney and Lee Ross for their comments on earlier drafts of the essays; and Professor Tina Grotzer and Rebecca Miller

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# Introduction

LEE S. SHULMAN

I write the introduction to this collection of papers at the conclusion of the historic 2008 presidential election. This election is germane to this collection because it highlights the responsibility of citizens to weigh the arguments and proposals of competing candidates and to support those whose proposals are most reasonable and whose reasoning is most compelling. But voting citizens are also evaluating the characters, beliefs, personalities, and life histories of candidates. Should these judgments and evaluations be pursued through critical analyses of data and arguments, through the exercise of intuitive empathic "gut" feelings, or through some combination of both?

Is it a worthwhile goal for every citizen in a democracy to exercise good judgment? If such a goal is worthwhile, can good judgment be taught? Can the wherewithal to think critically, analytically, and soundly be learned by students, whether in the precollegiate years or in colleges and universities? Can these ways of thinking and reasoning be taught in formal educational settings? Even if they can, are the most important determinants of good judgment to be located in developed cognitive capacities or in the development of good character?

The founders of democratic societies disdained the claim that critical thinking and good judgment were hereditary gifts that were possessed only by a small, elite segment of the society. If such talents are not innate and not limited to a select aristocracy of women and men—if, in fact, these modes of thought and action are teachable—should they be treated as "basic skills" comparable to reading, writing, calculation, and—in our present era—fundamental technological literacy? Because evidence-based decision making is unlikely to be learned in the family or the neighborhood, should schools not be responsible for teaching this skill from kindergarten through graduate school? The question then becomes whether teaching evidence-based decision making really matters, whether it is possible, and how it might be accomplished.

An alternate view would subordinate evidence-based decision making to the development of desirable values, beliefs, attitudes, or habits. Other virtues may indeed be far more important than critical reasoning—such as kindness, empathy, love, loyalty, fairness, fidelity, beauty, or faith. We may err if we place too much emphasis on the academic values of reason and not enough on those in the moral, humane, religious, and aesthetic spheres. Which is better: to have leaders of questionable virtue reasoning clearly and relying on carefully collected and weighed evidence; or to rely on fundamentally decent, sensitive, and just men and women who will use evidence imperfectly but nevertheless in a humane and considerate manner?

This volume includes five essays commissioned by the American Academy of Arts and Sciences to respond to these questions. The respondents include three psychologists: Jerome Kagan, Richard Nisbett, and David Perkins; a science educator, Tina Grotzer; and a political and moral philosopher, Eamonn Callan. They offer quite different perspectives on these common questions, perspectives sufficiently distinctive that finding common grounds for comparison is frequently difficult.

Three of the authors—Nisbett, Perkins, and Grotzer—gather the growing evidence that critical judgment, probabilistic reasoning, and clear thinking can be taught, whether in general or specifically in the teaching of particular disciplines, such as the sciences. They further argue that once learned, such modes of thinking can, with limits, be transferred to other domains and are therefore likely to lead to more general capacities to think critically and effectively. Kagan scoffs at such claims for generic critical-thinking abilities, insisting that good judgment is much more likely to be domain, discipline, and context specific. He further expresses doubt that cognitive capacities alone are sufficient. Callan shares a modicum of Kagan's skepticism. He reflects on how difficult it has been for him, a seasoned philosopher and experienced scholar, to learn to think across traditional disciplinary boundaries. He suggests Americans should learn to reason about and embrace questions of values and moral choice rather than learn to weigh likelihoods and the warrant of empirical evidence.

Concern for whether higher education is indeed "adding value" to the abilities of undergraduate students has now reached the state and national policy arena. U.S. Secretary of Education Margaret Spellings appointed a commission—under the chairmanship of Charles Miller, who had led the Texas higher education commission—to examine the quality of U.S. higher education. One of the central items on the commission agenda was whether colleges and universities were holding themselves accountable for improving the quality of knowledge and thought demonstrated by their students. While the value added in specific professional programs, such as law, engineering, and dentistry, might be quite obvious, what is added by undergraduate liberal education?

Although most of the critics of the Spellings Commission attacked the specter that multiple-choice tests might be employed to answer that question, the most frequently cited example of such an assessment was not a multiple choice test but an open-ended essay exam, the Collegiate Learning Assessment. This assessment of critical thinking and evidence evaluation has been designed by some of the nation's premier scholars of assessment and cognition and seeks to measure the gains in general critical thinking and reasoning abilities achieved by college students over the course of their undergraduate experience.

Americans may tend to orient toward general processes of thinking and problem solving rather than to deep substantive understanding within specific disciplinary domains. This, at least, appears to be the perception overseas. Several years ago, a group of colleagues and I met at Rhodes House at

Oxford University to discuss the first draft of our book *Educating Lawyers* (Sullivan et al. 2007). At a critical point in the two days of discussion, one of the British colleagues asserted—with substantial concurrence from his fellows—that the trouble with U.S. legal education is that its goal is to teach students "to *think* like lawyers," to engage in the analytical reasoning associated with the processes, strategies, and dispositions of the law rather than with the concepts, principles, and facts of the law—the "black letter law"—that are the core of legal understanding and competence.

My colleagues and I at the Carnegie Foundation have for the past decade been studying education in a number of professions—law, clergy, engineering, medicine, nursing, scholarship (the Ph.D.), and school teaching. We are persuaded that education for the learned professions is not a matter of intellectual development alone, though that is a central challenge of every professional school. The candidates in these fields must also develop high levels of technical skill; they must learn to do, perform, and act. Even though technical accomplishments are often disdained by the academy (note the lower prestige of "clinical appointments" in academic schools of medicine, nursing, or education), they are the attributes that distinguish the most accomplished professionals. Yet even technical excellence is insufficient. The well-educated professional must develop an internalized sense of responsibility, an integrity that is inherent in their identities and embodied in their thought, skills, and capacities for responsible judgment and action. In the Carnegie studies we refer to these three kinds of learning as habits of mind, habits of practice, and habits of the heart. I am persuaded that this three-fold representation would also map nicely onto the learning needed by citizens: to think and act with integrity is no small feat.

The readers of these essays will find them challenging in their disagreements, but need not make an either/or choice among the several perspectives presented here. They are not mutually exclusive because all, in their way, promote one of the most powerful ideas in contemporary thought, that of 'practical judgment.' When we say that we aim to help students develop the capacities to reason critically and act responsibly, we may be saying that we wish them to learn to engage well in the process of *practical reason*. Whether choosing a car to buy, a candidate for whom to vote, a medical treatment to elect, or an engineering design to pursue, individuals reason practically as they mull their alternatives. They do seek and evaluate empirical evidence in connection with their possible choices. How much fuel does a hybrid car really save, and how much lower is the amount of pollution it pours into the air? What is more important, a candidate's positions on Iraq, abortion, evolution, prayer in schools, or healthcare? Do I prefer a leader with the "right" policies but questionable character to one who appears honest and sincere but disturbingly uninformed about important issues?

These are the kinds of questions that call for the exercise of practical reason, a form of thought that draws concurrently from theory and practice, from values and experience, and from critical thinking and human empathy. None of these attributes is likely to be thought of no value and thus able to be ignored. Our schools, however, are unlikely to take on all of them as goals of the educational process. The goal of education is not to render practical arguments more theoretical; nor is it to diminish the role of values in practical reason. Indeed, all three sources—theoretical knowledge, practical know-how and experience, and deeply held values and identity—have legitimate places in practical arguments. An educated person, argue philosophers Thomas Green (1971) and Gary Fenstermacher (1986), is someone who has transformed the premises of her or his practical arguments from being less objectively reasonable to being more objectively reasonable. That is, to the extent that they employ probabilistic reasoning or interpret data from various sources, those judgments and interpretations conform more accurately to well-understood principles and are less susceptible to biases and distortions. To the extent that values, cultural or religious norms, or matters of personal preference or taste are at work, they have been rendered more explicit, conscious, intentional, and reflective.

In his essay for this volume, Jerome Kagan reflects the interactions among these positions by arguing:

> We are more likely to solve our current problem, however, if teachers accept the responsibility of guaranteeing that all adolescents, regardless of class or ethnicity, can read and comprehend the science section of newspapers, solve basic mathematical problems, detect the logical coherence in non-technical verbal arguments or narratives, and insist that all acts of maliciousness, deception, and unregulated self-aggrandizement are morally unacceptable.

Whether choosing between a Prius and a Hummer, an Obama or a McCain, installing solar panels or planting taller trees, a well-educated person has learned to combine their values, experience, understandings, and evidence in a thoughtful and responsible manner. Thus do habits of mind, practice, and heart all play a significant role in the lives of citizens.

Our writers offer a rich array of perspectives on the potential for the educational process to inform and enrich this complex set of processes. I commend their offerings to the readers of this volume: you will find them stimulating, disturbing, and enlightening in turn.

## REFERENCES

Fenstermacher, G. 1986. Philosophy of research on teaching: Three aspects. In *Handbook of Research on Teaching*, 3rd ed., ed. M.C. Wittrock, 37-49. New York: Macmillan.

Green, T.F. 1971. *The Activities of Teaching*. New York: McGraw-Hill.

Sullivan, W.M., Colby, A., Wegner, J.W., Bond, L., and Shulman, L.S. 2007. *Educating Lawyers: Preparation for the Profession of Law*. San Francisco: Jossey-Bass.

CHAPTER 1

# Decision Making and Its Development

DAVID N. PERKINS

Review your activities over the last few weeks. Perhaps you can recall a decision that did not turn out so well. The outcome might not have been your fault: Even when we ponder long and wisely, circumstances intervene—a hurricane, a flu, a flat tire. But people often recognize something they could have done to make a better decision in the first place. "If I had thought about it more carefully, I would have recognized that five or six things could go wrong, so at least one of them was almost bound to." "I could easily have bought some time to get more information." "If I had considered the possible side effects more, I would have realized that plan B was really better than plan A." "I let myself be influenced far too much by what others were saying." And so on.

I get this simple exercise from a friend and colleague of many years, Robert Swartz, a prominent figure in the critical-thinking movement. The exercise is suitable for teachers, children, professors, businesspeople. In groups it generates remarkably rich conversations about the art and craft of decision making. Almost everyone can respond with at least one significant decision that did not go so well and how the decision might have been better approached by paying more attention to one or another kind of evidence.

We should not be surprised. Our lives are woven out of decisions. We are constantly deciding—whether to do homework or go to a movie, whether to accept a job offer or keep looking, whether to call someone for a second date, whether to vote for this person or that, support this policy or that. Moreover, decision making is not one of those human capabilities like breathing or everyday conversation that pretty much takes care of itself. A complicated world and our complicated selves ensure that decision making is often hard and sometimes, to our later chagrin, disastrously easy.

Looking to the larger scale, the decisions of leaders are likewise not untroubled. Historian Barbara Tuchman (1984) in *The March of Folly* systematically analyzed a number of historical decisions that she argues were "folly"—unwisely taken at the time, with ample warning from insiders and outsiders. Examples include King George's decision to play tough with the American colonies, leading to the American Revolution; and U.S. involvement in Vietnam. The January 1986 decision to launch the Challenger space shuttle despite serious concerns from engineers is another often-mentioned example: executive concerns about the appearance of progress inappropriately overrode technical reservations (Starbuck and Milliken, 1988). The shuttle exploded shortly after launch. The poorly conceived Bay of Pigs invasion of Cuba is a further common target of critique (e.g., Johnson 2004).

Imagining a society where evidence-based decision making is more of a deliberate craft, where most people make decisions somewhat better than they typically do today—because education, mentoring, and other means of fostering good decision making have brought this about—is enticing. So, too, is imagining a society where adolescents are more cautious about experimenting with sex and drugs, where adults less often fall into dead-end jobs or dead-end relationships, where care for the elderly involves more planning and foresight. So, too, is imagining a world where not only do individuals better navigate their way through the complexities of life but where larger-scale decisions—matters of public office and public policy—reflect more informed and attentive leaders and citizens. My aim in this essay is briefly to explore the prospects of creating such a world.

Focusing on everyday decision making, the discussion moves through several themes: first, what distinguishes decision making from other kinds of thinking; then, descriptions of how decision making goes wrong and prescriptions for what counts as good decision making and how education might develop good decision making; finally, a particular problem: how better decision making might serve not just individual interests but civic engagement and society at large.

Research tells us a lot today about how decision making goes right or wrong. What we know adds up not so much to a template for perfect decision making as to a vision of artful self-regulation responsive to the circumstances, sometimes more analytic, sometimes more intuitive, sometimes making checklists, sometimes telling stories and counterstories to oneself. Mode needs to match occasion. The best efforts to improve decision making through education have beneficial results. However, these efforts focus only on some aspects of the challenge. Educational and other institutions would do well to invest much more in this fundamental cognitive craft through which we shape our lives and our larger society.

## DEFINING DECISION MAKING

How does decision making differ from other kinds of thinking, for instance, planning, reasoning, or analyzing? The boundaries between such everyday categories inevitably are fuzzy, all the more so because they tend to draw on one another—one decides on a plan or plans how to decide, reasons out a decision or decides on the most important reasons (e.g., Moshman 2005). That acknowledged, decision making most centrally is a problem of choice (Galotti 2002). One must select from among alternative paths leading toward the future. The paths may comprise alternative plans, go/no-go choices, or beliefs to accept or reject—as with religious faiths, political philosophies, scientific theories, or personal policies.

Often the challenge goes beyond deciding between given alternatives. One might need to find reasonable alternatives in the first place or to look creatively beyond the obvious options to others more promising. Even so, choice remains central. In the search for a good choice, many factors can figure: goals and values to be pursued, time pressure, side effects, opportunity costs, stable versus changing circumstances, available knowledge, interests of others as well as oneself, and more (Byrnes 1998; Galotti 2002; Jacobs and Klaczynski 2005).

While decision-making situations vary enormously in their particulars, this account centers on what might be called everyday decision making—for instance, purchase decisions; forming and severing personal relationships; voting and other political commitments; educational and job decisions; and choices regarding sex, recreational drugs, and the like. People addressing such everyday decisions typically face possibilities of *action* rather than, or in addition to, belief; *have time* for reflection rather than needing to respond quickly; have *some familiarity* with the area in question but lack deep professional expertise; and feel they are *personally involved* rather than making technical decisions on matters not close to them.

An ordinary example: A couple of years ago, I attended a conference in Athens. My wife came along and we took time to enjoy the classic city. On our last day we spent an hour-and-a-half looking at Oriental rugs in a small shop. We spent considerable thoughtful time sorting out which rugs we liked best and ended up buying three medium-size rugs. We knew something about the pricing of these rugs, and the costs seemed reasonable. Our decision, like countless others that people make every day, had all the earmarks of a typical decision-making process: an action taken after reflection, based on some familiarity with the area, and having personal involvement.

The decision also was a mistake, we later concluded: not a serious one, but a mistake nonetheless. Why? How do decisions go wrong?

## CHALLENGES OF DECISION MAKING

The next day we felt that we should have bought only one or perhaps two of the rugs. Our imminent departure had led us to overpurchase. Leaving behind an attractive buy was difficult. An accident of schedule—our imminent departure—unduly influenced us (the shop owners did nothing to press us) in a way that advertisers frequently mimic with headlines like "One day only" or "Limited time offer." Amsel et al. (2005) argue that avoidance of future regret often strongly and inappropriately figures in decision making. In effect, my wife and I feared the regret of a lost opportunity, a decision-making pitfall we should have recognized from prior experience.

Were we sure we made a mistake? This is an important question because appraisal of decisions after the fact suffers from what is called "hindsight bias," the distorting effect of knowing how things turned out (e.g., Fischhoff and Beyth 1975; Teigen 1986). We were confident we had erred. We recalled how during shopping we were much more attracted by one of the rugs, significantly by the second, and found the third simply pleasant. This should have been a signal for caution. After all, the rugs were being shipped, so we could have taken a couple of days to decide about the second and third rugs and then e-mailed the shop owner with little realistic risk that others would have purchased exactly those rugs. We could even have photographed the rugs with our digital camera for another look later. We had done both these things in the past.

To generalize from this and many other ordinary examples: decision making, broadly speaking, goes wrong because it is not sufficiently evidence based. People often act impulsively and impressionistically, with a limited view of the matter at hand, not looking beyond what the obvious options offer; not sufficiently consulting past experiences, general knowledge, informed friends and colleagues, and other sources; or not weaving evidence together in a coherent way. The technical literature on the psychology of decision making foregrounds how poor decision making reflects lack of self-regulation to elaborate and clarify one's goals and the goals of relevant others, imaginatively search for promising options, carefully assess the costs and consequences of adopting those options, and so on (e.g., Baron 1988; Byrnes 1998; Galotti 2002; Janis 1989).

That is the big picture. Now for some details.

### *The Challenge of Representing Complexity*

One obvious challenge of decision making is simply that decisions are often complex, involving several options, multiple criteria, and diverse knowledge about the situation. Managing all the elements is hard, and overlooking something important is easy. Means are needed to organize and integrate the ideas and information important to a decision.

The good news is that people have conceptual tools for coping with this complexity. The tools are not always fully or well used, but they are powerful. Two rather different modes of representation figure prominently in both everyday and more expert decision making: *quantitative/tabular* (quantitative for short) and *narrative*.

The quantitative approach often takes simple list form, as in checklists of product features or tallies of pros and cons. At the far end of technical finesse are expected-utility models. These involve an intricate tabular analysis, with each of several options scored for each of several criteria and the criteria weighted for relative importance (e.g., Baron 1988; Dawes and Corrigan 1974; von Winterfeldt and Edwards 1986). Multiplying each option score times the weight of the criterion and summing the results yields an overall score for the option. The probabilities of various consequences can also be incorporated into the analysis. Impressively sophisticated as this is, it is a method that does not serve all situations well, a matter elaborated later.

Narrative offers another mode of representation for decision making. Simple versions of the narrative mode involve concise causal stories in favor of or against options: "I'm sympathetic with his goals, but okaying this would set a precedent we'd have to live with forever." "If we order today, we'll have to have the materials sent by express or they simply won't get here in time." Complex versions involve elaborate argument. In criminal law, for instance, consider how the prosecution motivates the jury to return a guilty verdict by weaving the evidence into a story, a "theory of the crime" that combines the three themes of motive, method, and opportunity. This story must stand against counterstories advanced by the defense, which cast the evidence in a different light and challenge some of it.

While the conceptual tools of quantitative and narrative representation can help with decision making, their ready, widespread use is complicated by a number of factors. For decisions that invite technical approaches, the more intricate analyses require knowledge and skills many people do not have. On the quantitative side, most people do not know when to attempt or how to manage the expected utility procedures. On the narrative side, most people are unlikely to be conversant with the niceties of hypothetico-deductive reasoning. However, lack of technical knowledge is probably not the principal mischief maker. A considerable amount of decision making is simply shallow. People do not try hard enough to be better informed, to consider multiple possibilities, and to carefully evaluate them. Why is this?

### *The Trend to Oversimplification*

Benign factors lurk behind many quick and dirty decisions. Occasionally choices arise in urgent circumstances. With no time for elaborate analysis, one must take one's best shot, which can in fact be quite good. Other benign factors include the fact that investment in a complex analytic process can be costly, many decisions are not all that important, and the prospective gains from taking the longer, more thorough route might not outweigh the prospective benefits of available shortcuts. For important decisions, the available information may not support the most thorough styles of analysis anyway. Figuring in relative probabilities of consequences will add minimal value if the probabilities are little more than guesses.

On the other hand, many not-so-benign factors lead to shallow explorations of decisions. A pointed folk saying—"Between two options, choose the third"—points to one of the most basic causes: important options beyond the obvious ones often exist. The same can be said of criteria. Many decision situations do not make salient some of the promising options and pertinent criteria. The situations create the illusion of a completely stated problem: a couple of apparent choices and two or three obvious considerations. However, a little digging reveals hidden layers.

This was true of the rugs story. Our focus on *which* made overlooking deferred purchase strategies easier. Similarly, given the option of buying a neighbor's used car, many people will assume their choices are yes or no after a test drive. But perhaps they could "choose the third" and make a deal to rent the car for a week to see how they like it, the rental going toward the purchase price if they're happy.

Problems of saliency aside, elaborate decision making demands intense mental effort. Herbert Simon (1957) famously characterized the problem of human beings' *limited rationality:* cognitive bottlenecks steer us toward expeditious but sometimes unfortunate shortcuts. Touching on the rugs purchase once more, my wife and I had a lot on our minds and little room for much more. Analogously, a manager focusing on the substance of a tricky decision can easily forget a colleague whose judgment should be heard both for counsel and to maintain the relationship.

Keeping things simple is a natural and generally adaptive tendency. Contemporary "dual processing" models argue that people have two modes of processing: intuitive and analytic[1] (e.g., Epstein 1994; Klaczynski 2005; Reyna et al. 2005; Stanovich 1999; for a critical assessment, see Evans 2008). Intuitive decision making is rapid, is only marginally conscious, and at its best is deeply informed by experience in the domain in question. Imagine how you might size up a job candidate in the course of a brief conversation, responding to all sorts of nuances you could not readily name. In contrast, analytic decision making is more conscious, deliberate, effort-demanding, systematic, and analytical, pondering a number of options and integrating a range of considerations toward a conclusion by using narrative, quantitative, or mixed approaches.

Efficient, fairly intuitive processing dominates our day-to-day activities—we would need a month to get through a day otherwise—and also many medium- to high-stakes decisions. Often this serves well enough, but sometimes the limited horizons and technical shortfalls of intuitive processing leave us blind to significant options, benefits, and risks. Moreover, people sometimes deceive others and even themselves about their commitment to explicit evidence, formulating articulate rationales that are no more than post hoc justifications of intuitive convictions.

### *The Hazards of Heuristics and Biases*

Intuitive processing is replete with what are sometimes called heuristics and biases. These rules of thumb often serve in a rough-and-ready way but can prove deeply misleading (Kahneman et al. 1982). Sometimes characterized as cognitive illusions, these include, for instance, confirmation bias (the tendency to seek confirmatory and fail to seek disconfirmatory evidence), social stereotyping, the fundamental attribution error (the tendency to explain others' behavior as reflecting abiding personality characteristics while seeing one's own behavior as a response to situational demands), the neglect of opportunity cost (the cost incurred by foregoing the benefits of A when you choose B over A), and the "waste not" heuristic around sunk costs (the feeling that you have to get your money's worth out of a cost already irretrievably incurred, even though a change in circumstances, or something else, may have made the effort of doing so no longer worth the gain).

Another important bundle of biases, termed *prospect theory,* won Daniel Kahneman the 2002 Nobel Prize for economics (his partner in this work, Amos Tversky, unfortunately had died or he would have shared the award)

1. Other terms are sometimes used.

(Kahneman and Tversky 1979). Prospect theory focuses on decisions that involve gains and losses, often under conditions of uncertainty.

The theory has several nuances, but one of the most basic points is easily stated: People are strongly loss-averse—changes viewed as losses usually are treated as considerably more painful than equivalent changes viewed as gains are treated as rewarding. Contrary to Ben Franklin, a penny saved is worth more than a penny earned. A $100 bill is worth more to you, by roughly twice as much, when you have it and think of yourself as potentially losing or spending it than when you don't have it and might gain it. For instance, people usually won't bet $100 against a fifty-fifty chance of getting $X until X gets up to about $200 (e.g., Tversky and Kahneman 1992).

To see how losing versus gaining works in a nonmonetary case, imagine that Tony is more of a Superman than a Spiderman fan and Patrick the opposite. Unfortunately, Tony receives a Spiderman action figure on his birthday, and Patrick receives a Superman action figure. Will they trade? Probably not, because once Tony possesses a Spiderman figure, trading it away gets coded as a loss, likely to seem too dear compared to gaining a Superman action figure unless the initial preference difference is very great.

Such differences reflect what is called a *framing effect:* losses and gains are counted relative to the baseline from which decision makers see themselves as starting. Framing effects are errors of reasoning because the underlying situation is the same no matter how framed. Tony would enjoy the Superman figure more and Patrick the Spiderman figure more if only they could get past their loss aversion and make the trade.

Framing effects also influence risky situations. People tend to be risk-averse about gains, preferring a smaller sure thing to a chance at a greater gain; and they tend to be risk-seeking about losses, preferring a risk of a greater loss to a certain smaller loss. One notable study asked a number of ambulatory patients, graduate students, and physicians about their preference between two different treatments for lung cancer (none of the subjects actually suffered from the malady) (McNeil et al. 1982). For about half the subjects the results of the two treatments were expressed in gain terms (e.g., survival rates at various points in time), and for the rest in loss terms (e.g., mortality rates). One of the treatments involved a higher risk of early death but greater long-term survival. When the treatments were described in terms of survival rates, subjects tended to shun the risky "early death" treatment; they tended to choose it when the treatments were described in terms of mortality rates.

In principle, people might notice that the treatments could be described either way and thus more objectively think through the matter. After all, the job of analytic processing is to monitor the output of intuitive mechanisms and catch shortcuts when they seem likely to do serious mischief. One problem, though, is that analytic processing inevitably misses a lot. Constant checking would require far too much of our cognitive resources.

Another problem is that analytic processing generally is unaware of specific glitches such as loss aversion or sunk costs. For instance, proceeding in a broadly analytic way, one might happily register a sunk cost as a real loss in a pro-con list. Sophisticated analytic practice involves not only an elaborated quantitative or narrative approach but alertness to specific traps.

### *The Neglect of Intuition at Its Best*

Without question quick, intuitive decision making serves well to move us through the minor decisions of the day. When the stakes are low, and even more so when we have experience to build on, why think hard about a decision? If we are occasionally wrong, so what? We can hope to learn from our mistakes and do better next time.

However, for more important decisions, the moral of the story so far might seem to be "analytic: good; intuitive: bad." To avoid Simon's limited-rationality bottleneck, decision makers should fight the intuitive impulse and adopt well-elaborated narrative and quantitative approaches with the help of support systems from pencil-and-paper to spreadsheets.

A significant body of research, however, shows that *sometimes intuitive decisions are better.* Malcolm Gladwell's (2005) popular book *Blink* reviews a range of such examples, albeit somewhat uncritically. In general, intuition can serve well when the decisions have a personal character, for instance preferences for food, art, or perhaps even another person to spend one's life with. For example, in laboratory experiments where subjects were invited to choose a jam they liked or a poster to hang in their apartments, subjects asked to approach the task intuitively showed greater satisfaction later on with their choices than did subjects asked to take an analytic approach (Wilson et al. 1993; Wilson and Schooler 1991).

Why is this? Often we do not have precise access to our reasons for liking something. More broadly, in some areas of life we cannot simply read off the tops of our minds the many tacit goals that guide our behavior. Adopting an analytic approach can disrupt our intuitive attunement to our deep interests, leading to worse decisions. (These tacit goals may themselves invite surfacing and reconsideration, but that is another story.)

Research also argues that an intuitive approach often better serves when people have well-developed experience in a domain. Studies of experts have yielded a model called recognition-primed decision making (RPD) (e.g., Klein 1998; Lipshitz et al. 2001). Experienced firefighters, ship commanders, tank platoon leaders, and so on tend to make decisions by sizing up a situation rapidly in order to understand it. From this, a good prospective solution quickly and naturally emerges. When the expert has doubts, instead of brainstorming many solutions and comparing them, he or she typically adopts a narrative tactic of limited scope, assessing the solution at hand by doing a mental simulation and, if the solution seems wanting, reaching for another prospect. Especially in time-pressured circumstances or where efficiency is important, the point is not so much to choose the absolute best among all possible options as it is to arrive at a good workable solution and move forward.

RPD should not be seen as limited to professional expertise. In many of the ordinary activities of life—choosing a smart alternative route when you encounter a traffic jam on your usual commute, deciding whether to try to fix a plumbing problem yourself or call the plumber—RPD may well figure effectively. When my wife and I were buying Oriental rugs in Greece, we had enough experience to recognize a risk of overpurchasing. Perhaps next time our recognition will be better primed!

Does this suggest a moral directly opposite "analytic: bad; intuitive: good"? Do we just need to develop enough knowledge and experience in the domain in question to underwrite intuitive decision making? As a general policy this will not work. Many life decisions occur only now and then, with most people unlikely to accumulate the rich expertise that could drive sound intuitive decision making.

Moreover, considerable research shows that when multiple reasonably clear criteria bear on a decision people are not good at intuitively integrating their impressions into an overall judgment. For instance, college admissions processes that depend on people sizing up candidates are markedly less predictive of academic success than adding up scores for the multiple criteria, even when some of the individual scores are themselves subjective judgments (Dawes 1982). Human judges lean too much toward seeing each case as individual and foregrounding this or that attractive or unattractive feature. Unfortunately this makes the final judgments worse, a trend difficult to convince people of because we are enormously attracted to the idea that nuanced holistic judgment always wins over adding up numbers (Galotti 2002, ch. 5).

### *Summing Up the Challenges of Decision Making*

Decisions often involve a range of options not apparent at first, as well as consequences of character, magnitude, and likelihood that are easily missed or mistaken. Quantitative and narrative styles of representation help us to manage the complexity, but they are useless if we do not seek out that complexiy. Instead, intuitive impressions rule. Often they are not well grounded in rich experience and personal sensibility. Often, misleading heuristics and biases are in the mix. Thus, thoughtful, careful decision makers must attend to and watch out for a number of factors.

However, relatively intuitive approaches sometimes yield good service, and more elaborate analyses sometimes yield no better choices and occasionally worse ones by disrupting sound intuitions. The trade-offs between relatively more analytic and intuitive approaches as well as between quantitative and narrative approaches lead to the question: What in the end is good decision making? If we want to educate people to make better choices, what practices should we be cultivating?

## GOOD DECISION MAKING

The quality of decision making can be evaluated in two ways: by examining how well particular choices work out and by examining the processes leading up to those choices. The first approach is, in a sense, the final word on the matter. However, systematically applying it is hard.

For one problem, decisions often fall short or indeed succeed because of unforeseen and not reasonably foreseeable events. Moreover, we often have no sure way of knowing what would have happened had we chosen differently. If a year ago we bought stock A rather than stock B, today we can look up how stock B did; but if we took job A rather than job B, who's to say how job B would have gone?

Furthermore, another troublesome cognitive illusion, *hindsight bias,* makes it difficult to judge what choice should have been made earlier knowing only what one knew at the time. People drastically overestimate the before-the-fact likelihood of events they know have actually occurred, and they also tend to view outcomes as unsurprising—"everyone knows that!" In one study, students read accounts of obscure historical events with different outcomes reported for different students and one group of students receiving no information about outcomes (Fischhoff and Beyth 1975). Asked to estimate the likelihood of various outcomes before the events, students who read that a particular outcome had actually occurred assigned it a much greater probability than the no-outcome group. In another study, Teigen (1986) had one group of students rate the "truth" of a proverb (e.g., "absence makes the heart grow fonder") while another group rated their "truth" of its opposite (e.g., "out of sight, out of mind"). Each proverb *and* its opposite generally earned "true" ratings.

In summary, defining good decision making by whether the particular choice actually works out well is a problematic approach. We do better to examine the character of the decision-making process itself.

### *The Limits of Utility Models*

As mentioned earlier, another way of characterizing good decision making involves the idea of expected utility. The utility strategy calls for constructing a tabular representation rating each option on each criterion, with the criteria weighted for their importance. If all this is done right, the decision recommended by the model can be shown to maximize utility for the decision maker (e.g., Baron 1988). Accordingly, the utility model might be a tempting normative standard for good decision making, providing a rigorous foundation for educational efforts.

However, the utility model does not offer the universal answer it may seem to at first. The model leaves out its sometimes high cost-in-effort and also assumes the decision maker's capability and available time. Moreover, the conclusion that utility will be maximized requires several background assumptions. For instance, all relevant options and criteria need to be in play, yet decision making often suffers from neglecting a less obvious option or criterion. Decision makers' ratings have to reflect their true goals and values, which sometimes are not consciously accessible.

Also the criteria need to add to the overall utility independently of one another rather than interacting. However, one characteristic commonly enhances or undermines the value of another. For instance, in a stereo system the contributions of speaker quality and amplifier quality are not independent: Higher-quality speakers contribute less without a good amplifier to drive them.

Such reservations do not challenge the considerable utility of the utility model, which often proves valuable in situations with several criteria and many tradeoffs across different options. This can easily happen for competing purchase decisions or job opportunities with different advantages and disadvantages. The quantitative/tabular approach provides a way to represent and review the situation, even when the ideal conditions for its application are not met. The issue is not whether the utility model is a good tool in the toolkit—it is—but whether it provides a universal normative model for good decision making—it doesn't.

## GOOD DECISION MAKING AS A DOUBLE BALANCING ACT

If the utility model does not offer the perfect account of a good decision-making process, what does? Perhaps no one template will suffice. Effective strategy requires sizing up the situation; it requires "deciding how to decide." Good decision making is thus a situation-responsive double balancing act of the intuitive and analytic, narrative and quantitative methods suited to the circumstances.

That is, good decision making is an adaptive response to the particulars (Payne et al. 1993), which might help to explain the finding from Galotti and colleagues (2006) that students' self-reported decision-making styles (e.g., more intuitive versus analytic) were not predictive of the number of options or attributes they considered in evaluating college majors. The demands of the specific decision may influence what people do more than their stylistic predilections. This would fit the general social science observation that behavior is determined more by situational characteristics than by personal characteristics (Ross and Nisbett 1991).

Deciding how to decide can be an almost reflexive or a highly deliberative matter. In any case, it often will lead the decision maker to a middle level of investment in decision making that neither risks an extremely intuitive decision nor bears the high costs of the most elaborate styles of analysis. For example, one line of experimentation asked subjects to consider options such as possible apartment rentals, applying a number of criteria to a range of alternatives. Faced with many options, people typically will quickly eliminate most of them as failing to meet one or another condition they view as necessary (for several similar examples, see Galotti 2002, ch. 4). A shopper might cross off any apartment on a busy street and any apartment over a certain cost per month. Such tactics reduce the options to a few inviting closer consideration. Strictly speaking, the elimination process is a normative mistake unless the elimination criteria are truly necessary conditions. The strategy risks missing the rare hidden gem; for example, an over-budget apartment so beautiful and convenient that one rethinks one's budget. However, the strategy makes the decision process much more manageable.

A narrative approach also can bring the decision maker to a middle level of investment, one that is more than a quick take but much less than a saga. Recall how research on expert decision making reveals clear patterns of narrative elaboration, such as testing promising solutions with mental simulations (Klein 1998; Lipshitz et al. 2001). Other strategies for making the most of one's narratives without letting them become hideously complex include settling time, such as "sleeping on it" or taking a walk, and repeated rehearsal to reappraise a narrative. I remember one person telling me that he talked over decisions with his cat. A deliberate counternarrative, such as the defense's response to the prosecution, is another tactic and a good way to test the integrity of a narrative.

Narrative and quantitative modes of representation involve trade-offs that affect how well they suit a particular situation. Narratives can deflect needed critical examination through the neatness of the stories they tell. Studying informal everyday reasoning, Perkins et al. (1991) argued that people taking positions on controversial issues often displayed a *makes-sense epistemology,* suspending critical judgment as soon as they arrived at one way of telling the story that made sense. Also, narrative forms quickly become unmanageable as they incorporate more dimensions and details. Quantitative/tabular forms can accommodate many options and criteria readily if tediously just by adding rows and columns.

On the other hand, even simple quantitative forms are hard to track without the help of pencil and paper or a spreadsheet. The causal-intentional character of narrative and counternarrative supports memory. Also, a narrative embodies an explanatory account of the promise of an option that might be more revealing than toting up scores.

Some situations clearly lend themselves more to a quantitative or narrative style. Apartment features like price, number of rooms, and location can be evaluated relatively independently of one another for their contribution to the overall desirability of an apartment, thus inviting a quantitative style. In contrast, to evaluate a poem by scoring it on independent dimensions of rhythm, metaphor, allusion, and so on would be odd: too much depends on how the various features integrate with one another.

Finally, mixed modes are often natural. For instance, a narrative style may morph into a quantitative style as more and more factors surface for consideration and demand organization. Alternatively, a quantitative exploration might reveal interacting factors that crystallize into a narrative more compelling than a tally of scores. Deciding how to decide is not just a single choice as one tackles a decision but a choice remade as ideas and information develop.

With more intuitive and analytic narrative and quantitative modes of representation available, what are some of the factors that inform a good double balance? At least three are worth considering: *stakes, knowledge,* and *personal resonance.*

### *The Significance of Stakes for Balanced Decision Making*

Stakes refer to the import of a decision for oneself and relevant others. Stakes vary enormously, from trivial, such as what flavor of ice cream to order for dessert, to substantial, such as whom to marry or whether to accept an enticing job offer. In the double balancing act of decision making, the basic guideline is simple: High stakes recommend more investment in narrative and/or quantitative analysis to improve the quality of the decision, assuming available time and information.

High stakes do not necessarily favor a quantitative style with options, attributes, and ratings. The appropriateness of an analytic approach depends on the character of the decision. However, high stakes do caution against leaving either the quantitative or the narrative mode out of the picture. The two offer different perspectives, they do not necessarily yield the same recommendation, and they can function as checks on each other, with discrepancy an invitation to deeper processing.

Although high stakes recommend significant analysis, significant does not necessarily mean maximal. Often more and more investment in thinking through a decision encounters sharply diminishing returns. On the narrative side, efforts to explore complex stories and counterstories can proliferate endlessly in the absence of key information. One example of this is the construction and appraisal of conspiracy theories around the Kennedy assassination. Nor do we need the grand scale of national events to doubt whether an elaborate tale with shaky grounds reveals what's really going on. Everyday institutional life in corporations and academic institutions displays plenty of tenuous tale spinning.

Elaborate quantitative approaches also commonly show diminishing returns. In principle, good decision making calls for keeping even seemingly weak options on the checklist: in the search for an apartment, an initially unlikely prospect might prove competitive because of high scores on features neglected in a first impression. However, if the initial culling of a long list is not too aggressive, this is unlikely. . In principle one can improve the quality of a decision by carefully weighting criteria or estimating the probabilities of various options succeeding—but if one cannot reliably do so, one may just be introducing noise into the analysis. Also, criteria are often correlated with one another, in which case relative weighting does not matter so much. Dawes (1982), studying the use of utility models to predict graduate school performance based on admissions criteria, found that different weightings of different criteria—say grade point average and GRE scores and certain interviewer impressions—did not matter because they overlapped a lot. One might as well keep it simple and weigh them all equally.

A final strategic point for deciding how to decide says that the stakes might not be quite as high as they seem. For some decisions, how one pursues the opportunities of a choice once made may be more important than which among reasonably promising options one selects. For example, the "right" college or graduate program seems as much a matter of what one makes of it as which one picks.

*The Significance of Knowledge for Balanced Decision Making*

Knowledge, experience, and understanding of a situation are tremendously important in the balancing act of good decision making. Fundamental to the pursuit of sound choices is taking stock of what one knows and critically appraising it. For example, in purchase decisions people assume a strong correlation between price and quality. However, such relationships vary considerably. In product areas where standards are enforced and prominent brand names figure, price differences are likely to reflect what manufacturers spend on advertising more than anything else. Buy generic drugs!

Consulting with others potentially more knowledgeable is a common recourse in decision making—but it also requires critical assessment of the input. Are these others really more expert than you? Do they have any reason to be biased? Would you do better to trust the most expert among them or go with the trend of their responses (on "the wisdom of crowds," see Surowiecki 2004)? Individual consultations aside, the age of the Internet makes certain kinds of information very accessible but not necessarily very reliable. For example, a quick Internet search for the promise of weight-reducing drugs reveals a cascade of strong claims in scientific language, but the claims are roundly debunked by reputable medical Internet sites. Assessing reliability remains a crucial part of the process.

Besides the search for objective information, there is the knowledge of lived experience. Rich experience in a domain makes possible and even recommends a somewhat intuitive narrative mode, especially when the stakes are low to moderate or time is a factor. Expertise enables the decision maker to build quickly an understanding of the situation from which a viable path forward emerges. "Expert" need not mean professional expertise but simply the sort of experience a serious weekend gardener or experienced commuter might attain. Byrnes (1998, 38) notes four sources from which decision makers can draw options: memory, analogical reasoning, causal reasoning, and advice. The first three benefit from a reasonable measure of experience in the area in question.

Experience can, however, prove entrapping: The better constructed the box, the harder to think outside it. So long as the solution is somewhere "in the box," experience should help. However, sometimes the solution lies elsewhere. The history of innovation includes many examples where entrenched belief systems stood in the way of novel theories—for example, the theory of continental drift and the bacterial theory of ulcers offered much-resisted counternarratives to the received narratives of their times. For more personal decisions, seriously pursued counternarratives can help people shake a false sense that they know the score. If you're afraid that leaving the formality of the workplace for the freedom of retirement will leave you at loose ends, disorganized and with little to fill your days, ask yourself to envision in some detail what sort of life you might construct. If you have always felt you would be uncomfortable in an urban environment, ask yourself to envision in some detail what life might be like in *this* urban setting *today*.

With some choices, we don't have enough pertinent experience to tell ourselves reliable stories. We are rare visitors to many of life's puzzles. Not often do we face major medical or care decisions for aging parents. Gut responses are likely to be unreliable. When we are not well-oriented, deliberately seeking out information and elaboration is especially important, and the more detached quantitative style, even if only in the form of a pro-con list, provides a way of organizing what information we do have or can gather from friends and other sources. This information can then be supplemented by whatever sensible stories we can tell ourselves. Also, we can try to remind ourselves about the sorts of heuristics and biases discussed earlier, lest they lead us to construct superficially persuasive but poorly grounded stories.

Situations where we are "visitors" shade into even more challenging situations where we find ourselves profoundly disoriented, unsure about how to characterize the problem at hand. Consider a medical situation where the doctors themselves do not know what is going on, or financial anomalies whose cause is unclear and could be the result of computer error or fraud or sloppiness. In such circumstances, a quick decision might be ill advised. Deciding how to decide might best be a matter of deciding not to decide yet! If doing so is safe, stall, buying time to build a better understanding. If decisions of some sort must be made, sometimes they can take the form of hedges or choices that can later be reversed.

Research on expertise warns that we sometimes are not the experts we think we are. Overall, people's judgments in college admission processes actually are not as predictive of academic success for admittees as simply adding up scores (Dawes 1982). Extensive experience with an activity does not always add up to discernment. Consider how many people never get good at sports or games they regularly play. Or consider how some people have a pattern of troubled relationships, falling into the same pitfalls over and over. Investigators have singled out some of the characteristics that help us build reliable judgment from extended experience: recurrent rather than unique situations, a greater focus on things than on human behavior, feedback available regarding success rather than no feedback, stable versus dynamic situations, and the like (Shanteau 1992).

### *The Significance of Personal Resonance for Balanced Decision Making*

For some kinds of decisions more than others, one's personal intuitions about the situation have an intrinsic relationship to the desired outcomes. Compare investing $10,000 in the stock market with spending $10,000 on a painting for your living room. If you are an experienced investor, you might have a feel for the merits of the stock, but the ultimate aim is financial return. In contrast, the ultimate aim of purchasing the painting is to acquire an object that you will still enjoy looking at many years later. Your feelings about the painting today are a sample of what you ultimately want out of it.

An intrinsic relationship between one's intuitive feelings and the matter at hand informs many life decisions, for instance regarding the relationships one sustains, the place where one lives, or the profession one pursues. One can compose a narrative or quantitative analysis for any of these high-stakes decisions, but to make such choices without asking whether one *liked* the other person, the dwelling, or the profession would be odd. In such cases, the intuitive voice of personal resonance (or dissonance) is a tremendously important data point, often approaching a necessary condition.

When personal resonance has special bearing, good narrative elaboration may serve the decision process better than quantitative/tabular elaboration. Consider how poetry or prose can capture essential personal qualities. In contrast, decisions regarding stock investments, insurance policies, and washing machines have a kind of neutrality that invites treating them largely in terms of objective advantages and disadvantages.

### *Balanced Decision Making in Summary*

Good decision making can be seen as a double balancing act. The decision maker decides how to decide, adopting a more intuitive or analytic approach in a more narrative or quantitative or mixed style suited to stakes, knowledge, and personal resonance.

- High-stakes decisions recommend a more analytic approach with both narrative and quantitative/tabular representations to crosscheck one another but with caution about diminishing returns for extended elaboration.
- Extensive knowledge and experience enable more effective use of intuition and narrative modes of representation—but with awareness that the situation may require "thinking out of the box" in ways that challenge one's knowledge and experience.
- Personal resonance gives a special priority to personal intuitive reasons—not because they offer a more accurate read on an objective reality but because they represent personal affinities or aversions that are likely to continue to color one's experience of the path taken.
- Finally, even a relatively intuitive decision of the moment deserves due analytic consideration of commonly overlooked matters such as opportunity costs, cognitive illusions (e.g., loss aversion), and biasing influences (e.g., social pressure).

Although such principles and their refinements offer no calculus of normative correctness, they do show how the thoughtful decision maker might take stock and choose a smart approach. However, as the saying goes, advice is cheap. What does it take to put good decision-making practices into action in learners' everyday lives?

## TEACHING DECISION MAKING

Fostering better decision making might seem simply a matter of informing learners about how to play the game. Here are the good moves and a little practice, now go forth and decide better! However, information and exercise alone are not likely to do the job.

First, good decision making, as with any everyday kind of thinking, is highly dispositional. Appropriate knowledge and skills need the company of alertness to occasions and readiness to engage them seriously and thoughtfully. Several lines of research argue that sophisticated thinking depends not just on abilities but dispositions, with people commonly performing below capacity for lack of commitment or sensitivity to occasion (e.g., Dweck 2000; Perkins and Ritchhart 2004; Perkins et al. 2000; Stanovich 1999). Individuals vary considerably in their openness or aversion to the sorts of ambiguities and complexities that emerge in working through a difficult choice, as gauged by such dispositional indices as *need for cognitive closure* (Kruglanski and Webster 1996) or *need for cognition* (Cacioppo et al. 1996). For instance, tricky, emotionally loaded decisions can prompt costly procrastination during which the problem becomes greater—especially when the decision maker postpones the decision without using the additional time to gather information or counsel.

Besides appropriate dispositions, good decision making calls for self-regulation (Byrnes 1998). Effective decision makers decide how to decide in particular situations, monitor their progress, perhaps revise their strategies in midstream, and take stock afterward to improve future practice. Accordingly, interventions should foster relevant skills and knowledge, cultivate positive dispositions, and develop metacognitive self-regulation of decision-making practices.

Byrnes (1998) among others has pointed out two fundamentally different approaches to cultivating better decision making. One targets high-priority areas such as adolescent sexuality, conflict and violence, drug and alcohol use, or parenting practices. The other aims at teaching general decision-making skills and dispositions.

### *Teaching Decision Making in High-Priority Areas*

Adolescence offers an attractive zone for interventions because of patterns of adolescent risk-taking. Byrnes cautions that the surge in risk-taking does not appear to reflect anything about the teenage mind as such but rather the reduction of parental controls during that period. Indeed, adults show similar patterns of risk-taking. However, adolescents as a group still in school provide a convenient and important intervention population.

Programs focusing on adolescent sexuality and risk provide a class of well-researched examples of the targeted approach. Reyna et al. (2005) provide a convenient review in the context of discussing a particular developmental theory of decision making. "Just-say-no" programs that push abstinence appear not to work well, their impact on sexual restraint and taking precautions minimal. Moreover, abstinence programs can hardly be considered efforts to foster decision making. Instead, they promote a particular decision. More effective programs engage the student in understanding the risks of sexual activities and the ways of protecting oneself and one's partners. Several such programs have been shown to produce near-term effects on rates of abstinence and use of protection.

Often the impact fades in a few months. However, the authors particularly like a program called *Reducing the Risk: Building the Skills to Prevent Pregnancy, STD, and HIV* (Barth 1996) for which studies suggest somewhat longer-term effects. Reyna et al. (2005) foreground some critical features of the program's pedagogy. Students learn what the dangers are, what can be done about them, and their own capabilities to act effectively. Role-playing and other techniques help develop in-the-moment dispositions and capabilities. "Social inoculation" equips students to deal effectively with social pressure. All this unfolds over a considerable period of time.

What makes such interventions effective? They speak more to intuitive decision making in a particular context than to analytic decision making in general. They equip learners with a range of basic understandings that offer clear immediate implications for sexual caution. Reyna et al. (2005) characterize this as a matter of accumulating and using appropriate "gists," relatively simple ways of understanding situations that allow ready inference of appropriate courses of action.

For another example, the *Resolving Conflict Creatively Program* (RCCP) focuses on violence-prevention with elementary school children (Aber et al. 1998). Some fifty lessons foster attitudes and skills around deciding how to handle conflict situations, including building cultural awareness and sensitivity to interpersonal and intergroup relationships. The methods include examples, role playing, discussion, and reflection.

Propensity to violence considerably increases during the elementary school years. Systematic research on RCCP implementations suggests that the program dampens this trend for many learners while not reversing it. Results were measured in multiple ways, with hostile attributions to hypothetical scenarios, response choices to hypothetical scenarios, reported aggressive fantasies, depression, and actual conduct problems. Results varied depending on gender, age, depth of implementation, and other factors (Aber et al. 1998; Aber et al. 2003).

RCCP and similar programs typically emphasize narrative approaches to decision making. Less commonly used are coolly analytical tools such as pro-con lists or tables of options crossed with dimensions of evaluation. Reyna et al. (2005) argue that in high-risk areas such as sexual behavior efforts to reason through complex trade-offs of risks and gains can be counterproductive. More insightful gists, broad understandings that strongly recommend cautionary practices, afford better management of one's behavior. The learning process in these programs develops practical and prudent expertise and uses role-playing rehearsals of highly charged situations to address not only knowledge and skill but dispositions and self-regulation. In doing so, such programs appropriately treat decisions around sexuality and violence as high stakes (e.g. the risk of venereal disease or injury), requiring knowledge and experience (built up in part through gists and role playing), and reflecting positive and negative personal resonance (sexual attractions or surges of temper addressed through discussion and role playing).

Targeted instruction in decision making in high-priority areas can work, even in areas as sensitive and gland-driven as adolescent sexuality and violence. But the strength of such programs is also their weakness: By intent and design they target particular areas rather than general decision-making capabilities and dispositions. Many of the important decisions people face are not in chronic, high-risk areas but are encountered only now and then. Developing a full-scale program of instruction for every type of decision would not make sense.

### *Teaching Decision Making as a General Craft*

Byrnes (1998) reviews three programs designed to cultivate the general craft of decision making, drawing on an earlier review of efforts to teach adolescents decision making by Beyth-Marom et al.(1991). The GOFER program's emphasis is clear from its acronym: Goals clarification, Option generation, Fact-finding, consideration of Effects, and Review (Mann et al. 1988). The Personal Decision Making program emphasizes a decision-making process of five steps: identifying alternatives, formulating criteria, applying the criteria to alternatives, summarizing the results, and self-evaluation (Ross 1981). The Odyssey program to teach thinking is an extensive intervention of one hundred lessons, including a ten-lesson unit on decision making, with attention to anticipating outcomes, acquiring and assessing information, articulating preferences, and applying weights to dimensions to manage complex decisions (Herrnstein et al. 1986).

All three programs address adolescents. All consist of a few lessons on decision making to be taught in a school context. All emphasize application of multiple attributes to options in order to score them. All operate as independent mini-courses within the curriculum. All include the teaching of specific strategies or procedures toward understanding the decision situation, identifying options, examining consequences, and evaluating options in terms of their consequences. They seek to help learners develop the basic skills and dispositions of an analytic, quantitative style of decision making.

Some interventions with a similar strategic emphasis engage the rhythm of schooling in a different way. The literature on the thinking-skills movement makes a distinction between stand-alone and infused interventions (e.g., Swartz and Perkins 1989; Perkins 1995, ch. 8). Whereas stand-alone interventions constitute courses or mini-courses of their own, infused interventions combine the cultivation of thinking with learning in the disciplines.

Robert Swartz and his colleagues have worked on infused models of the teaching of thinking for many years (Swartz and Parks 1994; Swartz et al. 2007). Their approach includes considerable attention to decision making, fostering attention to options, consequences, costs, and related matters. Graphic organizers often are used to help learners express and order their thinking around content-related issues. In one typical application, students take on the role of Harry Truman pondering whether to drop atomic bombs on Hiroshima and Nagasaki (Swartz et al. 1998; for a brief account and graphic organizer, see Swartz 2000). The students are allowed to reason only with information available up to 1945. Intervention at early grades is possible too. A sample lesson for first graders uses *Horton Hatches the Egg* by Dr. Seuss and a simplified decision-making strategy—What could we do? What would happen if we did those things? What's the best thing to do?

The designers of infused programs would not expect occasional decision-making activities in history or reading to make learners better decision makers. Rather, they encourage frequent and consistent use of such practices across a variety of disciplines, aiming both to deepen disciplinary learning and instill decision-making practices that will spill over to other disciplines and to learners' everyday lives.

How confident can we be that such initiatives, stand-alone or infused, have the desired impact? A prior question concerns the entire enterprise of the teaching of general thinking skills and dispositions. This issue has been controversial (Anderson et al. 1996; Brown et al. 1989; Perkins and Salomon 1987, 1989). Some have argued, using concepts like *situated learning* (e.g., Lave and Wenger 1991), that enhancing cognitive capabilities in a general sense is unlikely. Effective initiatives need a contextual focus, as with the programs on adolescent sexuality and violence. For a while, the debate took a polarized "can't be done / can be done" form. My sense is that a more moderate position now prevails. In any case, I have argued elsewhere that the literature now offers a number of clear empirically grounded cases of enhancing various general cognitive skills (Grotzer and Perkins 2000; Perkins 1995; Ritchhart and Perkins 2005).

However, decision making per se has not been the focus of the best research. Byrnes (1998) observes that the evaluations of the GOFER, Personal Decision Making, and Odyssey programs all included some positive results—but on measures that emphasized students' knowledge of decision making. Researchers made no posttest effort to inventory students' decision-making behavior in real-world contexts or to engage them in simulated decision-making processes.

One can hope that the students' gains in knowledge and understanding would translate into shifts in practical behavior, but Byrnes warns that the pedagogical approaches taken seem somewhat didactic. Ideas about transfer of learning point to features that should enhance impact: metacognitive reflection; intensive simulated rehearsal, such as that which is characteristic of targeted approaches; and direct encouragement to apply the ideas widely, such as log-keeping activities around everyday decision making (e.g., Perkins and Salomon 1989; Salomon and Perkins 1989).

Many examples of infused approaches exist, but little research has been done in this area because embedding thinking strategies in disciplinary learning introduces many hard-to-control variables. Two kinds of outcomes—enhancement of disciplinary understanding and thinking—are relevant, and even without controlled studies we can reasonably claim that the extensive use of infused decision making or other thinking practices almost certainly fosters disciplinary understanding. Extensive research has demonstrated that thoughtful elaborative processing of content builds understanding (e.g., Cohen et al. 1993; Meyer and Land 2006; Wiske 1998).

On the other hand, the impact of infused approaches on students' general decision-making practices lacks rigorous evidence one way or the other. Informal reports of deeper writing about decision situations are encouraging, as are frequent anecdotes from students about how they applied one or another technique. However, these do not offer direct evidence of lasting general changes in decision making. Although inconvenient to investigate, this is an area that would be worth the effort.

To summarize, pedagogical approach is important. Didactic styles are likely to be less effective than approaches that involve metacognitive reflection and simulations. Fairly frequent activities over a considerable period of time are likely to have greater impact than a brief unit. Approaches that focus on single disciplines or topics are likely to be less effective than approaches that deliberately range across disciplines and invite learners to make connections to their out-of-school lives, fostering transfer of learning.

Also, typical interventions such as GOFER lean toward the quantitative/tabular style of analysis, with options and attributes and ratings or checklists. They also neglect the importance of regulating decision making according to the critical dimensions of stakes, knowledge, and personal resonance, generally assuming medium to high stakes and making available necessary knowledge: not much attention is paid to sizing up the circumstances and deciding how to decide. The programs also often do not directly deal with typical heuristics and biases, including social influences like bandwagon effects. Accordingly, we might look toward interventions that take a more balanced decision-making approach, with learners encouraged to develop positive dispositions and self-regulation regarding which approach or what mixture applies when.

## DECISION MAKING AND CIVIC ENGAGEMENT

Better decision making has not just personal but social importance. The participative character of democracies calls for informed citizens who thoughtfully consider matters of policy and justice, adding to the collective wisdom by voting, campaigning, protesting, and engaging in informal discourse. One of the principal goals of education is generally taken to be preparation for such roles.

Thus, however schools address decision making in general, they would do well to engage the peculiar dilemmas of personal decision making for the public good. Imagine, for instance, that civic engagement was approached much the same way as programs on adolescent sexuality and violence, with assiduous attention to naive beliefs, social inoculation against misleading pressures, simulation activities to foster behavioral patterns of thoughtful civic participation resistant to undue influence, and so on.

Interventions with such a clear social agenda should include ample attention to the contribution of social interactions to decision making. One baleful influence is *groupthink* (Janis 1972), a phenomenon that runs all the way from PTA meetings to national politics. Groupthink is the tendency for group members to influence one another in ways that lead to an artificial and misleading consensus. It's a matter of following the crowd, deferring to influential figures, and keeping contrary thoughts to oneself when a trend gathers momentum.

Quite the opposite phenomenon is documented by James Surowiecki (2004) in his recent *The Wisdom of Crowds*. Surowiecki reviews numerous research results and natural circumstances demonstrating that the common trend across a number of individuals often yields remarkably good judgments and predictions—better than most of the individuals involved, even the experts. Cases range from estimating the number of marbles in a jar to predicting elections and economic trends.

The wisdom of crowds is good news for the potential of democratic societies and free markets. But it comes with a seeming paradox: How can we have both groupthink and the wisdom of crowds? The answer is that they reflect different circumstances. Groupthink thrives on close interactive relationships between the people involved, so that opinions can snowball. In contrast, the wise crowd generally involves people not in close touch, with varied sources of information, and reaching independent judgments.

Although students certainly could prepare better for decision making in civic contexts, the challenge goes well beyond individual commitment and capability. Thoughtful independent judgment is not so well served by typical political processes and institutions. Even reasonably committed members of the polity cannot find it easy to function in an ideal way. Consider the inordinate burden of understanding complex public issues. No matter whether the theme is immigration, tax laws, military commitments, or healthcare, the media are replete with debate from power figures and interest groups. Every statement has a counterstatement. Misinformation is commonplace, as registered by watchdog groups that fact-check political speeches. Statistics are used to lead and mislead. The principal voices strive for simplistic compelling stories that will win allegiance. Sources written in the neutral manner of reasoned opinion are often deeply biased.

Now consider the challenge from the perspective of balanced decision making and the three factors: stakes, knowledge, and personal resonance. In civic engagement, stakes often have the unfortunate configuration of low personal, high public significance. Many individuals correctly judge that large-scale policy or leadership decisions will not much affect their personal lives. Even when the personal impact could be great, they note that their opinion or vote is a drop in the bucket—their expected return on investment of effort is very low. As to knowledge, most people cannot be deeply knowledgeable about the welter of issues in play, and efforts to acquire some basic and reliable grounding are frustrated by the adversarial and often manipulative character of political PR. As to personal resonance, the natural turn of public controversy is to personalize everything with broad appeals to identity and emotion—even issues that would better be considered in detached analytic ways. In summary, the typical pattern of public discourse around major issues and offices is singularly unsupportive of, indeed in many ways actively undermining of, thoughtful citizenly engagement.

To develop citizenly skills and dispositions while neglecting large-scale patterns that undermine thoughtful engagement would be shortsighted. To get results, we need to attend to both. One can envision institutions that help rather than hinder civic engagement by clarifying stakes, providing reliable knowledge, and handling personal resonance in an honest way. Imagine, for instance, that major newspapers, regardless of their political leanings, routinely made available fact checks of political statements, with lead-ins always on the front page. Imagine that Google provided prominent front-page links to such analyses for every user who did not explicitly opt out. Imagine that the media took a cue from the way technology products are often analyzed in reviews, organizing summaries of issues with tables itemizing factors and briefly characterizing features. Occasionally one sees this, but it could be commonplace. Imagine that important and orienting factual information—not information under significant debate—were widely and actively "advertised" to produce better public calibration around important issues (because the reality is that most people remain seriously underinformed even when critical information is widely accessible).

Ideas such as these bring with them many challenges. The point is not that any one of these ideas is a magic bullet but that educating for more thoughtful civic engagement makes little sense if the social institutions that undermine thoughtful civic engagement continue to be disregarded.

## THE FUTURE OF DECISION MAKING

Just as the role of decision making in individual and collective endeavor is enormous, so is the research on decision making extensive. Many prominent themes are hardly touched here, including moral aspects of decision making, the significance of time pressure, the complexity of rapidly changing situations, the detection of important decision points handled by default but meriting reconsideration, the role of will and intentions in following through on in-principle decisions (the "New Year's Resolutions" problem), goal revision in contrast with evaluating options relative to current goals, decision avoidance, regret avoidance as a driver of decision making, decision-making styles, and the intricacies and pitfalls of group decision making.

Although speaking to all these motifs, the literature also displays significant blind spots. Galotti (1995) notes that relatively little research has tracked real-life decision making in nonexperts, her studies of college choice and college major choice being an important exception. We know little about which heuristics and biases investigated in the laboratory come up the most in realistic circumstances. Evidence positive or negative of the impact of interventions on actual everyday behavior is sparse.

These limits acknowledged, the present exploration advocates for more attention to be paid to the following areas of neglect:

*1. Beyond analytical to well-grounded intuitive decision making.* Much of the literature on decision making and most educational interventions targeting general decision making treat it as ideally an analytical enterprise. However, research tells us that in certain contexts well-grounded intuitive thinking serves decision making better. Accordingly, what has here been characterized as balanced decision making, with the right balance sought situation by situation as the person decides how to decide, would serve personal and public interests better than a doggedly analytic approach.

*2. Beyond quantitative/tabular to narrative styles of decision analysis.* Approaches to cultivating general decision-making capabilities tend to foreground quantitative analysis—options, attributes, ratings, scores, or junior versions of the same, such as pro-con lists and tallies. This is often a powerful mode of analysis, but research on decision making suggests that narrative analysis is potent as well. The particular character of the decision can lend itself to one or the other or to a blend.

*3. Both high-priority targets and general decision making.* While some people hope that the cultivation of general decision-making skills and dispositions will serve well enough, high-priority persistent trouble spots such as adolescent sexuality, drug use, violence, and civic participation almost certainly require targeted treatment. Good practice depends too much on context-specific knowledge encoded in ways that make it fluently available in the moment, and on managing tricky aspects of personal resonance, for anyone to expect that general decision-making skills and dispositions will powerfully inform such areas.

However, personal and public life include a myriad of medium- to high-stakes decisions that occur only now and then. One cannot prepare young learners for hundreds of specific decisions case-by-case. Some researchers have claimed that general cognitive skills cannot be significantly enhanced, but plenty of evidence exists to the contrary. Therefore, general decision-making skills and dispositions are important too.

*4. Beyond improving people to improving institutions.* Improving citizenly decision making tends to be viewed as solely a matter of improving citizens—better people for a better democracy. However, the quality of decision making greatly depends on contextual support as well as the skills and dispositions of participants. In many ways, current public institutions and patterns of discourse undermine rather than sustain good decision making. This invites attention to social innovations that would make thoughtful civic participation more natural and responsible—and the same applies to innovations on a smaller scale, as within corporate, government, and educational institutions.

My recommendation is emphatically expansive: Much more can be done than is being done. We know a lot today about how decision making might go better, and this knowledge provides a platform on which to build. Moreover, the best of current programs to improve decision making, both targeted and general, seem likely to have some beneficial effects.

However, comprehensive efforts to enhance decision making should include more attention to intuitive and narrative approaches. Efforts to improve general decision making should not be seen as substitutes for addressing high-priority targets and vice versa. Making people better decision makers should figure as part of a larger agenda of developing social settings to be more supportive of thoughtful decision making.

As to research, we do not know enough about the impact of interventions, particularly those focused on improving decision making generally. Nor do we have good maps of the variety of decisions people face in their lives and the pitfalls that cause the most trouble outside of laboratory studies and simulations. Such research is challenging because it requires finding ways to track people's decision making "in the wild," but it is important enough to pursue with more vigor.

In present patterns of schooling as in our society at large, the improvement of everyday decision making gets meager attention. Yes, one can point to the occasional course or other intervention, but the reality is that most people spend little learning time on decision making as such. Few areas of skill and character promise so much payout and receive so little pay-in. Whether to invest in fostering everyday decision making is a decision also. These pages are something of an argument for its importance and priority.

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## REFERENCES

Aber, J., J. L. Brown, and S. M. Jones. 2003. Developmental trajectories toward violence in middle childhood: Course, demographic differences, and response to school-based intervention. *Developmental Psychology* 39:324–348.

Aber, J., S. M. Jones, J. L. Brown, N. Chaudry, and F. Samples. 1998. Resolving conflict creatively: Evaluating the developmental effects of a school-based violence prevention program in the neighborhood and classroom context. *Development and Psychopathology* 10:187–213.

Amsel, E., T. Bowden, J. Cottrell, and J. Sullivan. 2005. Anticipating and avoiding regret as a model of adolescent decision making. In *The Development of Judgment and Decision Making in Children and Adolescents,* ed. J. E. Jacobs and P. A. Klaczynski, 119–156. Mahwah, NJ: Erlbaum.

Anderson, J. R., L. M. Reder, and H. A. Simon. 1996. Situated learning and education. *Educational Researcher* 25(4):5–11.

Baron, J. 1988. *Thinking and Deciding.* New York: Cambridge University Press.

Barth, R. P. 1996. *Reducing the Risk: Building Skills to Prevent Pregnancy, STDs, and HIV.* Santa Cruz, CA: ETR Associates.

Beyth-Marom, R., B. Fischhoff, M. J. Quadrel, and L. Furby. 1991. Teaching adolescents decision making. In *Teaching Decision Making to Adolescents,* ed. J. Baron and R. V. Brown, 19–60. Mawah, NJ: Erlbaum.

Brown, J. S., A. Collins, P. and Duguid. 1989. Situated cognition and the culture of learning. *Educational Researcher* 18(1):32–42.

Byrnes, J. P. 1998. *The Nature and Development of Decision Making: A Self-Regulation Model.* Mahwah, NJ: Erlbaum.

Cacioppo, J. T., R. E. Petty, J. A. Feinstein, W. B. G. Jarvis. 1996. Dispositional differences in cognitive motivation: The life and times of individuals varying in need for cognition. *Psychological Bulletin* 119(2), 197–253.

Cohen, D. K., M. W. McLaughlin, and Talbert, J. E., eds. 1993. *Teaching for Understanding: Challenges for Policy and Practice.* San Francisco: Jossey-Bass.

Dawes, R. M. 1982. The robust beauty of improper linear models in decision making. In *Judgment Under Uncertainty: Heuristics and Biases,* ed. D. Kahneman, P. Slovic, and A. Tversky, 391–407. Cambridge, UK: Cambridge University Press.

Dawes, R. M., and B. Corrigan. 1974. Linear models in decision making. *Psychological Bulletin* 81:95–106.

Dweck, C. S. 2000. *Self-theories: Their Role in Motivation, Personality, and Development.* Philadelphia: Psychology Press.

Epstein, S. 1994. Integration of the cognitive and psychodynamic unconscious. *American Psychologist* 49:709–724.

Evans, J. 2008. Dual-processing accounts of reasoning, judgment, and social cognition. *Annual Review of Psychology* 59:255–278.

Fischhoff, B. and R. Beyth. 1975. "I knew it would happen": Remembered probabilities of once-future things. *Organizational Behavior and Human Performance* 13:1–16.

Galotti, K. 1995. A longitudinal study of real-life decision making: Choosing a college. *Applied Cognitive Psychology* 9:459–484.

Galotti, K. 2002. *Making Decisions That Matter: How People Face Important Life Choices.* Mahwah, NJ: Erlbaum.

Galotti, K. M., E. Ciner, H. E. Altenbaumer, H. J. Geertz, A. Rupp, and J. Woulfe. 2006. Decision making styles in a real-life decision: Choosing a college major. *Personality and Individual Differences* 41:629–639.

Gladwell, M. 2005. *Blink: The Power of Thinking without Thinking.* New York: Little, Brown.

Grotzer, T. A., and D. N. Perkins. 2000. Teaching intelligence: A performance conception. In *Handbook of Intelligence,* ed. R. J. Sternberg, 492–515. New York: Cambridge University Press.

Herrnstein, R. J., R. S. Nickerson, M. Sanchez, and J. A. Swets. 1986. Teaching thinking skills. *American Psychologist* 41:1279–1289.

Jacobs, J. E. and P. A. Klaczynski, eds. 2005. *The Development of Judgment and Decision Making in Children and Adolescents.* Mahwah, NJ: Erlbaum.

Janis, I. 1972. *Victims of Groupthink: Psychological Study of Foreign-Policy Decisions and Fiascoes.* 2nd ed. Boston: Houghton Mifflin.

Janis, I. L. 1989. *Crucial Decisions.* New York: The Free Press.

Johnson, D. D. P. 2004. *Overconfidence and War: The Havoc and Glory of Positive Illusions.* Cambridge, MA: Harvard University Press.

Kahneman, D., and A. Tversky. 1979. Prospect theory: An analysis of decisions under risk. *Econometrica* 47:263–291.

Kahneman, D., P. Slovic, and A. Tversky. 1982. *Judgment under Uncertainty: Heuristics and Biases.* Cambridge, UK: Cambridge University Press.

Klaczynski, P. A. 2005. Metacognition and cognitive variability: A dual-process model of decision making and its development. In *The Development of Judgment and Decision Making in Children and Adolescents,* ed. J. E. Jacobs and P. A. Klaczynski, 39–76. Mahwah, NJ: Erlbaum.

Klein, G. 1998. *Sources of Power: How People Make Decisions.* Cambridge: MIT Press.

Kruglanski, A., and D. Webster. 1996. Motivated closing of the mind: "Seizing" and "freezing." *Psychological Review* 103(2):263–283.

Lave, J., and E. Wenger. 1991. *Situated Learning: Legitimate Peripheral Participation.* New York: Cambridge University Press.

Lipshitz, R., G. Klein, J. Orasanu, and E. Salas. 2001. Taking stock of naturalistic decision making. *Journal of Behavioral Decision Making* 14:331–352.

Mann, L., R. Harmoni, C. Power, G. Beswick, and C. Ormond. 1988. Effectiveness of the GOFER course in decision making for high school students. *Journal of Behavioral Decision Making* 1:159–168.

McNeil, B., S. Pauker, H. Sox, and A. Tversky. 1982. On the elicitation of preferences for alternative therapies. *New England Journal of Medicine* 306:1259–1262.

Meyer, J. H. F., and R. Land, eds. 2006. *Overcoming Barriers to Student Understanding: Threshold Concepts and Troublesome Knowledge.* London: Routledge.

Moshman, D. 2005. Commentary: The development of thinking. In *The Development of Judgment and Decision Making in Children and Adolescents,* ed. J. E. Jacobs and P. A. Klaczynski, 327–334. Mahwah, NJ: Erlbaum.

Payne, J. W., J. R. Bettman, and E. J. Johnson. 1993. *The Adaptive Decision Maker.* New York: Cambridge University Press.

Perkins, D. N. 1995. *Outsmarting IQ: The Emerging Science of Learnable Intelligence.* New York: The Free Press.

Perkins, D. N., M. Farady, and B. Bushey. 1991. Everyday reasoning and the roots of intelligence. In *Informal Reasoning,* ed. J. Voss, D. N. Perkins, and J. Segal, 83–105. Hillsdale, NJ: Lawrence Erlbaum Associates.

Perkins, D. N., and R. Ritchhart. 2004. When is good thinking? In *Motivation, Emotion, and Cognition: Integrative Perspectives on Intellectual Functioning and Development,* ed. D. Y. Dai and R. J. Sternberg, 351–384. Mawah, NJ: Erlbaum.

Perkins, D. N., and G. Salomon. 1987. Transfer and teaching thinking. In *Thinking: The Second International Conference,* ed. D. N. Perkins, J. Lochhead, and J. Bishop, 285–303. Hillsdale, NJ: Lawrence Erlbaum Associates.

Perkins, D. N., and G. Salomon. 1989. Are cognitive skills context bound? *Educational Researcher* 18(1):16–25.

Perkins, D. N., S. Tishman, R. Ritchhart, K. Donis, and A. Andrade. 2000. Intelligence in the wild: A dispositional view of intellectual traits. *Educational Psychology Review* 12(3):269–293.

Reyna, V. F., M. B. Adam, K. M. Poirier, C. W. LeCroy, and C. J. Brainerd. 2005. Risky decision making in childhood and adolescence: A fuzzy-trace theory approach. In *The Development of Judgment and Decision Making in Children and Adolescents,* ed. J. E. Jacobs and P. A. Klaczynski, 77–106. Mahwah, NJ: Erlbaum.

Ritchhart, R., and D. N. Perkins. 2005. Learning to think: The challenges of teaching thinking. In *Cambridge Handbook of Thinking and Reasoning,* ed. K. Holyoak and R. Morrison, 775–802. New York: Cambridge University Press.

Ross, J. A. 1981. Improving adolescents' decision making skills. *Curriculum Inquiry* 11:279–295.

Ross, L., and R. E. Nisbett. 1991. *The Person and the Situation: Perspectives of Social Psychology.* Philadelphia: Temple University Press.

Salomon, G., and D. N. Perkins. 1989. Rocky roads to transfer: Rethinking mechanisms of a neglected phenomenon. *Educational Psychologist* 24(2):113–142.

Shanteau, J. 1992. Competence in experts: The role of task characteristics. *Organizational Behavior and Human Decision Processes* 53:252–266.

Simon, H. A. 1957. *Models of man: Social and Rational.* New York: Wiley.

Stanovich, K. E. 1999. *Who is Rational? Studies of Individual Differences in Reasoning.* Mahwah, NJ: Erlbaum.

Starbuck, W. H., and F. J. Milliken. 1988. Challenger: Fine-tuning the odds until something breaks. *Journal of Management Studies* 25:319–340.

Surowiecki, J. 2004. *The Wisdom of Crowds: Why the Many are Smarter than the Few and How Collective Wisdom Shapes Business, Economies, Societies and Nations.* New York: Little, Brown.

Swartz, R. J. 2000. Thinking about decisions. In *Developing Minds: A Resource Book for Teaching Thinking,* ed. A. L. Costa, 58–66. Alexandria, VA: ASCD.

Swartz, R. J., A. L. Costa, B. K. Beyer, R. Regan, and B. Kallick. 2007. *Thinking-Based Learning: Activating Students' Potential.* Norwood, MA: Christopher-Gordon Publishers.

Swartz, R. J., S. Fischer, and S. Parks. 1998. *Infusing the Teaching of Critical and Creative Thinking into Secondary Science: A Lesson Design Handbook*. Pacific Grove, CA: Critical Thinking Press and Software.

Swartz, R. J., and S. Parks. 1994. *Infusing the Teaching of Critical and Creative Thinking into Secondary Science: A Lesson Design Handbook.* Pacific Grove, CA: Critical Thinking Press and Software.

Swartz, R. J., and D. N. Perkins. 1989. *Teaching Thinking: Issues and Approaches.* Pacific Grove, CA: Midwest Publications.

Teigen, K. 1986. Old truths or fresh insights? A study of students' evaluations of proverbs. *British Journal of Social Psychology* 25:43–49.

Tuchman, B. 1984. *The March of Folly.* New York: Alfred A. Knopf.

Tversky, A., and D. Kahneman. 1992. Advances in prospect theory: Cumulative representation of uncertainty. *Journal of Risk and Uncertainty* 5:297–323.

von Winterfeldt, D., and W. Edwards. 1986. *Decision Analysis and Behavioral Research.* New York: Cambridge University Press.

Wilson, T. D., D. J. Lyle, J. W. Schooler, S. D. Hodges, K. J. Klaaren, and S. J. LaFleur. 1993. Introspecting about reasons can reduce post-choice satisfaction. *Personality and Social Psychology Bulletin* 19:331–339.

Wilson, T. D., and J. W. Schooler. 1991. Thinking too much: Introspection can reduce the quality of preferences and decisions. *Journal of Personality and Social Psychology* 60:181–192.

Wiske, M. S., ed. 1998. *Teaching for Understanding: Linking Research with Practice.* San Francisco, CA: Jossey-Bass.

CHAPTER 2

# Can Reasoning Be Taught?

RICHARD E. NISBETT

Can people be taught to use abstract inference rules, such as the rules of logic, to reason about events in everyday life?

For 2,500 years the Western world believed that the answer to this was yes. Plato said "those who have a natural talent for calculation are generally quick at every other kind of knowledge; and even the dull, if they have had an arithmetical training . . . become much quicker than they would otherwise have been . . ." and "We must endeavor to persuade those who are to be the principal men of our state to go and learn arithmetic" (Plato 1875, 785).

The Romans agreed with their Greek predecessors, adding the study of grammar to the curriculum. The medieval scholastics were not ones to doubt the wisdom of the ancients and added to the curriculum the study of logic, especially syllogisms. The humanists of the Renaissance, even more in thrall to the ancients, added the study of Latin and Greek, and the curriculum was set for the next 400 years, culminating in the English public (*sic*) school system of the nineteenth century. One educator proclaimed the utility of Latin for teaching people how to think:

> My claim for Latin, as an Englishman and a . . . teacher is simply that it would be impossible to devise for English boys a better teaching instrument. . . . The acquisition of a language is educationally of no importance; what is important is the process of acquiring it. . . . The one great merit of Latin as a teaching instrument is its tremendous difficulty.

But the contention that the learning of abstract rule systems has any effect on people's ability to reason about everyday life problems was one of the first ideas to be attacked by the new discipline of psychology at the turn of the twentieth century. William James ridiculed the idea that the mind had muscles that could be exercised by arithmetic or Latin. The learning theorists of the 1920s and 1930s provided a theoretical rationale for rejecting the idea of highly general rules. Behavior and thought consisted of responses to concrete stimuli, and what was learned was a limited stimulus-response link. "(T)he amount of general influence from special training (is) much less than common opinion supposes" (Thorndike 1906, 246). Even the early cognitive scientists of the 1960s and 1970s rejected the view that reasoning was much influenced by general rules. Alan Newell declared "the modern position is that learned problem-solving skills are, in general, idiosyncratic to the task" (Newell 1980, 178).

An exception to the anti-inferential rules position of many twentieth-century psychologists was Jean Piaget, who held that people do have abstract inferential rules, including those corresponding to the rules of propositional logic, as well as particular cognitive schemas, including schemas for proportionality, probability, and the mechanical equilibrium principle of action-reaction (e.g., Inhelder and Piaget 1958; Piaget and Inhelder 1951/1975). However, Piaget was as insistent as other twentieth-century psychologists that such rules can't be taught but only induced from living in the particular world that we live in.

But the antirule, anti-instruction position of much of twentieth-century psychology is mistaken. My colleagues and I have shown that people do have inferential rules corresponding to a number of inferential rule systems—including probability and statistics, methodological principles that are relied on by the social scientist, the rules of cost-benefit decision theory, and what we call "pragmatic reasoning schemas." (Larrick et al. 1990) Moreover, these rules can be readily taught, some to a significant degree in classroom or laboratory settings lasting an hour or less.

Consider the following problem:

> Catherine is a manufacturer's representative. She likes her job, which takes her to cities all over the country. Something of a gourmet, she eats at restaurants that are recommended to her. When she has a particularly excellent meal at a restaurant, she usually goes for a return visit. But she is frequently disappointed. Subsequent meals are rarely as good as the first meal. Why do you suppose this is?

We have posed this sort of question to scores of people having educational levels ranging from college freshman to Ph.D.-level staff at major research institutions (Nisbett et al. 1987; Nisbett 1992). From freshmen, we almost never get anything other than a causal hypothesis: "Maybe the chefs change a lot" or "Maybe her expectations are so high that the reality will disappoint her." Such hypotheses are not necessarily wrong, but they miss underlying statistical points. From undergraduates who have had a course in statistics, we often get answers that reflect an appreciation of the probabilistic nature of restaurant meal quality: "Maybe it was just by a chance that she got such a good meal the first time," which is surely right, as far as it goes. From graduate students in psychology, who have typically had two or three courses in statistics, we usually get a statistical answer, often of high quality, such as "There are probably many more restaurants where you can get an excellent meal some of the time than there are restaurants where you can get an excellent meal all of the time. So if she gets an excellent meal it's probably in a restaurant that is only very good on average. Therefore if she gets a truly excellent meal then there's no place to go but down—on average." From Ph.D.s in science we nearly always get a statistical answer, usually of high quality.

Can you teach people statistical principles that can affect their understanding of everyday life events without having them take hundreds of hours of courses? Yes, we can teach people how to reason about events like Catherine's disappointment in laboratory sessions lasting less than an hour (Fong et al. 1986). We can teach rules like the law of large numbers in purely abstract fashion by talking about urns with balls of different colors; defining the concepts of population parameter, sample parameter, and sample size; and pointing out that larger samples will on average reflect population parameters better than smaller samples. We can also teach by presenting people with a number of concrete problems in everyday life that require the law of large numbers for solutions. For example, we can ask people to think about the following sort of problem:

> David is a high school senior choosing between two colleges. He has friends at both colleges. His friends at College A like it a lot on social and academic grounds. His friends at College B are not so satisfied, being generally unenthusiastic about the college. He visits both of the colleges for a day and meets some students at A who are not very interesting and a professor who gives him a curt brush-off. He meets several students at College B who are lively and intelligent and a couple of professors take a personal interest in him. Which college do you think he should go to?

Most people who are uninstructed in statistics think David should go to the place he likes, not the place his friends like. But you can massage people's probabilistic intuitions by saying, in effect, "We can think of David's impressions of each campus as a sample parameter. But David's sample is very small and could well be misleading. His friends have a much larger sample of the colleges, and we would expect that their sample parameters are closer to the population parameter of college satisfaction for people like David. So David should probably go with what his friends think."

Teaching people the rule in the abstract, using arbitrary events like balls in an urn, and teaching people the rule using concrete examples like the college-choice problem are both effective in getting people to apply statistical solutions to problems that require them. The two together are even more effective. Moreover, the effects last over a period of at least several weeks, and for the concretely trained subjects an influence is found for problems far in surface content from the problems they were trained on (Fong and Nisbett 1991).

We find similar benefits for teaching people principles of behavioral science methodology. Think about the following problem:

> The promoters of a local Lose Weight Now! organization have claimed that, on the average, their members lose ten pounds during their first three months of attending meetings. To test this claim, a public health nurse kept records of weight lost by every new member who joined the Lose Weight Now! branch during 2006–2007. Out of 138 people who started to attend meetings, 81 kept attending for at least three months, and, indeed, the average amount of weight lost by these people was 9.7 pounds. Does this study establish that the Lose Weight Now! program is effective in helping people to lose weight?

The flaw in any conclusion that the program is effective is the "self-selection" possibility. That is, the people who stuck with the program may have been those who were going to lose weight anyway. Those who didn't stick with the program may have been those who weren't losing weight and had given up. They might even have gained weight. That you're going to lose weight if you enroll in the Lose Weight Now! organization is not clear.

We find that two years of graduate training in psychology greatly increases the likelihood that people will spot the potential artifact in problems that require understanding of the self-selection principle, or the relevance of control groups, or consideration of the base rate for a given outcome (Lehman et al. 1988). Medical training improves people's solutions to such problems somewhat, and training in chemistry and law does nothing whatever (Lehman et al. 1988). We have not tried laboratory training sessions to teach such principles, but I don't doubt that this could easily be done, with results that would be lasting.

How about logic? Taking a course in formal logic actually does nothing for the ability of undergraduates to reason about everyday life problems that require the logic of the conditional (Modus ponens, Modus tollens, etc.; Lehman and Nisbett 1990).

Even two years of graduate education in philosophy does nothing for conditional reasoning, although it is effective for some types of syllogistic reasoning and for the ability to come up with damaging counterarguments to a proposition (Morris and Nisbett 1992).

I would explain the difference between the teachability of statistical and methodological reasoning on the one hand and the difficulty in teaching logical reasoning on the other as being due to the differential "gracefulness" of increments to the rule system. People already have rudimentary, intuitive versions of probabilistic and methodological rules, and when we teach them we are improving on rule systems about which they already have some inkling. The difficulty in teaching logic may be a matter of alarm to some, but not to me. I think the rules of logic fall into two categories—those everybody induces by virtue of long practice in the world, such as "or exclusion" (either A or B is the case but not both), and those that are highly artificial, such as the more nonintuitive implications of the conditional or most syllogistic forms. (Bertrand Russell said about the medieval monks' development of the syllogism that it was as barren intellectually as they themselves were reproductively.)

How about cost-benefit rules? Are people capable of making their choices in the highly rational fashion required by the formal axioms of choice? Economists have gone through three phases on this question. In the first phase, economists maintained that all choices are in fact made in accordance with those abstract rules. Then Herbert Simon loosened the requirements a bit by introducing the concept of "bounded rationality": given the brevity of life, people consider choices only to the extent that they are important and information about the relevant utilities and probabilities are easy to come by (Simon 1955). This bounded rationality sounded to most people as if it were rational enough. But then research, especially that by psychologists Daniel Kahneman and Amos Tversky, showed that people weren't even very boundedly rational. They spend as much time shopping for a shirt as for a refrigerator; they are risk averse in situations where there is a potential gain and risk-seeking in situations where there is a potential loss; they are subject to severe framing effects (for example, reaching opposite conclusions about the same formal problem when encouraged to think about the problem as a possible gain than they do when encouraged to think about it as a possible loss); they calculate value not with respect to some absolute scale but merely with respect to their current state; and they don't use proper probabilities at all but rather something more like "decision weights"; and on the list could go (Tversky & Kahneman 1981).

While not denying any of these pejorative characterizations of the decision maker, I have good news. Formal principles of cost-benefit analysis can be taught in such a way as to make people more likely to employ them in everyday choices (Larrick et al. 1990). Moreover, people are better off when they do use those principles.[1]

Consider the following problem:

> Several months ago you bought tickets to a basketball game in a nearby city. That game will be played tonight. However, the star of your team is not playing, the opposing team is weaker than expected, and snow has begun to fall. Should you go to the game or tear up the tickets?

If you said you should go to the game because it would be uneconomical not to consume something you've paid for, you're not thinking like an economist, who has a valuable rule for making such decisions; namely, the "sunk cost" rule, which follows from the choice axioms. This rule says that you should not consume something that you've paid for, *unless its value is positive at the present time.* You've already spent the money; it's sunk. You can't retrieve any part of it by suffering through an unpleasant and possibly risky drive to watch a game that is likely to be boring.

Do economists live their lives using such principles? We gave policy problems and everyday life-choice problems to University of Michigan economists, biologists, and humanities professors (Larrick et al. 1993). They included, in addition to sunk cost problems, "opportunity cost" problems, where the trick is to recognize that you shouldn't pursue some course of action when another course of action offers a likely lower cost and a likely higher benefit. For example, we gave study participants a sunk cost problem that asked whether they agreed with the university's decision to tear down the old hospital and put up a new one, even though the cost of putting up a new one was nearly as high as

1. The arguments by economists on this latter point are not very persuasive: The cost-benefit rules must be beneficial because 1) under the assumptions made by economists they can be shown to maximize outcomes and 2) corporations pay decision experts for advice. Unfortunately, corporations also pay for handwriting analysts, lie detectors, and motivation experts to jump around on stage to unknown effect.

the cost of renovating the old one and the old one had been extremely expensive to build. Economists and everyone else should say that the cost of the old hospital is sunk and therefore irrelevant to the present choice.

Economists do in fact say that, and they are much more likely to apply cost-benefit principles in the avowedly normatively correct way to all kinds of policy problems and personal choices (e.g., Walk out of a lousy movie or stay to the bitter end?) But biologists and humanities professors are not nearly as likely to use those principles as economists. And biologists and humanities professors are not much more likely to use those principles than their students.

How about training in economics short of a doctorate? Does a course in economics make you more likely to use the cost-benefit rules? No. Undergraduates who have had a single course in economics are no more likely to use cost-benefit rules in analyzing policy questions or making personal decisions than are undergraduates who have never had a course in economics (Larrick et al. 1993).

But we can teach college students how to use the sunk cost and opportunity cost principles in sessions lasting less than an hour (Larrick et al. 1990). And the new rules stick around. Two weeks after training them, we call them in the guise of an opinion poll and ask questions that don't look at all like the ones on which they were trained. The students use the normatively correct rules more than do untrained students.

But how do I know they're better off using "normatively correct" rules? I've already admitted that neither the abstract optimality nor the fact that corporations hire decision experts provides much reason to believe that the rules are correct.

But our research shows that use of the rules is associated with life outcomes that people desire. Faculty members who regularly use cost-benefit rules when making choices get higher salaries and bigger raises than do those who less regularly use the rules (Larrick et al. 1993). Undergraduates who more frequently use the rules have higher GPAs. One might ask whether this finding can be attributed to the self-selection principle: Are the students who use the rules, or claim to do so, more intelligent than those who do not use the rules? Actually, students who have higher grades than their SAT scores (a pretty good indicator of intelligence) would predict are more likely to use the rules. Being wise about choices helps you to achieve more than you would otherwise.

To date we have studied and found effective ways of teaching a significant number of rule systems. We will continue to identify many more inferential rules that are pragmatically helpful to people, and we will also find surprisingly efficient ways to teach those rules.

## REFERENCES


Fong, G. T., D. H. Krantz, and R. E. Nisbett. 1986. The effects of statistical training on thinking about everyday problems. *Cognitive Psychology* 18:253–292.

Fong, G. T., and R. E. Nisbett. 1991. Immediate and delayed transfer of training effects in statistical reasoning. *Journal of Experimental Psychology: General* 120:34–45.

Inhelder, B., and J. Piaget. 1958. *The Growth of Logical Thinking from Childhood to Adolescence*. New York: Basic Books.

Larrick, R. P., J. N. Morgan, and R. E. Nisbett. 1990. Teaching the use of cost-benefit reasoning in everyday life. *Psychological Science* 1:362–370.

Larrick, R. P., R. E. Nisbett, and J. N. Morgan 1993. Who uses the cost-benefit rules of choice? Implications for the normative status of microeconomic theory. *Organizational Behavior and Human Decision Processes* 56:331–347.

Lehman, D. R., R. O. Lempert, and R. E. Nisbett. (1988). The effects of graduate training on reasoning: Formal discipline and thinking abut everyday life events. *American Psychologist* 43:431–443.

Lehman, D., and R. E. Nisbett. 1990. A longitudinal study of the effects of undergraduate education on reasoning. *Developmental Psychology* 26:952–960.

Morris, M. W., and R. E. Nisbett. 1992. Tools of the trade: Deductive reasoning schemas taught in psychology and philosophy. In *Rules for Reasoning,* ed. R. E. Nisbett. Hillsdale, NJ: Erlbaum.

Newell, A. 1980. One last word. In *Problem Solving and Education*, ed. D. Tuma and F. Reif. Hillsdale, NJ: Erlbaum.

Nisbett, R.E. 1992. *Rules for Reasoning*, ed. R.E. Nisbett. Hillsdale, NJ: Earlbaum.

Nisbett, R.E. et al. Teaching reasoning. *Science* 283: 625–631.

Piaget, J., and B. Inhelder. 1951/1975. *The Origin of the Idea of Chance in Children*. New York: Norton.

Plato. 1875. *The Dialogues of Plato*. Oxford: Oxford University Press.

Simon, H. A. 1955. A behavioral model of choice. *Quarterly Journal of Economics* 69:99–118.

Thorndike, E. 1906. *Principles of Teaching*. New York: Seiler.

Tversky, A., and D. Kahneman. 1981. The framing of decisions and the psychology of choice. *Science* 21:453-458.

CHAPTER 3

# Is Critical Thinking a General Talent?

JEROME KAGAN

Human beings demand that any activity that exacts a cost in money, effort, and energy must have a purpose that is ethically praiseworthy. Formal education is expensive, demands continued perseverance by teachers and pupils, and expends psychic and biological energy. Thus, to inquire into its purposes is appropriate.

The ancient Athenians had no difficulty providing an answer to this query. The assignment given to Athenian educators was to produce the next generation of responsible citizens. This category had moral connotations because its critical features—which applied only to male citizens, not to females or slaves—were respect for the gods, loyalty to the polis, and perfecting one's talents. The clergy who administered the church schools of Medieval Europe, like those in charge of the Islamic classes in Islamabad today, understood that their goal was to inculcate an unquestioning religious faith and commitment.

Late-nineteenth-century Americans, sensing their country was on the cusp of expanded wealth and power, recognized that their recent European immigrants had to learn to read, write, do sums, and adopt an ethic of self-reliance in order to hasten their identification with their new national category. And, remarkably, this curriculum worked well for about four generations until history's muse, bored with the lack of excitement, rearranged the actors, scenery, and plot line. Contemporary Americans and Europeans, confronting an extraordinary diversity in mores, religion, and country of origin within their populations appreciate that these social facts demand an unusual level of tolerance for all ethical views and a willingness to suppress the natural temptation to rely on one's ethnicity, religion, or family pedigree for reassurance of self's virtue when this stabilizing belief is momentarily threatened. As a result, wealth and the enhanced status associated with a professional vocation have become primary signs of a person's dignity. But the combination of a technological economy and the failure of public schools serving economically compromised urban neighborhoods to prepare their youth for the intellectual demands of contemporary society have made it more difficult for marginalized youth to become upwardly mobile. Schools have an important responsibility in helping to solve this problem.

One would think that educators would have responded by teaching the linguistic, mathematical, and scientific competences the new economy required. But their inability to motivate many disadvantaged youth to master these domains in order to choose technical vocations was embarrassing.

Although the schools bear some of the blame, the families of these children also share responsibility for the failure. But because blaming victims for their errors has become politically incorrect, the schools took the brunt of the criticism and sought a goal that seemed to be more attainable, socially relevant, and ethically neutral enough to avoid offending the public.

An enthusiasm for promoting "critical thinking" appeals to some as an answer to this social need. Students should be able to evaluate evidence so that, as adults, they can arrive at more correct judgments of the truth or falsity of popular claims. But Poincare understood that facts do not speak. The remote sections of Widener Library contain volumes full of facts, but the passageways are remarkably quiet because a mind confronting a corpus of facts must have some a priori premises and a body of relevant knowledge in order to begin the task of evaluating their truth or falsity. Imagine a person unfamiliar with the physics of light who sees a pencil resting in a tall glass half-full of water. The evidence this scene presents is perceptually compelling. The pencil appears to bend at the point where it penetrates the surface of the water. Lacking the principles of physics, the person might conclude that water can bend pencils.

The assumption that an abstract psychological competence called "critical thinking" can transcend the body of information being analyzed is as flawed as the belief that honesty, empathy, and civility are traits that most individuals display across varied settings. Unfortunately, the idea of "critical thinking," independent of the context in which this function is applied, resembles Newton's concept of the ether or Wechsler's concept of IQ. Neither is a phenomenon in nature; not a flamingo but a unicorn.

Consider some examples of highly intelligent adults who enjoyed excellent educations and community respect because of their ability to evaluate the evidence in their restricted domain of talent. Francis Collins, a biologist respected by colleagues and the head of the Human Genome Project, confessed that his evaluation of the scientific data led him to the conclusion that God intended the forms and mechanisms that represent the facts of modern evolutionary biology; Richard Dawkins, brooding on exactly the same evidence, came to the opposite conclusion. The icon of critical reasoning, Albert Einstein, rejected the new ideas in quantum mechanics because they denied determinism; Niels Bohr found the new theories perfectly reasonable. Kurt Gödel, author of the incompleteness theorem and a scholar Einstein regarded as a better logician and mathematician than he, had his wife taste his meals first because he believed that his food might be poisoned. A distinguished panel of American intellectuals appointed by the National Academy of Sciences published a report, which made newspaper headlines in 2006, declaring that their critical evaluation of all the evidence led them to conclude that there were no biological differences between the sexes with implications for human behavior or cognitive abilities. The majority of biologists, neuroscientists, and psychologists who were familiar with the same corpus of evidence were surprised by this judgment. In their opinion, the panel's conclusion was dramatically inconsistent with the facts. These few examples should be sufficient support for the claim that one can teach critical thinking within a specific domain of knowledge but cannot teach critical thinking as an abstract talent that transcends domains. Could one teach "athletic skill" outside of a particular sport or "aesthetic appreciation" independent of the form the artistic product assumed?

Teachers can train children, in the first eight or twelve grades, to evaluate the correctness of answers to a set of long-division problems, to decide on the amount of food and water a cage of gerbils requires in order to survive, or to estimate the amount of raw sewage that if emitted from a factory into a river that would kill life-forms. Americans should be able to evaluate newspaper reports claiming that vitamin E prolongs life or that the nursing of infants has a benevolent effect on their future health. But the correctness of these evaluations depends on possession of specific knowledge. If citizens do not know the premises held by the scientists making these claims, their sources of evidence, and a relevant corpus of valid facts, they cannot evaluate the correctness of the declarations. Twelve-year-olds who can detect errors in solutions to long-division problems because they have been taught the rules of arithmetic are not able to transfer that skill to decide how much food and water the gerbils need. Put plainly, reasoning, like emotion and morality, is contextualized.

Hence, schools must first teach children the facts and principles of specific domains—biology, chemistry, physics, psychology, sociology, mathematics, history, linguistics—so that they might become better analysts of the evidence in each of these disciplines. The specificity of the principles within each domain makes it difficult to generalize from one to the other. A knowledge of physics, for example, would lead most adults to assume that altering the sequence of the elementary components of a derived product should change the product. Geneticists, however, have learned that a few amino acids, which are the building blocks of proteins, can be the product of different sequences of the three nucleotides that comprise their foundation, as if the sequence "ran" retained its meaning when it was "anr," "rna," or "nar."

A knowledge of history and sociology would lead most youth to conclude that because human welfare depends on the integrity and health of the society in which persons live, most private or public decisions should be guided by that principle. However, a large number of evolutionary biologists are convinced that the primary urge behind most behaviors and decisions, whether animals or human beings, is to maximize the inclusive fitness of self and self's genetic relatives and to award less priority to the health and integrity of strangers or the larger community. Evaluating the truth of any empirical claim requires knowledge of the facts in that domain.

The decision to celebrate critical thinking separate from a particular corpus of evidence required the coming together of a number of historical changes in our society. The most significant was the demand to honor an egalitarian ethic. No person is entitled to a smug feeling of superiority or to special privilege because of his or her occupation, education, or family pedigree. This rebellion against any elite status began several centuries earlier but was accelerated after the civil rights movement of the 1960s. I applaud the rationale and consequences of this ethic, which has enhanced the dignity and privileges of minorities and women. But there are no free lunches; a price must be paid for striving to meet this ideal.

One of the costs is a reluctance to acknowledge the presence of a value judgment in all educational reforms. The emphasis on critical thinking rests on the assumption that facts and skills have an automatic priority over feelings and sentiments. This bias characterizes the economists and political scientists who advocate Rational Choice Theory. John Rawls was celebrated by philosophers and political scientists because he returned the ethical notions of fairness and justice to theories in these disciplines. The problem with this premise should be obvious. Loyalty to a rationality based on facts and deductions from those facts chases to the periphery serious consideration of the morality of a decision or action. Societies that either ignore the moral implications of their actions or cannot find a consensual ethic that the majority applauds generate a feeling of confusion, uncertainty, or spiritual emptiness in their members. Thomas Jefferson noted that if a moral dilemma were stated to a farmer and a professor, the former would more often arrive at the right answer. I suspect that the average plumber or truck driver would be as capable of judging the morality of a Congressional or Supreme Court decision as the average lawyer, physician, professor, scientist, or chief executive officer.

Most decisions by a legislature, board of directors, or school committee are based on the selection of a primary beneficiary from four possible candidates: the individual, their family, the society in which they live, or the world community. Rarely does any decision benefit all four. Furthermore, on some occasions, the criterion for the decision is an intuitive judgment of its moral worth, for example preserving the Arctic Refuge in Alaska. "The appeal to cool, rational analysis" Thomas Nagel wrote "is too often an excuse for refusing to listen to the clear warnings of conscience or common sense" (Nagel 1972, 770). When Congress allocates funds to NASA to explore Mars, we understand that although few Americans will benefit from that expenditure the advanced understanding of our universe is a moral good. Most Supreme Court decisions cannot be defended by listing their concordance with objective evidence on human biology or psychology but only by understanding the ethical beliefs of a majority in the society.

Many contemporary educators resist the suggestion that an important reason for twelve to twenty years of formal schooling is that this procedure is a just, fair way to select the 15–20 percent of the youth who will be given the responsibility of flying 200 travelers to a destination, operating on bodies and brains, defending the rights of victims in court, designing new buildings, investing pension funds, inventing new medicines, or filling cavities. The fact that only a small proportion of the members of a society are needed to fill these technical positions implies the politically incorrect idea of an elite. Because this concept is tainted, this truth, which older societies celebrated, has become ragged.

Each individual requires, at a minimum, a body and mind healthy enough to reproduce and care for the next generation, reasonable predictability of the future, protection from danger, social harmony, a belief that some acts and personal properties are always more virtuous than others, and assurance that others in the community share the same ethos. Preparation of the next generation of needed technical personnel and fulfilling the six more-general requirements mandates that we train each generation in the intellectual skills their historical era demands and prepare as many as possible to act with responsibility, honesty, and empathy in case the vicissitudes of life happen to select them from the very large number who could fill one of the needed roles. Most adults born with an intact brain and who enjoyed an adequate education are potentially ready to be chosen. The sad fact that not all can be plucked from the larger group is inconsistent with our egalitarian ethos, as well as the idealistic wish for a classless society. Hence, educators are tempted to posit ethically neutral abstractions, like critical thinking, as primary goals because these beautiful ideas temporarily mute our unhappiness over the inevitability of social differentiation. The concept of critical thinking has the additional advantage of supporting our love affair with rationality as the primary basis for personal and public decisions. We are more likely to solve our current problem, however, if teachers accept the responsibility of guaranteeing that all adolescents, regardless of class or ethnicity, can read and comprehend the science section of newspapers, solve basic mathematical problems, detect the logical coherence in non-technical verbal arguments or narratives, and insist that all acts of maliciousness, deception, and unregulated self-aggrandizement are morally unacceptable.

## REFERENCE

Nagel, T. 1972. Reason and national goals. *Science* 177:766–770.

CHAPTER 4

# Teaching Evidence-Based Citizenship

EAMONN CALLAN

For the last few years I have been coteaching an interdisciplinary humanities course for freshmen. For about three weeks in the middle of the course I take the podium to ponder the significance of two U.S. Supreme Court cases, *Brown v. Board of Education* and *San Antonio v. Rodriguez.* My lectures during those weeks exhibit disciplinary impurity at its most shameful or adventurous. (Which adjective you favor depends on how much or how little you value disciplinary purity). Legal case analysis, American social and political history, social psychology, constitutional theory, and political philosophy all jostle together as my lectures proceed. I do not tell my students which of my utterances are to be located in social history, as opposed to philosophy, and so on. They have enough trouble following me without the distraction of a running commentary on my many disciplinary transgressions. With the possible exception of philosophy, I can claim to be no more than a diligent amateur in the many areas on which my teaching touches.

But why teach *any* course with such dilettantism? A more sober alternative in a cotaught course that includes several disciplines would be to assign different instructors tasks that were carefully aligned with their expertise. As a philosopher who writes about politics and education, I might have suitably circumspect things to say about rival theories of justice, what these entail with regard to racial discrimination in state educational provision, and so on, all the while scrupulously avoiding saying things that might intrude on the academic turf of colleagues who are knowledgeable precisely where I am ignorant. And when my colleagues take their turns at the podium, they would evince a reciprocal respect for my territorial boundaries.

The first thing we might notice about my imagined sober alternative is that the pedagogy in that scenario really ceases to be interdisciplinary. A pageant of experts speaking on some common themes that occupy them in their respective disciplines are not engaged in *inter*disciplinary teaching. At best, they provide their students with an assemblage of thematically related disciplinary fragments. One might hope that some students will have the imagination and tenacity to create for themselves an integrated understanding from the fragments on display. But to suppose that what they create is to be credited to their teachers is rather like saying that the farmer taught the chef to cook just by supplying the raw ingredients.

Now this hardly gets me off the hook. I have only made a distinction between teaching that is genuinely (albeit perhaps recklessly) interdisciplinary and teaching as the sequential presentation of disciplinary fragments that might (or might not) help some students to construct interdisciplinary understanding. I have given no reason to try to do the former. What might be the most obvious reason to do so also turns out to be not very helpful. A platitude about the growth of knowledge is that the most fertile areas of investigation are often found at the boundaries of adjoining disciplines. Yet the platitude seems more applicable to the conduct of research training than the teaching of introductory college courses. If the most promising areas for academic innovation are in fact to be found at the edges of established disciplines, then good research training will draw novices in that direction. But it does not follow that introductory college courses must start nudging anyone along that route long before serious research training has started, which will never happen for the great majority of students in such courses.

I want to canvas an alternative rationale for a kind of interdisciplinary teaching that has a proper place in the first year of college, and in high school for that matter, though I will also be candid about my lingering misgivings about such teaching. The rationale can be brought into focus through a question I urge students to think about in the unit on *Brown* and *Rodriguez:* To what extent has America succeeded in realizing the moral promise of freedom and equality for all its citizens, regardless of their race? For rhetorical convenience, I shall call this the *Brown* question. I tell my students that they will not learn nearly enough in our course to be entitled to an intellectually assured answer to the *Brown* question. But I also stress that this is the question that really matters. In the larger scheme of things, it matters far more than their grade or even the passions for law, history, or political philosophy that might be sparked in their efforts to come to grips with the question.

The question I stress acquires its looming significance within the perspective of American citizenship, and when I urge that question upon my students I am mindful of the fact that the great majority of them already are American citizens or will be in the fullness of time. To identify with that perspective is not merely to congratulate oneself for enjoying a set of legal rights and privileges that most human beings are denied; it is to see oneself as the inheritor of a remarkable experiment in republican self-government that takes securing the freedom and equality of all citizens as the moral imperative of government. And to see oneself in that light is also to accept some responsibility for making the experiment work, which means interpreting wisely and acting resolutely in support of the moral imperative that defines the experiment. That is not an ideologically partisan point within American politics; it is common ground, for example, between those who would argue that *Brown* and the Civil Rights movement that followed fully realized the color-blind legal dispensation that free and equal citizenship demands and others who would claim that progress in defeating American racism has been either modest or illusory and that new and more aggressive forms of political intervention are needed to erase the lingering effects of racial caste in America. If the first of these views were true (or closer to the truth than the stipulated alternative), then a necessary task for the good citizen would be to conserve what was accomplished in the Civil Rights movement against erosion undertaken in the seductive guise of group rights, the pursuit of de facto desegregation, or the like; if the second were (roughly) true, then to regard a color-blind legal dispensation as the consummation of racial equality would attest to grievous moral complacency at best and complicity in oppression at worst. Asking students to confront the *Brown* question is not like asking them to think about the causes or consequences of the Peloponnesian War; it is asking them whose side they are on in a struggle that their lives already encompass and whose importance cannot decently be evaded. In deciding on party affiliation, whom to vote for, and which side to take in a host of political debates with compatriots, choosing well depends in no small part on good-faith effort to grasp the right answer, whatever answer that might be.

If students ask the *Brown* question seriously, they must also construct at least a provisional answer on the basis of available evidence. This makes the specifically cognitive tasks they face in grappling with the academic material I present rather different than these tasks would be if the students had to think about them merely as novice philosophers, historians, legal scholars, or the like. In particular, answering the *Brown* question qua citizen requires an integration of fact and value that pushes beyond the boundaries of any merely disciplinary understanding.

Consider Thurgood Marshall's claim that "unless our children begin to learn together, there is little hope that our people will learn to live together."[1] What Marshall calls "living together" can only be charitably understood as something like "living together *as equals.*" After all, whites and blacks in America lived together under Jim Crow without learning together, but that is hardly the kind of civic coexistence that Marshall envisaged. The broad political and legal context of Marshall's remark suggests that he likely had at least a couple of things in mind under the rubric of living together as equals: Americans would enjoy equal economic opportunity irrespective of race; they would also reciprocate respect for each other throughout all social institutions, whatever their race might be. Marshall's thesis, then, is that without the kind of racial commingling that de facto desegregation would secure the promise of free and equal citizenship will remain out of reach for many Americans.

Marshall's thesis is crucial to how one answers the *Brown* question, and a huge body of social scientific research bears on the thesis. But the thesis is such that evidence adduced for or against it cannot be exclusively empirical. That is so for the obvious reason that the concepts of equal opportunity and reciprocal respect are open to rival interpretations, and the interpretation any one of us might favor is properly a matter of moral judgment. Such judgments cannot be warranted by any appeal to value-neutral data. For example, if cultural differences rather than the quality of state educational provision explained much of

1. *Milliken v. Bradley*, 418 U.S. 717, 783 (1974). For a circumspect defense of the educational and civic benefits of integration, see Clotfelter (2004). A somewhat more skeptical view is evident in Thernstrom and Thernstrom (2004).

the difference in average educational achievement between whites and others, would that signify inequality of educational opportunity between the relevant racial groups, or should we interpret cultural differences as irrelevant to the measurement of opportunity? If some citizens regard practices intrinsic to the culture of others with disdain, does this mean they fail to respect others as equal citizens whenever the impugned practices correlate with some socially marginalized racial identity? Answers to these particular questions are presupposed by Marshall's thesis because they are required by any tolerably precise understanding of what it would mean for Americans to live together as equals. But both answers and questions are freighted with an irreducible moral meaning, no matter how sophisticated and compelling our social science could become in addressing matters relevant to the *Brown* question.

You might insist that our predicament here can still be escaped through a tidy division of labor between disciplines. Suppose we say that political philosophers rightly concern themselves with the rival interpretations to which concepts such as equal opportunity and mutual respect among citizens are open. They argue among themselves about which interpretation is best. Some are partisans in that debate, while others remain agnostic, either claiming that no one's argument for any one interpretation of the concept has yet been decisive or that permanent, reasonable disagreement among competing interpretations is just what we should expect. Social scientists, for their part, need not dabble in intramural philosophical debate about whose interpretation is morally best. They might take any one interpretation of equal opportunity—call it interpretation *A*—and then investigate empirically how well or badly Marshall's thesis withstands scrutiny, given that interpretation. They do not on this account have to assume that *A* is a morally better interpretation than any of the alternatives. They can merely confine their attention to showing that if *A* is the preferred option, then de facto desegregation is (or is not) necessary to achieving equal opportunity across America's color lines.

The division of labor across disciplines I have just sketched may placate scruples about moral neutrality in the social sciences, but it cannot by itself furnish the answer to the *Brown* question that citizens need. Citizens, unlike scholars, cannot just sit on the fence about what equal opportunity means on its most compelling interpretation. They must choose now, mustering whatever knowledge and imagination they can find in order to choose well. Their distinctive contribution to the experiment of republican self-rule must be enacted in political decisions within the tumult of contemporary politics; it cannot be deferred to some remote future when philosophers have settled, if they ever do, on the best understanding of justice for free and equal citizens and social scientists have thoroughly explored the empirical ramifications of that understanding. That is why a civic education for such people will push against academic boundaries and the limits of our established knowledge, trying to integrate the often fragmentary and provisional outcomes of disciplinary inquiry and struggling to clarify political decisions that must be made with much more courage and hope and less cognitive confidence than fastidious scholars could content themselves with.

But now we come back to the problem of dilettantism. I have argued that a certain kind of interdisciplinary learning is integral to education for democratic citizenship, using the *Brown* question to throw into relief the distinctive character of such learning. The lectures I give my freshman class are an attempt to foster such learning. Still, my efforts require me to engage with much material beyond my expertise. What worries me when I reflect on what I do was never better expressed than by Nietzsche in *The Gay Science.* After a characteristically dazzling passage that describes the human cost of intellectual specialization, he turns his attention to the alternative for scholars:

> But you would have it otherwise—cheaper and fairer and above all more comfortable—isn't that right, my dear contemporaries? Well then, but in that case, you also immediately get something else: instead of the craftsman and master, the "man of letters," the dexterous, "polydexterous" man of letters who, to be sure, lacks the hunched back—not counting the posture he assumes before you, being the salesman of the spirit and the "carrier" of culture—the man of letters who really is nothing but "represents" almost everything, playing and substituting for the expert, and taking it upon himself in all modesty to get himself paid, honored, and celebrated in place of the expert. (Nietzsche 1974, 323)

If you want to put some flesh on Nietzsche's abstractions at this point, imagine the contemporary "public intellectual" whom you detest the most: glib, intellectually reckless, sophistical, and so on. Of course, we are likely to admire some public intellectuals while detesting others, though I fear that in many cases the difference has more to do with who flatters or offends our prejudices rather than who really escapes or succumbs to the fate of Nietzsche's "salesman of the spirit." My worry then is that the kind of teaching I have defended is perilously susceptible to this particular corruption.

And if I should fret about my own integrity as a teacher, I should worry all the more about the learning I promote when I foist the *Brown* question on my students. In the course I teach, they will become familiar with only a tiny fraction of the social scientific evidence that bears on the question and will achieve the most rudimentary grasp of the relevant complex arguments in political philosophy and constitutional theory. How could educational outcomes as scant as these entitle anyone to even a provisional answer to the *Brown* question? And if not, what could possibly be the educational point of my insisting on their need to confront the question?

A thorough answer to these questions would require a lengthy (and perhaps tedious) disquisition on the relation between cognitive and moral virtue in democratic citizenship. But a passable short answer might begin from some prosaic facts about contemporary American citizenship without ascending to the heights of philosophical arguments about citizenship. A recent study by political scientists John Hibbing and Elizabeth Thiess-Morse yields the following rather depressing description of how most Americans perceive their own politics:

> [T]he kind of government people want is one in which ordinary people do not have to get involved. We show that people want to distance themselves from government not because of a system defect but because many people are simply averse to political conflict and many others believe political conflict is unnecessary and an indication that something is wrong with governmental procedures. People believe that Americans all have the same basic goals, and they are consequently turned off by political debate and deal making that presuppose a lack of consensus. People believe that these activities would be unnecessary if decision makers were in tune with the (consensual) public interest rather than the cacophonous special interests. Add to this the perceived lack of importance of most policies and people tend to view political procedures as a complete waste of time. (Hibbing and Theiss-Morse 2002, 7)

To *invent* an account of political attitudes less in keeping with conceptions of democratic citizenship, such as mine, that demand strenuous cognitive and moral effort from citizens would be difficult. Moreover the authors' evidence suggests that the attitudes they describe are little affected by education, at least as it is currently practiced (Hibbing and Theiss-Morse 2002, 146–147).

The very attempt to encourage an evidence-based approach to the *Brown* question might seem merely quixotic given both the empirical reality of American citizenship that Hibbing and Thiess-Morse describe and the negligible progress my students can be expected to make in answering the question as a consequence of my teaching. But an important distinction to bear in mind is between the cultivation of civic virtue and the mitigation of civic vice. I do not expect that students who may have just come to appreciate that controversy about equality and race in America is entangled with intellectually deep questions about facts and values are now on the threshold of a consistently reflective and informed citizenship. That being so, only delusions of grandeur could induce me to think of myself as cultivating Socratic civic virtue. But I can still see educational value in the more elementary endeavor of countervailing some of the very civic vices that Hibbing and Theiss-Morse expose—for example, the smug moral complacency of those who think that the common good is transparently clear to all of us, so that only disruptive "special interests" would challenge the status quo. I am not at all sure if I enjoy much success even relative to that more modest goal. But the hope that I can achieve something in that regard is enough to keep me teaching in dangerous proximity to salesmen of the spirit.

## REFERENCES

Clotfelter, C. T. 2004. *After Brown: The Rise and Retreat of School Desegregation*. Princeton: Princeton University Press.

Hibbing, J. R. and E. Theiss-Morse. 2002. *Stealth Democracy: America's Beliefs about How Government Should Work*. Cambridge: Cambridge University Press.

Nietzsche, F. 1974. *The Gay Science,* trans. Walter Kaufman. New York: Random House.

Thernstrom, A, and S. Thernstrom. 2004. *No Excuses: Closing the Racial Gap in Learning*. New York: Simon & Schuster.

CHAPTER 5

# Learning to Reason about Evidence and Explanations: Promising Directions in Education

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## INTRODUCTION

*Recently people were sickened by eating tainted spinach. Government authorities rushed to gather evidence about the source and scale of the problem and whether it extended to other leafy green vegetables. How would you decide whether to feed leafy green vegetables to your child?*

*Sometimes when you put on sunscreen, you break out in an angry red rash. You haven't noticed any obvious pattern in which sunscreens cause a rash. How can you figure out what to do?*

What does it mean to encourage a scientifically literate population? We live in an age where an abundance of information is readily available at our fingertips. How do we help children grow up to be critical consumers of scientific information and to reason effectively about it in the service of better lives and a healthier planet? What about creating the next generation of scientists? How do we open the door so that more students can pursue science? These are questions that science education researchers strive to answer and K–12 educators grapple with every day.

This paper considers the difficulties students have in reasoning about scientific evidence and the current discourse in K–12 education research and practice about the puzzles and what appear to be promising directions. It draws from the research literatures in cognitive science, development, and science education to provide an overview of the issues and to illuminate the nuanced and highly challenging problem space of scientific reasoning and evidence evaluation. Finally, it offers suggestions for the focus of our collective efforts for improving practice toward developing a more scientifically literate population. Given space considerations and the extensive research literature on this topic, this paper samples the available research literature but is by no means exhaustive.

## WHAT MAKES REASONING ABOUT SCIENTIFIC EVIDENCE SO DIFFICULT?

Educating for scientific literacy requires an answer to what makes reasoning about scientific evidence so hard. An expansive literature addresses this question, ranging from research on why people attend to certain types of information over others in a perceptual sense (e.g., Mack and Rock 1998) to why certain information is successful in capturing our attention (e.g., Sunstein 2002) and how default biases and heuristics make it difficult to reason well in any given situation (e.g., Nickerson et al. 1985). It includes research on people's difficulties with proportional reasoning, probabilities, and statistics (for a review, see Piatelli-Palmarini 1994). Another body of research focuses on reasoning about complexity—not only the requisite skills and patterns of thinking but ways of dealing with the cognitive load of many interrelated, typically dynamic concepts (e.g., Dorner 1989; Feltovich et al. 1993).

In the event that one surmounts these challenges in gaining, sustaining, and focusing attention and helping the public successfully reason about the scientific evidence at hand, the literature in the field also invites us to consider the sociology of the problem space. A diverse literature in its own right, it considers questions such as what is the nature of science and how do the patterns in science interact with how people attend, believe, and understand it? For instance, if science is a process of trading up for more powerful explanatory models, as Thomas Kuhn (1962) suggests, where does this leave the public, who might hold an accumulation model of how science works, in trying to reason about the available scientific evidence? From the perspective of the public, science might seem to change its mind a lot. The literature in the field also addresses how scientists handle uncertainty (e.g., Zehr 1999), how disagreements are vetted, and how local knowledge and "expert knowledge" interact to inform a problem space (e.g., Jasanoff 1997; Wynne 1992). Highly public incidents that draw upon scientific knowledge, such as the spinach scare outlined above, bring the public "along for the ride," which invites all sorts of opportunities to misunderstand the evidence and doubt the process of generating it. Highly visible cases where the scientific establishment, through failures of the disciplinary means that vet good science from bad, was initially wrong lead to further doubt and mistrust. An example is the well-publicized case of Judah Folkman, who proposed a radically different theory of cancer growth that was initially spurned by his colleagues. Folkman persisted in developing the theory of angiogenesis and to change the course of cancer treatment today. However, it's easy for the public to take away the simpler message that the scientific establishment was wrong than to evaluate the broader set of cases among which are many instances where the processes of science policed itself to keep bad science out of the public domain.

Given these challenges, it is no wonder that achieving a scientifically literate population is a focus of concern. We know a fair amount about the problem space and why it is so complicated. However, this knowledge doesn't lead to easy answers about what we should do. The sections that follow explore some of the key areas of research about scientific reasoning that illuminate the direction of research and practice in education. While these directions offer promise, the concluding section reflects upon these directions and considers what else we might be doing in light of how complicated the problem space is.

### *What Is Needed to Get Us to Change Our Minds? Confirmation Bias and Other Tendencies*

How do people respond to different types of evidence? In a seminal work, Deanna Kuhn and colleagues (1988) reviewed a wide-ranging set of studies and conducted targeted studies related to how people reason about evidence. They found that people typically don't change their minds and that they have a number of difficulties reasoning about evidence. For instance, Kuhn et al. found that people did not distinguish between the evidence and the theory itself. When evidence was discrepant with a theory, people failed to acknowledge it, or they adjusted or ignored it. In cases where they only moderately believed the theory, they often adjusted the theory to fit the evidence without considering the implications of doing so. They also had difficulty perceiving instances of a nonoperative variable or an operative variable that led to an outcome opposite of what they expected. These studies are part of a line of research leading to what has been called "confirmation bias"—the tendency to use evidence to confirm one's existing beliefs. Confirmation bias has been widely studied and corroborated in the field. For instance, Klahr and colleagues (e.g., Schunn and Klahr 1993; Klahr et al. 1993) found subjects are less skeptical of self-generated hypotheses than those generated by others and more rigorously tested other-generated hypotheses.

However, further discourse in the field suggested that when viewed in context and with a nuanced understanding of the nature of scientific reasoning, subjects' responses in earlier studies might make scientific sense (e.g., Karmiloff-Smith 1984; Koslowski 1996). Koslowski (1996) argued that scientists do not work in a theory vacuum, so studies asking subjects to reason about theoretically impoverished situations are incomplete and might distort what would be considered scientifically appropriate in a given situation. Like scientists who use "working hypotheses" that don't fit all available data to reduce processing demands and to organize data in order to search for patterns, people might hold on to an initial theory because of a temporary lack of a better one. Koslowski raised the question of when theory modification is scientifically legitimate. The real issue, she argued, is not whether one seeks confirmation or disconfirmation but whether one considers plausible alternative hypotheses. Science often proceeds by reformulating rather than discarding a theory because of disconfirming evidence. Dunbar (1995) studied scientists in the lab and found that experienced scientists tend to pay great attention to inconsistent results but that most often they changed particular features of their hypotheses rather than discarding it entirely. On the other hand, he found less confirmation bias in experienced scientists than in inexperienced ones but that the former often discarded useful data.

Chinn and Brewer (1998) studied how students responded when confronted with anomalous data or evidence that contradicts their current theories of the world. They found that students responded in seven ways. Students might 1) ignore the data; 2) reject the data (often offering a different explanation); 3) exclude the data from the domain of the specific theory; 4) hold the data in abeyance; 5) reinterpret the data while retaining the theory; 6) reinterpret the data and make peripheral changes to the theory; and 7) accept the data and change theory A, possibly in favor of theory B. However, for each response type, Chinn and Brewer offered examples from historical cases of scientific reasoning to show that scientists also use these response patterns. Karmiloff-Smith (1984) found that children temporarily ignore disconfirming data until they form a solid theory; then they turn to those data again to try to come up with a new theory to explain them; then they generate a unifying theory.

Reaching a conclusion opposite of what one originally expects may also depend upon the tools that one has within his or her repertoire. A greater focus on concepts that support the interpretation of research data, such as statistical inference, random sampling, reliability, and regression to the mean, can support effective modeling and reasoning about data. These concepts typically bridge the science and math curricula and might not receive attention in either place. Petrosino and colleagues (2003) argue that concepts of variability, which are central to data modeling, are given short shrift in school instruction. They report on an eight-week unit in which fourth graders were given the tools to think about what was suggested by the distribution of their data and thus successfully coordinated the data with conjecture to reach a finding opposite of what they initially expected.

This key area of research points to the importance of nuance in how evidence is interpreted. While important general patterns of reasoning are involved, the effective interpretation of evidence relies on many contextual factors. This suggests that mastering and being able to transfer such skills requires diverse, contextualized opportunities from which learners can discern more expert patterns of engagement.

*When Does One Thing Actually Cause Another? Causality as Covariation*

Consider how you might think about the following questions: "What is causing a rash sometimes when you put on sunscreen but not other times?" Or, "What might be causing you to feel ill sometimes after eating?" One of the first things that most people do is to search for a pattern that goes along with or co-occurs with the outcome. For instance, you might realize that you only get a rash when you wear a sunscreen strength of 40 SPF or higher. Or perhaps you get ill after eating certain kinds of foods or at certain times of the day.

How we detect that a cause and effect relationship exists has a profound impact on what we view as relevant evidence. Kuhn and colleagues (1988) found that people relied on covariation of two or more variables to suggest a causal relationship. The variables might covary in different ways ("When I drink less water, I feel more tired" or "The more caffeine I drink, the more productive I am") or in more than one direction ("The more caffeine I drink, the more productive I am until I crash and get nothing done"). They also found that people tended toward false inclusion—to view any covariate as causal even in cases where it was merely correlational. Finding covariation with one variable, subjects were unlikely to test other uncontrolled variables. For instance, you might decide that sunscreen of SPF 40 and higher is the culprit in the rash, but you put on sunscreen of SPF 40 and higher only when you spend long periods of time in intense sun. Perhaps the high SPF level isn't what is causing your rash but long periods of exposure to intense sun.

Overapplied covariation can lead to assumptions and erroneous conclusions. For example, the College Board established a high positive correlation between students who took algebra in eighth or ninth grade and those who went to college. The U.S. secretary of education interpreted this to mean that courses in mathematics, including algebra, were the gateway to college (Bracey 1998). Yet, we don't know if a third variable, perhaps related to parenting or ability level, led to both outcomes. Further, while covariation in terms of temporal and spatial contiguity can be an important cue to the possibility of a causal relationship, as causality becomes more complex, relying on co-varying, contiguous variables can result in shortsightedness because some causes are spatially and temporally remote from their effects (Shultz and Mendelson 1975). Both of these kinds of errors can be detected in people's reasoning—the tendency to assign a causal relationship to one that is merely correlational and the tendency to look for local causes and effects and to miss spatially and temporally remote ones.

Research shows that people do use covariation, but this does not appear to be the whole story. Infants use contingency, expecting that objects act on one another only if they touch and that action is not enacted from a distance (Borton 1979; Leslie 1982, 1984; Leslie and Keeble 1987; Oakes 1993; Spelke et al. 1995; Van de Walle and Spelke 1993), and clear, age-related increases occur in people's ability to use contingency data to cue the possibility of a causal relationship. By preschool, children have gained greater understanding of the contextual nuances of applying temporal and spatial cues. They are less likely to pick a spatially remote event as a cause (Koslowski 1976; Koslowski and Snipper 1977; Lesser 1977) and when spatial contiguity cues conflict with temporal cues, children override the former in favor of the latter (Bullock and Gelman 1979). Time delays between causes and effects introduce difficulties for preschoolers (Siegler and Liebert 1974), but by five years of age children are able to deal with time delays when the delays have an identifiable explanation (Mendelson and Shultz 1976); for instance, the physical effects that result from illness after contact with a contamination (Kalish 1997). Adults are able to override temporal and spatial contiguity cues when the specific context—for instance, the possibility of a complex interaction between two competing causes—suggests the need to (Michotte 1946/1963). Adults also are more likely to have and therefore use information about the contingency relations between two events—how often they are likely to co-occur (e.g., Kelley 1973; Nisbett and Ross 1980).

Research also underscores how nuanced people's reliance on covariation data are. Siegler and Liebert (1974) found that when they varied the degree of covariation (100 percent to 50 percent) between events and introduced variability into the temporal contiguity (immediate versus five-second delay), eight- and nine-year-olds were more sensitive to the lack of perfect covariation than five-year-olds, perhaps due to the distraction of time delays and being less likely to notice the lack of perfect covariation. Gopnik et al. (2004) have argued that young children can override imperfect correlation, may be accepting of the probabilistic context, and may indeed reason as Bayesians, summing across experiences to discern frequencies of particular patterns. Investigations of how people use contingency data in determining cause and effect relationships suggests an age-related increase in the accuracy of third- and seventh-grade children's and adults' judgments of a cause-effect relationship (Shaklee and Goldston 1989; Shaklee and Mims 1981).

Is covariation all that people use in determining a causal relationship? Consider the following two statements: 1) A high correlation exists between the numbers of churches and the crime rate in the United States; 2) A high correlation exists between growing up in certain neighborhoods and the likelihood that one will engage in crime. If you are like most people, you considered what causal mechanism might be in play in each case and were less likely to assign a causal link between churches and crime rate as between growing up in a tough neighborhood and engaging in crime. Research suggests that people do not engage in Popperian mechanism-independent evaluation of evidence. In the sunscreen example, you might also notice that each time you got the rash the sunscreen came out of a white bottle. However, most of us would rule out bottle color as a plausible causal mechanism no matter how highly correlated it is.

Even preschool children attend to mechanism in their causal explanations (e.g., Bullock 1979; Baillargeon et al. 1981). Despite a clear recognition of covariation as a cue to a potential causal relationship, even young children are sensitive to mechanism (Bullock 1979) and as early as four and five years of age can override spatial discontiguity if plausible mechanisms exist. Even three-year-olds aren't indifferent to causal mechanisms; they just do not have much information about them (Baillargeon et al. 1981). Preschoolers realize that seemingly uncaused events required explanation, even if they are unable to specify the details (Bullock 1984, 1985; Corrigan 1995; Gopnik et al 2004; Shultz and Kestenbaum 1985).

This area of key research suggests that our biases and our abilities might be separate, that while we are inclined to confuse correlation and causation, we are better able to assess causation than we always do. This suggests that helping people reflect upon their tendencies when evaluating evidence and cueing them to instances when they need to be alert to other variables should be effective.

*There's No Simple Way to Handle Complexity: Reductive Biases and Causal Default Patterns*

In the process of analyzing evidence, one implicitly makes decisions about how to bound the problem space. An unbounded space is untenable in many reasoning contexts; yet, as with spatially and temporally remote causes, more extended searching is sometimes needed. Similarly, one makes decisions about how to characterize the inherent features and complexity. In the same spirit of efficiency and comprehensibility, when dealing with complexity people tend to reveal "reductive biases." Feltovich et al. (1993) identified characteristics of concepts or situations that cause difficulty for most people and found that people tend to simplify phenomena in a type of reductive bias. For instance, people often reduce dynamic phenomena to static snapshots and continuous processes to discrete steps.

People reduce information into sets of heuristics as well. For instance, people tend to use an "availability heuristic" when sampling information (Tversky and Kahneman 1982). We sample the most available information from memory. Drawing conclusions from frequency of experience tends to serve us well but can cause errors by biasing the sample (examples include remembering events with shock value and so overestimating their occurrence; Sunstein 2002). Research on "intuitive toxicology" reveals that people hold assumptions about the nature of chemicals that are quite divergent with what experts believe (Sunstein 2002). Laypeople tend to believe that any human-made chemical is bad while any substance from nature is benevolent, whereas experts are more interested in the dosage and recognize that chemicals in nature can be as or more harmful than manufactured ones. Experts view naturally occurring radon as a much greater cancer threat than human-made sources of radiation. How such biases can influence public understanding and direct public sentiment in reasoning about scientific evidence is exemplified in the current look back at Rachel Carson's effectiveness in the banning of DDT, the lack of scientific evidence to support the banning, and the subsequent malaria deaths (Sunstein 2002; Tierney 2007).

How we reach conclusions about the world around us is also impacted by how we structure causality. Grotzer and colleagues (Grotzer 2004; Perkins and Grotzer 2005) identified nine simplifying causal assumptions that people tend to make in their explanations. People assumed 1) linearity as opposed to nonlinearity; 2) direct connections between causes and effects without intervening steps or indirect connections; 3) unidirectionality as opposed to bidirectionality; 4) sequentiality as opposed to simultaneity; 5) that causes and effects are obvious and perceptible as opposed to nonobvious and imperceptible; 6) active or intentional agents as opposed to nonintentional ones; 7) determinism—where effects must consistently follow "causes" or the "cause" is not considered to be the cause as opposed to probabilistic causation; 8) spatial and temporal contiguity between causes and effects as opposed to spatial gaps or temporal delays; 9) centralized causes with few agents—missing more complex interactions or emergent effects as opposed to decentralized causes or distributed agency. Substantial support for these tendencies exists in the research literature (e.g., Feltovich et al. 1993; Ferrari and Chi 1998; Wilensky and Resnick 1999). For instance, Resnick (1996) refers to the "centralized mindset" and Driver et al. (1985) identified a tendency toward simple linear causal explanations.

Reductive biases and heuristics can help us quickly and efficiently process information. Therefore, in some respects they make sense. In other contexts, however, we might miss parts of the causal story and make uninformed decisions. This key area of research invites reflection on the tendency in education to reduce complex phenomena to simpler versions and raises questions about how we can help learners develop awareness and a reflective stance on the heuristics and causal reasoning patterns that they employ.

*Summary Points*

The sum of the research in these key areas suggests the difficulty of understanding the nature of scientific reasoning and evidence evaluation without the nuanced context that surrounds such reasoning and evaluation. Strategies that might seem simplistic, reductive, or misguided in one context might fit with scientific practice in another context. Brem and Rips (2000) found that people's ability to reason about evidence was significantly better in information-rich than information-poor conditions. Participants in their study tended to prefer evidence, but the value they placed on explanations rose significantly when they believed information was scarce. Participants in rich information contexts referred to evidence twice as often as those in poor information contexts. At the same time, people engage in simplifying strategies that complicate their ability to evaluate evidence well. People appear to hold biases that compete with expert evidence-evaluation skills. While generalizable skills do apply across evidence-evaluation contexts, how those skills are enacted in a given situation depends largely on the nuances of the context. Researchers have written about this as the coordination of two problem spaces (e.g., Klahr and Dunbar 1988; Kuhn et al. 1988). What does all this suggest for research on understanding causality and reasoning about evidence? Further, what does it suggest for educational practice?

The developmental research community has responded to the difficulties of the problem space by carefully controlling task demands so that young children can reveal their emerging competencies. Broadly, this work reveals young children to be far more competent in their reasoning than earlier research suggested. These studies are useful as a suggestion of what aspects of more complex competencies children hold at given ages. They also suggest what *might* be possible in real-world contexts. However, these competencies don't typically carry over to scientific reasoning tasks that feature authentic, ill-structured, and compound forms of complexity within a given problem context (for a review, see Grotzer 2003). The response of the educational research community has been to study more-authentic context-rich tasks. Research investigations that reflectively build our knowledge of evidence evaluation skills through a combination of context-lean and context-rich tasks and specifically analyze them through that lens are likely to offer the deepest insights into how people reason about scientific evidence.

## EFFORTS IN K–12 EDUCATION AND RESEARCH TO IMPROVE SCIENTIFIC EVIDENTIAL REASONING

Evidence evaluation holds a clear place in the K–12 science standards. The standards call for the ability to reason about evidence in relation to scientific explanation. For instance, they state that students should "use evidence to generate explanations, propose alternative explanations, and critique explanations and procedures" (National Research Council 1995). Further, students should "develop descriptions, explanations, predictions, and models using evidence" (National Research Council 1995). The standards place a particular focus on the relationship between evidence and explanations by requiring that students be able to "think critically and logically to make the relationships between evidence and explanations" and be able to account for anomalous data. The standards also recognize some of the puzzles involved in teaching children to reason well about evidence. For instance, they call for the ability to "recognize and analyze alternative explanations and predictions" (National Research Council 1995). They acknowledge some of the difficulties that students have in evaluating evidence and attempt to alert teachers to these difficulties. For instance, "teachers of science for middle-school students should note that students tend to center on evidence that confirms their current beliefs and concepts (i.e., personal explanations), and ignore or fail to perceive evidence that does not agree with their current concepts" (National Research Council 1995). Of course, what the standards call for and what happens in K–12 classrooms are two different pictures. The following paragraphs consider some of the promising directions that science education research has taken and some of the difficulties of enacting these innovations in the classroom.

### *Inquiry-Based Science*

The focus in the standards is largely on the evaluation of evidence in the context of scientific inquiry—as opposed to evaluating evidence in the process of assessing research in the popular press and elsewhere. For instance, the standards focus on "the ability to conduct inquiry and develop understanding about scientific inquiry, including asking questions, planning and conducting investigations, using appropriate tools and techniques to gather data, thinking critically and logically about relationships between evidence and explanations, constructing and analyzing alternative explanations, and communicating scientific arguments" (National Research Council 1995).

Increasingly, inquiry-based science approaches, in which students pursue questions through experimentation, are finding their way into K–12 classrooms. While inquiry-based instruction is typically hands-on, the two approaches are not synonymous, with "hands-on" including teacher-posed activities and recipe-like lab experiences that are not necessarily "minds-on" too (Driver et al. 1985). The move toward inquiry-based science recognizes the important epistemological knowledge that students gain in such contexts, the increased likelihood of transfer, and the ability to deal with ill-structured real-world problems. Inquiry-based science also offers students the opportunity to learn scientific reasoning—how nuanced scientific reasoning can be and what aspects of scientific reasoning generalize across different contexts (Kuhn et al. 1992).

What do we know about the impact of inquiry-based instruction? Students have difficulty formulating research questions and plans for investigating them (Krajcik et al. 1998). Zimmerman (2000) summarized fourteen self-directed experimentation studies and found the following patterns: In general, third to sixth graders often generated uninformative experiments; made judgments that were based on inconclusive or insufficient data while ignoring inconsistent data and disregarding surprising results; attended to causal factors but not noncausal factors; were unsystematic in recording data, outcomes, and plans; and were influenced by and had difficulty disconfirming prior beliefs.

However, this research also suggests some promise. Students did learn new strategies, but these appear to live side by side with old ones, not necessarily replacing them. Masnick and Klahr (2003) found that second- and fourth-grade children could both propose and recognize potential sources of error before they could design unconfounded experiments. They used evidence to guide their reasoning, making predictions and drawing conclusions based on the design of their experiments, and they were sensitive to the context of reasoning: they differentiated the role of error in relative and absolute measurements. Masnick and Klahr (2003) argued that long before children have acquired the formal procedures necessary to control error, they have a surprisingly rich—albeit unsystematic—understanding of its various sources.

Further, the research on how good learners and bad learners think about evidence suggests specific ways that we might help all learners to learn better. Schauble et al. (1992) found that good learners generate and state many more alternative hypotheses, their experiments are more controlled, and they do a more extensive search of the problem space. They are more systematic—recording results and goal-oriented plans. When students hold more-sophisticated conceptual models, they are more likely to try to make sense of disconfirming or surprising evidence (e.g., Dunbar 1993).

Helping students engage in authentic, inquiry-based science gives them the opportunity to learn scientific reasoning and also increases the knowledge demands on teachers in numerous ways. To be effective, teachers need nuanced epistemological knowledge, a considerably greater content knowledge basis upon which to respond to puzzles and questions that arise, and much more sophisticated pedagogical knowledge (to name but a few of their needs). What students end up learning may indeed be more valuable, but what is learned and the quality of learning is typically far more divergent than with traditional, didactic teaching approaches and content costs may accrue if the teacher is not highly skilled in figuring out how to weave content exploration into the inquiry context.

*The Epistemology of Science*

Engaging in effective inquiry-based science practices is more than knowing how to carry out experiments, however. Sandoval and Reiser (2004) have argued that students need to understand the epistemological commitments that scientists make—the processes they value for generating and validating knowledge. They call for foregrounding these commitments in the context of inquiry-based approaches. This goes beyond helping students learn to "think like scientists." The aim here is to help students learn the nature of science and the epistemological underpinnings of the discipline. The national science standards also address the importance of knowledge of the epistemology of science. They call for an understanding of the ways of knowing and finding out in the discipline; for instance, "scientists develop explanations using observations (evidence) and what they already know about the world (scientific knowledge). Good explanations are based on evidence from investigations." And "scientific explanations emphasize evidence, have logically consistent arguments, and use scientific principles, models, and theories. The scientific community accepts and uses such explanations until displaced by better scientific ones. When such displacement occurs, science advances" (National Research Council 1995).

Research suggests that peoples' ability to reason about evidence may be limited by their epistemological development (Lederman et al. 2002; Sandoval 2003, 2005) and that students with more epistemological knowledge generally perform better in science (e.g., Linn and Songer 1993). This type of knowledge provides the broad context for everything else learned in science and puts students in a better position to join scientific communities.

But understanding the epistemology of science isn't just for future scientists. Making sense of the wealth of scientific data around us and trusting the scientific enterprise as a whole requires an understanding of how that knowledge is generated. The common view of science is often quite different from and leads to a different set of expectations than that held by scientists (Chalmers 1999). For example, scientists realize that conclusions are always tentative, that science is not a steady process of the accumulation of facts but that as evidence no longer fits a prevailing model, we trade up for more explanatory models in a Kuhnian paradigm shift (Kuhn 1962). What counts as evidence also can change as part of a paradigm shift. However, if the general population expects scientific knowledge to accumulate, trading up seems more like scientists are changing their minds, and, if that is part of science, why would you place your trust in scientific evidence and the conclusions scientists draw from it? Scientists need to consider carefully how to represent and communicate uncertainty (Zehr 1999), and the general population needs to understand what that uncertainty means in the context of a scientific framework.

In practice, helping students learn the epistemology of science holds a number of challenges: 1) understanding the tacit assumptions that scientists make; 2) preparing teachers to understand those assumptions; and 3) finding ways to make epistemological assumptions accessible at the right level for students without reducing them to a stereotyped set of steps.

Unpacking the tacit assumptions that scientists actually make has been an important line of research (e.g., Dunbar 1995). Scientific discovery and reasoning is a highly nuanced and opportunistic endeavor. In telling the story of the discovery of binary pulsars for which he eventually won a Nobel Prize, Russell Hulse (2003) talks of the process leading up to the discovery. He explains the data collection and careful note taking on the behavior of pulsars and the "error" in his data that emerged first as an annoyance and, after further reflection, as an interesting aberration, and, ultimately, as a pattern describing a previously unidentified phenomenon. His story underscores the nuanced attention to certain kinds of patterns and the reasoning processes to follow that characterize scientific reasoning—nuance that can be difficult to unpack and capture in understanding the scientific process.

In most cases, K–12 teachers do not hold the epistemological assumptions of a scientist. This is particularly an issue with K–5 teachers who may have little or no science background and are expected to teach all the disciplines, understand developmental issues, work with students who have different abilities, disabilities, and skill levels, may not speak English as their primary language, and so on. However, epistemology can also be an issue for middle and high school teachers who might be well versed in content but unfamiliar with how knowledge is generated in the sciences. Even if they once knew, the predominant modes of inquiry shift and change over time with new tools. For instance, in genetics, computers now make it possible to randomly run huge numbers of gene sequences searching for a match rather than using a theory-oriented approach to eliminate certain sequences first. Teachers need these understandings if they are to help students learn them.

Finally, making nuanced assumptions visible and accessible without reducing them to a set of stereotyped steps is difficult. Often scientific inquiry is taught in K–12 classrooms as a set of steps to follow; for example, "the scientific method" is often taught this way. In the first step, students are told to "get a hypothesis"—leaving out the entire idea-generation phase of scientific discovery! Lessons might be designed so that students engaged in inquiry are doing the inquiry either with or without explicit reflection on the processes. These stereotyped versions of science impact what the population expects of science as a field. Yet, as Bauer (1992) has argued, what the general population believes about the nature of scientific thinking includes many popular "shoulds" that would impede scientific progress. For instance, if scientists published all their data, the community would be mired in unsound or misleading data as well as that which might be constructive.

One approach is to teach about the nature of science by exploring historical and current-day examples of scientists and scientific reasoning. While this has the benefit of inviting students to consider the nuances of the field, such an approach would need to pay careful attention to how the cases are presented. As with the Folkman case, it's easy to skew students' sense of the discipline by sharing only examples that stand out for one reason or another, such as those that warrant historical recognition. Revolutionary science that cuts across disciplinary boundaries or that shifts the current paradigm is far less common than the everyday science that involves solving smaller-scale puzzles and slogging through data.

Despite the challenges, understanding epistemology is clearly a key to developing a population that knows how to think about scientific evidence. Students can learn to think about epistemological issues (Smith et al. 2000), and explicit reflection on epistemology results in more-informed views of the nature of science (Khishfe and Abd-El-Khalick 2002). A promising direction in science education research investigates students' ability to gain from the use of technology-based, epistemic tools that scaffold their framing of the epistemology (e.g., Bell and Linn 2000; Sandoval and Reiser 2004; Scardamalia and Bereiter 2004). In classrooms using these resources, students have, for instance, demonstrated the ability to negotiate the terms of explanations, engage in planful investigation (Schauble et al. 1991), and evaluate whether evidence fits with their explanations or not (Sandoval and Reiser 2004).

*Science as Argumentation*

The science education research community has shown growing interest in argumentation as a central scientific practice that students should learn (e.g., Driver et al. 2000; Kuhn 1993; Sandoval and Millwood 2005). The mere presentation of contradictory evidence is not enough to get students to change their minds (Chinn and Brewer 1998). Driver et al. (2000) argue that the practices of science teaching need to be reconceptualized so as to portray scientific knowledge as socially constructed—emphasizing the role of argumentation in science.

The standards outline a clear role for scientific discourse and argumentation in science classrooms. They call for teachers to "structure and facilitate ongoing formal and informal discussion based on a shared understanding of the rules of scientific discourse" (National Research Council 1995) and for students to develop the

> ability to engage in the presentation of evidence, reasoned argument, and explanation comes from practice. Teachers encourage informal discussion and structure science activities so that students are required to explain and justify their understanding, argue from data and defend their conclusions, and critically assess and challenge the scientific explanations of one another. (National Research Council 1995)

How argumentation is carried out matters. Debate about why certain explanations are better than others appears to be a critical component in developing epistemic criteria (Rosebery et al. 1992; Sandoval and Reiser 2004). Hogan (1999) found that students who engaged in lessons designed to encourage "metacognitive, regulatory, and strategic aspects of knowledge co-construction" were subsequently better able to articulate their collaborative reasoning processes than the students in control classrooms. Further, when one student uses an evidence evaluation strategy in a discussion, the strategy is more likely to be used by his or her classmates (Anderson et al. 2001; Pluta and Chinn 2007). Unfortunately, most teachers do not provide many opportunities for group or class discussion—expressing uncertainly about how to support such discussions, they opt instead to lecture (Newton et al. 1999). Student discussion, when it does occur, tends to focus on procedural aspects of the practical work rather than the actual science.

### *Modeling*

The epistemology of science involves thinking about the explanatory power of a model in light of the available evidence (e.g., Giere 1988; Hestenes 1992). Scientific knowledge is generated by discarding models that no longer fit the evidence and then trading up for more powerful models. Consider how different this is from typical "school science" where students are taught a "right answer" and are not always taught the rationale for that explanation.

Models are a natural extension of a classroom discourse that involves argumentation and teaching of the epistemology of science. Models are debated and defended and in this way render students' thinking visible (Lehrer and Schauble 2006) to the person espousing the model, to other students, and to the teacher. The models become an artifact of the sociocultural process in the classroom. Others have argued that models assist in the transfer of learning (Clement 2000) and in conceptual change (Gobert 2000).

How students think about models bears on how they use them to reason about evidence. Harrison and Treagust (2000) argue that most students believe in a one-to-one correspondence between a model and reality; therefore, students need to learn that all models fit in some ways but not in others. Perception of models appears to be rooted in students' understanding of the epistemology of science. Chittleborough and colleagues (2005) found that many students do have a good understanding of the role of models in the process of science and appreciate the multiplicity and representational yet changing nature of models. While some students have a fascination for true facts and single and correct models, others exhibit more sophisticated epistemologies of science. Chittleborough and colleagues (2005) also found that these understandings improve with learning opportunities. Thinking about models in science (as a learner or a scientist) demands a flexible commitment to the model that one holds. One needs to be able to view the model as a tentative explanation until a more fully explanatory one comes along. This can be hard for students, who often hold robust, alternative conceptions for many science concepts (e.g., Driver et al. 1985). The research on confirmation bias underscores the fact that people do not naturally consider rival models (Driver et al. 1996; Grosslight et al. 1991). Generating rival models from the outset is one way to encourage flexible commitment and deep consideration of the model in light of the available evidence (Grotzer 2002) and promises to lead to better evaluation of evidence.

*Infusing a Focus on Causality in Science Learning*

When reasoning about complex phenomena, students rely on a series of default assumptions that often distort the nature of the causality involved. For instance, students often give linear or narrative explanations that are story-like: "first this happened, then it made that happen, and so on." Such explanations have a domino-like quality to them that actually is absent from many science concepts. Concepts such as symbiosis, pressure or density differentials, and electrical circuits are distinctly nonlinear in form. They involve mutual, relational, or cyclic patterns (Grotzer 2003). Concepts might appear straightforward but reveal complexity as soon as one dives below the surface. In addition to nonlinear patterns, they may include nonobvious causes; time delays and spatial gaps between causes and effects; distributed, nonintentional agency; and probabilistic causation where the level of correspondence between causes and effects varies. Abrahamson and Wilensky (2005) found that many of the heuristics necessary for reasoning about complex systems run counter to those involved in reasoning about the linear systems with which students appear to be more familiar.

Causal default assumptions impact what evidence people attend to and the salience that they attach to it. For example, when spatial gaps and time delays are present, people are less likely to notice relevant evidence. Instances of distributed causal agency, where many people acting on one level contribute to an emergent outcome on another level, are difficult to analyze. For example, in the case of global warming, recognizing our individual contributions to the problem (and thus what we might do about them) is extremely difficult because evidence of the problem is available only at the level of the collective outcome.

Increasingly, science education research is considering how to help students learn to think about causality in more complex ways. Students need explicit opportunities to reflect on their default patterns, learn the new causal patterns, and observe how the latter do a better job explaining the phenomenon at hand. Offering rich opportunities to learn complex causal concepts where students have the opportunity to discover different phenomena has shown some promise. Wilensky and Resnick (e.g., Resnick 1996; Wilensky 1998; Wilensky and Resnick 1999) have used multiagent modeling in numerous studies on the concepts of emergence. They have demonstrated that constructionist opportunities to work with dynamic, object-based models that reveal complex causal concepts result in new insights into the nature of complex phenomena such as gas laws and the behavior of slime molds. Chiu and colleagues (2002) found that having mentors unpack their thinking about complex problems that are just beyond the independent ability of the students made a significant difference in the students' understanding of the concepts of simultaneity and randomness as these relate to chemical equilibrium as compared to students in a control group. Grotzer and colleagues (e.g., Grotzer and Basca 2003; Grotzer 2000; Perkins and Grotzer 2005) contrasted three pedagogical conditions across a number of science concepts (electricity, ecosystems, air pressure, and density) that engaged students in thinking about simultaneity, multiple causes and effects, nonobvious causes, nonlinearity, and outcomes due to balance or imbalance between multiple variables. They found that a combination of activities designed to reveal the underlying causal concepts and explicit discussion about the nature of causality (what is hard to grasp about it, how particular causal patterns differ from other causal patterns) led to deeper understanding. These students significantly outperformed students who participated only in the causally focused activities or who did not participate in the causally focused activities or discussion but did have "best practices" science units that included extensive model building by students, evaluating evidence, Socratic discussion, dynamic computer models, and attention to students' evolving models. The differences were especially dramatic for science concepts where the causality was least linear, sequential, and direct.

*Beyond Teaching Empiricism*

Osborne (2002) has argued that we need to move beyond a focus on empiricism when thinking about how students analyze evidence. A majority of the public interacts with science text in popular accounts or journalistic versions. Korpan and colleagues (1997) have argued that media reports of scientific research are a pervasive and important source of new scientific knowledge and that the ability to evaluate conclusions found in those reports is an important form of scientific literacy.

Korpan and colleagues (1997) found that students generated a range of requests for information and that they focused most often on *how* the research was conducted and *why* the results might have occurred. They made fewer requests for other types of information, such as w*hat* was found, *who* conducted the research, *where* it was conducted, or whether related research had been conducted. They seemed most influenced by the plausibility of the conclusions, typicality of the phenomena, and their own personal familiarity with the phenomena. In a series of studies conducted with his graduate students, Chinn (Buckland and Chinn 2007; DiFranco and Chinn 2007; Hung and Chinn 2007; Pluta and Chinn 2007) has also explored how students make sense of evidence in published studies and how they coordinate that data across studies. Pluta and Chinn (2007) considered how seventh graders resolved conflicting pairs of news stories. The stories were similar to those published in newspaper accounts but had a slightly greater emphasis on methodology. The studies focused on scientific cases (deformed frogs, dinosaur metabolism, aspartame, etc.) that students were given information about. Students primarily reasoned at the level of explanations. However, students often had difficulty connecting the study details to the specific explanation. They ignored study details that might have helped them to integrate the evidence and their explanation, as well as details that did not fit with their initial ideas. Direct replication failure was genuinely baffling to students. While few students were able to use the details of the study to coordinate the results, they revealed a wide range of strategies across the groups of students.

Ninety percent of students used more than one strategy (such as methodological differences, bias, chance, etc.) to account for the conflicting scientific interpretations within a given problem and 70 percent of students used more than one strategy across different problem types. This is promising, particularly in classrooms where students engage in discussion about evidence. Pluta and Chinn (2007) found that certain forms of reasoning were less common, such as reasoning about bias or chance. These concepts warrant additional attention to help students understand and apply them. In general, these studies stress the need for authentic practice in helping students learn how to apply strategies in particular instances.

## SUGGESTIONS FOR NEXT STEPS AND NEW DIRECTIONS TO IMPROVE SCIENTIFIC EVIDENTIAL REASONING

Scientific evidential reasoning is a challenging yet important problem space. We have much to build on in taking next steps, and some clear needs are present that suggest directions for our collective efforts in improving the scientific literacy of the general population through education.

A fairly extensive and informative research literature exists; it raises many puzzles but also offers solid information about approaches that are most promising. We have the most information about how students reason in the context of inquiry-based learning. The existing standards offer a strong basis from which to work. They draw solidly from the research base and make useful recommendations to classroom teachers. The focus, however, is largely on experimentation. Standards that include analyzing research evidence from published sources would promote greater scientific literacy even among those who do not plan to become scientists.

Far less research has looked at how students of different ages reason about published scientific reports of real world studies (Chinn and Malhotra 2002). Chinn and colleagues (e.g., Hung and Chinn, 2007; Pluta and Chinn 2007) have taken some important first steps here. More research focused on interpreting findings is needed. Continued exploration of the barriers to understanding is also needed so that we can find approaches that offer the most leverage in solving the problem. For instance, work focused on helping students examine their causal default assumptions may systematically impact how they generate explanations. Similarly, helping students understand the epistemology of science helps them to view science as an endeavor differently and to realize that it is more than just learning facts.

A better bridge between research and practice is needed. While a fair amount is known about evidence evaluation skills and the epistemological knowledge that supports them, these findings have been slow to make their way into mainstream practice. This lack of an effective bridge is a perennial problem in applying research findings. If future investigations were more closely situated at the intersection of practice and basic research on learning—in "Pasteur's Quadrant" (Stokes 1997)—a bridge might no longer be necessary. We need accessible pedagogies that build upon the research results. The kind of work that Sandoval and colleagues (e.g., Sandoval and Reiser 2004) are engaged in—designing computer programs that teach the epistemology of science—holds promise here.

Probably the biggest hurdle, however, has to do with supporting teachers. To assume that teachers will be able to teach the epistemology of science in all its nuances without a considerable investment in professional development and instructional materials is irrationally optimistic. The type of nuanced understanding called for in the science education research comes from a deep understanding of scientific inquiry and the expertise associated with having opportunities to engage in science. This stands in sharp contrast to the comfort level that many teachers, especially at the elementary level, have with science and the high rate of teacher turnover, particularly in urban schools.

What is obvious, even from this brief overview, is how challenging the problem space of scientific reasoning and education is. However, the pay-off from engaging with this problem space is a scientifically literate population: critical consumers of the abundance of available scientific information who can reason effectively about evidence and a generation of scientists capable of understanding a complex, dynamic world. Substantial resources already exist to support these efforts. The imperative is clear.

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## REFERENCES

Abrahamson, D. and U. Wilensky, 2005. The stratified learning zone: Examining collaborative-learning design in demographically-diverse mathematics classrooms. Paper presented at the annual meeting of the American Educational Research Association, Montreal, Canada.

Anderson, R. C., K. Nguyen-Jahiel, B. McNurlen, A. Archodidou, S. Kim, A. Reznitskaya, M. Tillmanns, and L. Gilbert. 2001. The snowball phenomenon: Spread of ways of talking and ways of thinking across groups of children. *Cognition and Instruction* 19:1–46

Baillargeon, R., R. Gelman, and E. Meck. 1981. Are preschoolers truly indifferent to causal mechanism? Paper presented at the biennial meeting of the Society for Research in Child Development, Boston, MA.

Bauer, H. 1992. *Scientific Literacy and the Myth of the Scientific Method.* Urbana, IL: University of Illinois Press.

Bell, P., and M. Linn. 2000. Scientific argumentation as learning artifacts: Designing for learning from the web with KIE. *International Journal of Science Education* 22(8):797–817.

Borton, R. W. 1979. The perception of causality in infants. Paper presented at the biennial meeting of the Society of Research in Child Development, San Francisco, CA.

Bracey, G. W. 1998. Tinkering with TIMMS. *Phi Delta Kappan* 80(1):32–36.

Brem, S. K., and L. J. Rips. 2000. Explanation and evidence in informal argument. *Cognitive Science* 24:573–604.

Buckland, L. and C. A. Chinn. 2007. Integrating evidence and models at the 7th Grade: A preliminary investigation. Paper presented at the American Educational Research Association Conference, Chicago, IL.

Bullock, M. 1979. Aspects of the young child's theory of causation. Ph.D. diss., University of Pennsylvania.

Bullock, M. 1984. Preschool children's understanding of causal connections. *British Journal of Developmental Psychology* 2:139–148.

Bullock, M. 1985. Causal reasoning and developmental change over the preschool years. *Human Development* 28:169–191.

Bullock, M., and R. Gelman. 1979. Preschool children's assumptions about cause and effect: Temporal ordering. *Child Development* 50:89–96.

Chalmers, A. F. 1999. *What is This Thing Called Science?* 3rd ed. Indianapolis: Hackett Publishing Co.

Chinn, C. A., and W. F. Brewer. 1998. An empirical test of a taxonomy of responses to anomalous data in science. *Journal of Research in Science Teaching* 35:623–654.

Chinn, C. A., and B. A. Malhotra. 2002. Epistemologically authentic reasoning in schools: A theoretical framework for evaluating inquiry tasks. *Science Education* 86:175–218.

Chittleborough, G. D., D. F. Treagust, and T. L. Mamiala. 2005. Students' perceptions of the role of models in the process of science and in the process of learning. *Research in Science and Technological Education* 23(2):195–212.

Chiu, M., C. Chou, and C. Liu. 2002. Dynamic processes of conceptual change: Analysis of constructing mental models of chemical equilibrium. *Journal of Research in Science Teaching* 39(8):688–712.

Clement, J. 2000. Model-based reasoning as a key research area for science education. *International Journal of Science Education* 22(9):937–977.

Corrigan, R. 1995. How infants and young children understand the causes of events. In *Social development: Review of Personality and Social Psychology,* Vol. 15, ed. N. Eisenberg. Thousand Oaks, CA: Sage Publications, Inc.

DiFranco, J. and C. A. Chinn. 2007. Reasoning about disparate data. Paper presented at the American Educational Research Association Conference, Chicago, IL.

Dorner, D. 1989. *The Logic of Failure.* New York: Metropolitan Books.

Driver, R., E. Guesne, and A. Tiberghien, eds. 1985. *Children's Ideas in Science.* Philadelphia: Open University Press.

Driver, R., J. Leach, R. Millar, and P. Scott. 1996. *Young People's Images of Science.* Buckingham, UK: Open University Press.

Driver, R., P. Newton, and J. Osborne. 2000. Establishing the norms of scientific argumentation in classrooms. *Science Education* 84:287–312.

Dunbar, K. 1993. Concept discovery in a scientific domain. *Cognitive Science* 17:397–434.

Dunbar, K. 1995. How scientists really reason: Scientific reasoning in real-world laboratories. In *Mechanisms of Insight,* ed. R. J. Sternberg, and J. Davidson, 365–395. Cambridge, MA: MIT Press.

Feltovich, P. J., R. J. Spiro, and R. L. Coulson. 1993. Learning, teaching, and testing for complex conceptual understanding. In *Test Theory for a New Generation of Tests,* ed. N. Frederiksen and I. Bejar, 181–217. Hillsdale, NJ: LEA.

Ferrari, M., and M. T. C. Chi. 1998. The nature of naïve explanations of natural selection. *International Journal of Science Education* 20:1231–1256.

Giere, R. N. 1988. *Explaining Science: A Cognitive Approach.* Chicago: University of Chicago Press.

Gobert, J. D. 2000. A typology of causal models for plate tectonics: Inferential power and barriers to understanding. *International Journal of Science Education* 22(9):937–977.

Gopnik, A., C. Glymour, D. M. Sobel, L. E. Schulz, T. Kushnir, and D. Danks. 2004. A theory of causal learning in children: Causal maps and Bayes nets. *Psychological Review* 111:1–31.

Grosslight, L., C. Unger, E. Jay, and C. Smith. 1991. Understanding models and their use in science: Conceptions of middle and high school students and experts. *Journal of Research in Science Teaching* 28:799–822.

Grotzer, T. A. 2000. How conceptual leaps in understanding the nature of causality can limit learning: An example from electrical circuits. Paper presented at the American Educational Research Association Conference, New Orleans, LA.

Grotzer, T. A. 2002. *Causal Patterns in Ecosystems: Lessons to Infuse into Ecosystems Units.* Cambridge, MA: Project Zero, Harvard Graduate School of Education.

Grotzer, T. A. 2003. Learning to understand the forms of causality implicit in scientific explanations. *Studies in Science Education* 39:1–74.

Grotzer, T. A. 2004. Putting science within reach: Addressing patterns of thinking that limit science learning. *Principal Leadership.* October.

Grotzer, T. A., and B. B. Basca. 2003. How does grasping the underlying causal structures of ecosystems impact students' understanding? *Journal of Biological Education* 38(1):16–29.

Harrison, A. G., and D. F. Treagust. 2000. Typology of school science models. *International Journal of Science Education* 22(9):1011–1026.

Hestenes, D. 1992. Modeling games in the Newtonian world. *American Journal of Physics* 60(8):732–748.

Hogan, K. 1999. Thinking aloud together: A test of an intervention to foster students' collaborative scientific reasoning. *Journal of Research in Science Teaching* 36(10):1085–1109.

Hulse, R. 2003. Keynote Speech: Research on Learning and Education (R.O.L.E.) Principal Investigators' and Contractors' Meeting, National Science Foundation, October 27-28, 2003, Crystal City, VA.

Hung, C. C., and C. A. Chinn. 2007. Learning to reason about the methodology of scientific studies: A classroom experiment in the middle school. Paper presented at the American Educational Research Association Conference, Chicago, IL.

Jasanoff, S. 1997. Civilisation and madness: The great BSE scare of 1996. *Public Understanding of Science* 6:221–232.

Kalish, C. 1997. Preschooler's understanding of mental and bodily reactions to contamination: What you don't know can hurt you, but cannot sadden you. *Developmental Psychology* 33(1):79–91.

Karmiloff-Smith, A. 1984. Children's problem-solving. In *Advances in Developmental Psychology,* vol. 3, ed. M. E. Lamb, A. L. Brown, and B. Rogoff, 39–90. Hillsdale, NJ: Lawrence Erlbaum Associates.

Kelley, H. H. 1973. The processes of causal attribution. *American Psychologist* 28(2):107–128.

Khishfe, R., and F. Abd-El-Khalick. 2002. Influence of explicit and reflective versus implicit inquiry-oriented instruction on sixth graders' views of nature of science. *Journal of Research in Science Teaching* 39:551–578.

Klahr, D., and K. Dunbar. 1988. Dual space search during scientific reasoning. *Cognitive Science* 12:1–48.

Klahr, D., A. L. Fay, and K. Dunbar. 1993. Heuristics for scientific experimentation: A developmental study. *Cognitive Psychology* 25:111–146.

Korpan, C. A., G. L. Bisanz, and J. Bisanz. 1997. Assessing literacy in science: Evaluation of scientific news briefs. *Science Education* 81(5):515–532.

Koslowski, B. 1976. Learning About an Instance of Causation. Unpublished manuscript, Cornell University.

Koslowski, B. 1996. *Theory and Evidence.* Cambridge, MA: MIT Press.

Koslowski, B., and A. Snipper. 1977. Learning about an instance of non-mechanical causality. Unpublished manuscript, Cornell University.

Krajcik, J., P. Blumenfeld, R. W. Marx, K. H. Bass, and J. Fredericks. 1998. Inquiry in project-based science classrooms: Initial attempts by middle school students. *Journal of the Learning Sciences* 7(3/4):313–350.

Kuhn, D. 1993. Science as argument: Implications for teaching and learning scientific thinking. *Science Education* 77(3):319-337.

Kuhn, D., E. Amsel, and M. O'Loughlin. 1988. *The Development of Scientific Thinking Skills*. Orlando: Academic Press.

Kuhn, D., L. Schauble, and M. Garcia-Mila. 1992. Cross-domain development of scientific reasoning. *Cognition and Instruction* 9(4):285–327.

Kuhn, T. S. 1962. *The Structure of Scientific Revolutions.* Chicago: University of Chicago Press.

Lederman, N. G., F. Abd-El-Khalick, R. L. Bell, and R. S. Schwartz. 2002. Views of nature of science questionnaire: Toward valid and meaningful assessment of learners' conceptions of nature of science. *Journal of Research in Science Teaching* 39(6):497–521.

Lehrer, R., and L. Schauble. 2006. Cultivating model-based reasoning in science education. In *Cambridge Handbook of the Learning Sciences,* ed. K. Sawyer, 371–388. New York: Cambridge University Press.

Leslie, A. M. 1982. The perception of causality in infants. *Perception* 11:173–186.

Leslie, A. M. 1984. Spatiotemporal continuity and the perception of causality in infants. *Perception* 13:287–305.

Leslie, A. M., and S. Keeble. 1987. Do sixth month old infants perceive causality? *Cognition* 25:265–288.

Lesser, H. 1977. The growth of perceived causality in children. *The Journal of Genetic Psychology* 130:142–152.

Linn, M., and N. Songer. 1993. How do students make sense? *Merrill Palmer Quarterly* 39(1):47–73.

Mack, A., and I. Rock. 1998. *Inattentional Blindness.* Cambridge, MA: MIT Press.

Masnick, A. M., and D. Klahr. 2003. Error matters: An initial exploration of elementary school children's understanding of experimental error. *Journal of Cognition and Development* 4(1):67–98.

Mendelson, R., and T. R. Shultz. 1976. Covariation and temporal contiguity as principles of causal inference in young children. *Journal of Experimental Child Psychology* 22:408–412.

Michotte, A. 1946/1963. *The Perception of Causality,* trans. T. R. Miles and E. Miles. New York: Basic Books.

National Research Council. 1995. *National Science Education Standards.* National Academies Press. http://www.nap.edu/readingroom/books/nses/.

Newton, P., R. Driver, R. and J. Osborne. 1999. The place of argumentation in the pedagogy of school science. *International Journal of Science Education* 21(5):553-576.

Nickerson, R., D. Perkins, and E. Smith. 1985. *The Teaching of Thinking.* Hillsdale, NJ: LEA.

Nisbett, R., and L. Ross. 1980. *Human Inference: Strategies and Shortcomings of Social Judgment.* Englewood Cliffs, NJ: Prentice-Hall.

Oakes, L. M. 1993. The perception of causality by 7- and 10-month-old infants. Paper presented at the Meeting of the Society for Research in Child Development, New Orleans, LA.

Osborne, J. 2002. Science without literacy: A ship without a sail? *Cambridge Journal of Education* 32(2):203–218.

Perkins, D. N., and T. A. Grotzer. 2005. Dimensions of causal understanding: The role of complex causal models in students' understanding of science. *Studies in Science Education* 41:117–165.

Petrosino, A. J., R. Lehrer, and L. Schauble. 2003. Structuring error and experimental variation as distribution in the fourth grade. *Mathematical Thinking and Learning* 5(2/3):131–156.

Piatelli-Palmarini, M. 1994. *Inevitable illusions: How Mistakes of Reason Rule Our Minds.* New York: John Wiley and Sons, Inc.

Pluta, W. J., and C. A. Chinn. 2007. Making sense of conflicting studies: Can students build complex evidence-based models? Paper presented at the American Educational Research Association Conference, Chicago, IL.

Resnick, M. 1996. Beyond the centralized mindset. *Journal of the Learning Sciences* 5(1):1–22.

Rosebery, A. S., B. Warren, and F. R. Conant. 1992. Appropriating scientific discourse: Findings from language minority classrooms, *Journal of the Learning Sciences* 2(1):61–94.

Sandoval, W. A. 2003. Conceptual and epistemic aspects of students' scientific explanations. *Journal of the Learning Sciences* 12(1):5–51.

Sandoval, W. A. 2005. Understanding students' practical epistemologies and their influence on learning through inquiry. *Science Education* 89(4):634–656.

Sandoval, W. A., and K.A. Millwood. 2005. The quality of students' use of evidence in written scientific explanations. *Cognition and Instruction* 23(1):23-55.

Sandoval, W. A., and B. J. Reiser. 2004. Explanation-driven inquiry: Integrating conceptual and epistemic scaffolds for scientific inquiry. *Science Education* 88:345–372.

Scardamalia, M., and C. Bereiter. 1994. Computer support for knowledge building communities, *The Journal of the Learning Sciences: Special Issue: Computer Support for Collaborative Learning* 3(3):265–283.

Schauble, L., R. Glaser, K. Raghavan, and M. Reiner, M. 1991. Causal models and experimentation strategies in scientific reasoning, *The Journal of the Learning Sciences* 1(2):201–238.

Schauble, L., R. Glaser, K. Raghavan, and M. Reiner. 1992. The integration of knowledge and experimentation strategies in understanding a physical system. *Applied Cognitive Psychology* 6:321–343.

Schunn, C. D., and D. Klahr. 1993. Self vs. other generated hypotheses in scientific discovery. *Proceedings of the Fifteenth Annual Conference of the Cognitive Science Society,* 1–7.

Shaklee, H., and D. Goldston. 1989. Development in causal reasoning: Information sampling and judgment rule. *Cognitive Development* 4:269–281.

Shaklee, H., and M. Mims. 1981. Development of rule use in judgments of covariation between events. *Child Development* 52:317–325.

Shultz, T. R., and N. R. Kestenbaum. 1985. Causal reasoning in children. *Annals of Child Development* 2:195–249.

Shultz, T. R., and R. Mendelson. 1975. The use of covariation as a principle of causal analysis. *Child Development* 46:394–399.

Siegler, R., and R. Liebert. 1974. Effects of contiguity, regularity, and age on children's causal inferences. *Developmental Psychology* 10(4):574–579.

Smith, C. L., D. Maclin, C. Houghton, and M. G. Hennessey. 2000. Sixth-grade students' epistemologies of science: The impact of school science experiences on epistemological development. *Cognition and Instruction* 18:349–422.

Spelke, E. S., A. Phillips, and A. L. Woodward. 1995. Infants' knowledge of object motion and human action. In *Causal Cognition: A Multidisciplinary Debate,* ed. D. Sperber, D. Premack, and A. J. Premack, 44–78. Oxford, UK: Clarendon Press.

Stokes, D. E. 1997. *Pasteur's quadrant: Basic Science and Technological Innovation.* Washington, DC: Brookings Institution Press.

Sunstein, C. R. 2002. *Risk and Reason: Safety, Law, and the Environment.* Cambridge, UK: Cambridge University Press.

Tierney, J. 2007. Fateful voice of a generation still drowns out real science. *New York Times.* June 5.

Tversky, A., and D. Kahneman. 1982. Judgment under uncertainty: Heuristics and biases. In *Judgment Under Uncertainty: Heuristics and Biases,* ed. D. Kahneman, P. Slovic, and A. Tversky, 3–20. Cambridge, UK: Cambridge University Press.

Van de Walle, G., and E. S. Spelke. 1993. Integrating information over time: Infant perception of partly occluded objects. Presented at the biennial meeting of the Society for Research in Child Development, New Orleans.

Wilensky, U. 1998. GasLab: An extensible modeling toolkit for connecting micro- and macro-properties of gases. In *Computer Modeling in Science and Mathematics Education,* ed. N. Roberts, W. Feurzeig, and B. Hunter. Berlin: Springer-Verlag.

Wilensky, U., and M. Resnick. 1999. Thinking in levels: A dynamic systems approach to making sense of the world. *Journal of Science Education and Technology* 8(1):3–19.

Wynne, B. 1992. Misunderstood misunderstanding: Social identities and public uptake of science. *Public Understanding of Science* 1:281–304.

Zehr, S. 1999. Scientists' Representation of Uncertainty. In *Communicating Uncertainty: Media Coverage of New and Controversial Science,* ed. S. M. Friedman, S. Dunwoody, and C. L. Rogers. Mahwah, NJ: LEA.

Zimmerman, C. 2000. The development of scientific reasoning skills. *Developmental Review* 20:99–149.

# Suggestions for Further Reading

## ADOLESCENT AND ADULT DEVELOPMENT AND PSYCHOLOGY

Alexander, T. 2007. *Children and Adolescents: A Biocultural Approach to Psychological Development*. Piscataway, NJ: Aldine Transaction.

Belenky, M., B. Clinchy, N. Goldberger, and J. Tarule. 1986. *Women's Way of Knowing: The Development of Self, Voice, and Mind*. New York: Basic Books.

Borman, K. M., and B. L. Schneider. 1998. *The Adolescent Years: Social Influences and Educational Challenges*. Chicago: National Society for the Study of Education.

Erikson, E. 1980. *Identity and the Life Cycle*. New York: Norton.

Kagan, J. 1989. *Unstable Ideas: Temperament, Cognition, and Self*. Cambridge, MA: Harvard University Press..

Kagan, J., and H. Moss. 1962. *Birth to Maturity*. New York: Wiley.

Kegan, R. 1982. *The Evolving Self: Problem and Process in Human Development*. Cambridge, MA: Harvard University Press.

Rice, F. P., and K. G. Dolgin. 2007. *The Adolescent: Development, Relationships, and Culture*, 12th ed. Boston: Allyn and Bacon.

Spacks, P. M. 1981. *The Adolescent Idea: Myths of Youth and the Adult Imagination*. New York: Basic Books.

Steinberg, L., with B. Brown and S. Dornbusch. 1996. *Beyond the Classroom: Why School Reform Has Failed and What Parents Need to Do*. New York: Simon & Schuster.

Steinberg, L. 2008. *Adolescence*, 8th ed. Boston: McGraw Hill Higher Education.

Steinberg, L. and R. Lerner, ed. 2004. *Handbook of Adolescent Psychology*, 2nd ed. Hoboken, NJ: Wiley.

## CREATION OF SCIENTIFIC KNOWLEDGE

Collins, H. M. 1992. *Changing Order: Replication and Induction in Scientific Practice*. Chicago: University of Chicago Press.

Dunbar, K. 2002. "Science as Category: Implications of InVivo Science for Theories of Cognitive Development, Scientific Discovery, and the Nature of Science." In *Cognitive Models of Science*, ed. S. Stich and P. Carruthers. Cambridge: Cambridge University Press.

Fleck, L. 1979. *Genesis and Development of a Scientific Fact*. Chicago: University of Chicago Press.

Gooding, D., T. Pinch, and S. Schaffer, eds. 1989. *The Uses of Experiment: Studies in the Natural Sciences*. Cambridge: Cambridge University Press.

Hacking, I. 1999. *The Social Construction of What?* Cambridge, MA: Harvard University Press.

Harding, S. 1993. "Rethinking Standpoint Epistemology." In *Feminist Epistemologies*, ed. L. Alcoff and E. Potter, 49-82. New York: Routledge.

Harding, S. 1991. *Whose Science? Whose Knowledge?: Thinking from Women's Lives*. Ithaca, NY: Cornell University Press.

Hull, D. 1988. *Science as a Process: An Evolutionary Account of the Social and Conceptual Development of Science*. Chicago: University of Chicago Press.

Kagan, J. 1998. *Three Seductive Ideas*. Cambridge, MA: Harvard University Press.

Knorr Centina, K. 1999. *Epistemic Cultures: How The Sciences Make Knowledge*. Cambridge, MA: Harvard University Press.

Kuhn, T. S. 1996. *The Structure of Scientific Revolutions*, 3rd ed. Chicago: University of Chicago Press.

Latour, B., and Steven Woolgar. 1986. *Laboratory Life: The Construction of Scientific Facts,* 2d ed. Princeton: Princeton University Press.

Laudan, L. 1984. "The Pseudo-Science of Science?" In *Scientific Rationality: The Sociological Turn*, ed. James Brown, 41-74. Dordrecht, Holland: Reidel.

Longino, H. E. 2002. *The Fate of Knowledge*. Princeton: Princeton University Press.

Longino, H. E. 2002. "The Social Dimensions of Scientific Knowledge," In *The Stanford Encyclopedia of Philosophy*, ed. E. N. Zalta, http://plato.stanford.edu/archives/sum2002/entries/scientific-knowledge-social/.

Longino, H. E. 1990. *Science as Social Knowledge: Values and Objectivity in Scientific Inquiry*. Princeton: Princeton University Press.

McMullin, E., ed. 1992. *Social Dimensions of Scientific Knowledge*. Notre Dame, IN: Notre Dame University Press.

Pickering, A. 1984. *Constructing Quarks: A Sociological History of Particle Physics*. Chicago: University of Chicago Press.

Ravetz, J. R. 1996. *Scientific Knowledge and Its Social Problems*. New Brunswick, NJ: Transaction Publishers.

Shapin, S., and S. Schaffer. 1985. *Leviathan and the Air Pump: Hobbes, Boyle, and the Experimental Life*. Princeton: Princeton University Press.

Sismondo, S. 1996. *Science without Myth: On Constructions, Reality and Social Knowledge*. Albany, NY: State University of New York Press.

## CRITICAL THINKING

Bassham, G., W. Irwin, and H. Nardone.  2007. *Critical Thinking: A Student's Introduction*, 3rd ed. Boston: McGraw Hill.

Beardsley, M. 1975. *Thinking Straight*. Englewood Cliffs, NJ: Prentice Hall.

Brown, L. 2007. *Critical Thinking*. New York: Weigl Publishers.

Browne, M. N., and S. M. Keeley. 2007. *Asking the Right Questions: A Guide to Critical Thinking*, 8th ed. Upper Saddle River, NJ: Prentice Hall.

Capaldi, N. 1987. *The Art of Deception: An Introduction to Critical Thinking: How to Win an Argument, Defend a Case, Recognize a Fallacy, See Through a Deception*, rev. ed. Buffalo, NY: Prometheus Books.

Carey, S. S. 2000. *The Uses and Abuses of Argument: Critical Thinking and Fallacious Reasoning*. Mountain View, CA: Mayfield Publications.

Chaffee, J., C. McMahon, and B. Stout. 2008. *Critical Thinking, Thoughtful Writing: A Rhetoric with Reading*, 4th ed. Boston: Houghton Mifflin.

Chaffee, J. 2007. *Thinking Critically*, 9th ed. Boston: Houghton Mifflin.

Ennis, R. H. 1996. *Critical Thinking*. Upper Saddle River, NJ: Prentice Hall.

Facione, P. A. 2007. *Critical Thinking: What It Is and Why It Counts*, http://www.insightassessment.com/pdf_files/what&why2006.pdf. Millbrae, CA: Insight Assessment.

Fisher, A. 2001. *Critical Thinking*. Cambridge: Cambridge University Press.

Fowler, M. 2008. *The Ethical Practice of Critical Thinking*. Durham, NC: Carolina Academic Press.

Freeman, J. B. 1988. *Thinking Logically: Basic Concepts for Reasoning.* Englewood Cliffs, NJ: Prentice Hall.

Groarke, L., C. W. Tindale, and J. F. Little. 2008. *Good Reasoning Matters!: A Constructive Approach to Critical Thinking*, 4th ed. Don Mills, Ont.: Oxford University Press.

Halpern, D. F. 2003. *Thought and Knowledge: An Introduction to Critical Thinking*, 4th ed. Mahwah, NJ: Lawrence Erlbaum Associates.

Halpern, D. F., and H. R. Riggio. 2002. *Thinking Critically about Critical Thinking*, 4th ed. Mahwah, NJ: Lawrence Erlbaum Associates.

Hughes, W., and J. A. Lavery. 2008. *Critical Thinking: An Introduction to the Basic Skills*, 5th ed. Peterborough, Ont.: Broadview Press.

Missimer, C. A. 2005. *Good Arguments: An Introduction to Critical Thinking*, 4th ed. Upper Saddle River, NJ: Pearson Prentice Hall.

Moon, J. A. 2008. *Critical Thinking: An Exploration of Theory and Practice*. London: Routledge.

Moore, B. N., and R. Parker. 2008. *Critical Thinking*, 9th ed. Boston: McGraw Hill.

Murray, R. M., and N. Kujundzic. 2005. *Critical Reflection: A Textbook for Critical Thinking*. Montréal: McGill-Queen's University Press.

Pofahl, J. 1996. *Creative and Critical Thinking*. Grand Rapids, MI: Instructional Fair - TS Denison.

Rudinow, J., and V. E. Barry. 2007. *Invitation to Critical Thinking*, 6th ed. Belmont, CA: Thomson Wadsworth.

Ruggiero, V. 2008. *Beyond Feelings: A Guide to Critical Thinking*, 8th ed. Boston: McGraw Hill Higher Education.

Seech, Z. 2005. *Open Minds and Everyday Reasoning,* 2nd ed. Belmont, CA: Thomson Wadsworth.

Sternberg, R. J., H. L. Roediger, and D. F. Halpern, eds. 2007. *Critical Thinking in Psychology*. Cambridge: Cambridge University Press.

Tucker, R. W. 1996. *Less than Critical Thinking*. Assessment and Accountability Forum 6 (3 and 4).

Zarefsky, D. 2005. *Argumentation: The Study of Effective Reasoning* (Course No. 4294), 2nd ed. Chantilly, VA: The Teaching Company.

## DECISION-MAKING, JUDGMENT, AND BELIEF

Brest, P., S. Levinson, J. M. Balkin, A. R. Amar, R. Siegel, eds. 2006. *Processes of Constitutional Decisionmaking,* 5th ed. New York: Aspen.

Cederblom, J. B., and D. W. Paulsen. 2006. *Critical Reasoning: Understanding and Criticizing Arguments and Theories*, 6th ed. Belmont, CA: Thomson Wadsworth.

Dalton, R. J., P. A. Beck, and R. Huckfeldt. 1998. "Partisan Cues and the Media: Information Flows in the 1992 Presidential Election." *American Political Science Review* 92 (1): 111-126.

Evans, J. St. B. T., and A. Feeney. 2004. "The Role of Prior Belief in Reasoning." In *The Nature of Reasoning*, ed. J. P. Leighton and R. J. Sternberg, 78-102. Cambridge: Cambridge University Press.

Gilovich, T., D. Griffin, D. Kahneman, eds. 2002. *Heuristics and Biases: The Psychology of Intuitive Judgment*. Cambridge: Cambridge University Press.

Hastie, R., and R. Dawes. 2001. *Rational Choice in an Uncertain World: The Psychology of Judgment and Decision Making*. Thousand Oaks, CA: Sage Publications.

Iyengar, S. S., and M. R. Lepper. 2000. "When Choice is Demotivating: Can One Desire Too Much of a Good Thing?" *Journal of Personality and Social Psychology* 79 (6): 995-1006.

Kahneman, D., and A. Tversky, eds. 2000. *Choices, Values, and Frames*. Cambridge: Cambridge University Press.

Maher, P. 2006. "The Concept of Inductive Probability." *Erkenntnis* 65: 185-206.

Matheson, K., and S. Dursun. 2001. "Social Identity Precursors to the Hostile Media Phenomenon: Partisan Perceptions of Coverage of the Bosnian Conflict." *Group Processes and Intergroup Relations* 4 (2): 117-126.

Piatelli-Palmarini, M. 1994. "Cognitive Illusions" and "Our Spontaneous Intuitions." *Inevitable Illusions: How Mistakes of Reason Rule Our Minds*, 17-42. New York: Wiley.

Shultz, T. R., J. A. Katz, and M. R. Lepper. 2001. "Clinging to Beliefs: A Constraint Satisfaction Model." In *Proceedings of the Twenty-Third Annual Conference of the Cognitive Science Society*, ed. J. D. Moore and K. Stenning. Mahwah, NJ: Erlbaum.

Vallone, R. P., L. Ross, and M. R. Lepper. 1985. "The Hostile Media Phenomenon: Biased Perception and Perceptions of Media Bias in Coverage of the 'Beirut Massacre." *Journal of Personality and Social Psychology* 49 (3): 577-585.

## EDUCATION AND COGNITIVE SCIENCE, PSYCHOLOGY, AND DEVELOPMENT

Aronson, J.A., and C.M. Steele. 2005. "Stereotypes and the Fragility of Academic Competence, Motivation, and Self-Concept." In *The Handbook of Competence and Motivation,* ed. A. Elliot and C. Dweck, 436-456. New York: Guilford.

Bruner, J. S. 1996. *The Culture of Education*. Cambridge, MA: Harvard University Press.

Bruner, J. S. 1977. *The Process of Education*. Cambridge, MA: Harvard University Press.

Bruner, J. S. 1971. *The Relevance of Education*. New York: Norton.

Bruner, J. S. 1966. *Toward a Theory of Instruction*. Cambridge, MA: Belknap Press.

Carey, S. Winter 2004. "Bootstrapping and the Origins of Concepts." *Daedalus* 133 (1): 59-68.

Carlson, J. S., and J. R. Levin, eds. 2007. *Educating the Evolved Mind: Conceptual Foundations for an Evolutionary Educational Psychology*. Psychological Perspectives on Contemporary Educational Issues. Charlotte, NC: Information Age Publications.

Gardner, H. 2006. *The Development and Education of the Mind: The Selected Works of Howard Gardner*. World Library of Educationalists Series. London: Routledge.

Gardner, H. 1999. *The Disciplined Mind: Beyond Facts and Standardized Tests, the K-12 Education that Every Child Deserves*. New York: Penguin.

Gardner, H. 1993. *Frames of Mind: The Theory of Multiple Intelligences,* 10th anniversary ed. New York: Basic Books.

Gardner, H. 1991. *The Unschooled Mind: How Children Think and How Schools Should Teach*. New York: Basic Books.

Gopnik, A., and L. E. Schulz. 2007. *Causal Learning: Psychology, Philosophy, and Computation*. Oxford: Oxford University Press.

Gopnik, A., C. Glymour, D. Sobel, L. E. Schulz, T. Kushnir, and D. Danks. 2004. "A Theory of Causal Learning in Children: Causal Maps and Bayes Net." *Psychological Review* 111 (1): 3-32.

Gopnik, A., and L. E.Schulz. 2004. "Mechanisms of Theory-Formation in Young Children: Trends." *TRENDS in Cognitive Sciences* 8 (8): 371-377.

Gopnik, A., A. N. Meltzoff, and P. K. Kuhl. 1999. *The Scientist in the Crib: What Early Learning Tells Us about the Mind*. New York: William Morrow & Company.

Goswami, U. C. 2008. *Cognitive Development: The Learning Brain*. Hove, UK: Psychology Press.

Lepper, M. R., and J. Henderlong. 2000. "Turning 'Play' into 'Work' and 'Work' into 'Play:' 25 Years of Research on Intrinsic versus Extrinsic Motivation." In *Intrinsic and Extrinsic Motivation: The Search for Optimal Motivation and Performance*, ed. C. Sansone and J. Harackiewicz, 257-307. San Diego, CA: Academic Press.

O'Donnell, A. M., R. Johnmarshall, and J. K. Smith. 2008. *Educational Psychology: Reflection for Action*, 2nd ed. Hoboken, NJ: Wiley.

Olson, D. R., and N. Torrance, eds. 1996. *The Handbook of Education and Human Development: New Models of Learning, Teaching, and Schooling*. Malden, MA: Blackwell Publishers.

Ormrod, J. E. 2007. *Educational Psychology: Developing Learners*, 6th ed., Upper Saddle River, NJ: Pearson Merrill Prentice Hall.

Pea, R., J. D. Bransford, A. Brown, and R. Cocking, eds. 2000. *How People Learn: Mind, Brain, Experience and School*, expanded ed. Washington, DC: National Academy Press.

Pressley, M., and C. McCormick. 2007. *Child and Adolescent Development for Educators*, 3rd ed. New York: Guilford Press.

Ranney, M., with T. Shimoda. 1999. "Education." In *The MIT Encyclopedia of the Cognitive Sciences*, ed. R. A. Wilson and F. C. Keil. Cambridge, MA: MIT Press.

Reif, F. 2008. *Applying Cognitive Science to Education: Thinking and Learning in Scientific and Other Complex Domains*. Cambridge, MA: MIT Press.

Ross, L., and R. E. Nisbett. 1991. *The Person and the Situation: Essential Contributions of Social Psychology*. Philadelphia, PA: Temple University Press.

Sawyer, R. K. 2006. *The Cambridge Handbook of the Learning Sciences*. Cambridge: Cambridge University Press.

Saxe, R., T. Tzelnic, and S. Carey. 2007. "Knowing Who-Dunnit: Infants Identify the Causal Agent in an Unseen Causal Interaction." *Developmental Psychology* 43 (1): 149-158.

Schulz, L. E., and A. Gopnik. 2004. "Causal Learning Across Domains." *Developmental Psychology* 40 (2): 162-176.

Smith, C., G. Solomon, and S. Carey. 2005. "Never Getting to Zero: Elementary School Students' Understanding of the Infinite Divisibility of Number and Matter." *Cognitive Psychology* 51 (2): 101-140.

Smith, E. E., and S. M. Kosslyn. 2006. *Cognitive Psychology: Mind and Brain*. Upper Saddle River, NJ: Pearson Prentice Hall.

Son, L. K., and A. Vandierendonck, eds. 2007. *Bridging Cognitive Science and Education: Learning, Memory, and Metacognition*, Special issue of *The European Journal of Cognitive Psychology, Psychology Press*.

Steele, C. M., and J. A. Aronson. 2004. "Stereotype Threat does not Live by Steele and Aronson Alone." *American Psychologist* 59 (1): 47-48.

Steele, C. M., S. J. Spencer, and J. Aronson. 2002. "Contending with Group Image: The Psychology of Stereotype and Social Identity Threat." In *Advances in Experimental Social Psychology,* ed. M. P. Zanna, 379-440. Vol. 34. San Diego, CA: Academic Press.
Steele, C. M. 2002. "Kenneth Clark's Context and Mine: Toward a Context Based Theory of Social Identity Threat." In *Race and Identity: Perspectives on American Society*, ed. G. Philogene. American Psychological Association.
Sternberg, R. J., J. C. Kaufman, and E. Grigorenko. 2008. *Applied Intelligence*. New York: Cambridge University Press.
Sternberg, R. J. 1997. *Thinking Styles*. Cambridge: Cambridge University Press.
van den Broek, P., R. F. Lorch, Jr., T. Linderholm, and M. Gustafson. 2001. "The Effects of Readers' Goals on Inference Generation and Memory for Texts." *Memory and Cognition* 29 (8): 1081-1087.
van den Broek, P., and K. Kremer. 2000. "The Mind in Action: What It Means to Comprehend." In *Reading for Meaning*, ed. B. Taylor, P. van den Broek, and M. Graves, 1-31. New York: Teacher's College Press.
van den Broek, P., M. Young, Y. Tzeng, and T. Linderholm. 1999. "The Landscape Model of Reading: Inferences and the On-Line Construction of a Memory Representation." In *The Construction of Mental Representations during Reading*, ed. H. van Oostendorp and S. R. Goldman, 71-98. Mahwah, NJ: Erlbaum.
White, J. 2002. *The Child's Mind: An Introduction to the Philosophy and Theory of Education*. New York: RoutledgeFalmer.

## EDUCATIONAL PHILOSOPHY AND POLICY

Callan, E. 1997. *Creating Citizens: Political Education and Liberal Democracy*. Oxford: Oxford University Press.
Callan, E. 1988. *Autonomy and Schooling*. Kingston, Ont.: McGill Queen's University Press.
Cooper, B. S., J. G. Cibulka, and L. D. Fusarelli, eds. 2008. *Handbook of Education Politics and Policy*. New York: Routledge.
Featherman, D. L. and M. A. Vinovskis, eds. 2001. *Social Science and Policymaking: A Search for Relevance in the Twentieth Century*. Ann Arbor, MI: University of Michigan Press.
Goldman, A. 1999. "Why Citizens Should Vote: A Causal Responsibility Approach." *Social Philosophy and Policy* 16 (2): 201-217.
Hanushek, E., and F. Welch. 2006. *Handbook on the Economics of Education*. Amsterdam: North-Holland.
Murphy, M., ed. 2005. *The History and Philosophy of Education: Voices of Educational Pioneers*. Saddle River, NJ: Pearson Prentice Hall.
Noddings, N. 2006. *Philosophy of Education*, 2nd ed. Boulder, CO: Westview.

Scheffler, I. 1991. *In Praise of the Cognitive Emotions and Other Essays in the Philosophy of Education*. New York: Routledge.

Sizer, T., with N. Sizer. 1999. *The Students Are Watching: Schools and the Moral Contract*. Boston: Beacon Press.

Sizer, T. 1996. *Horace's Hope: What Works for the American High School*. New York: Houghton Mifflin.

Yankelovich, D. 1991. *Coming to Public Judgment: Making Democracy Work in a Complex World*. Syracuse, NY: Syracuse University Press.

Winch, C., and J. Gingell. 1999. *Key Concepts in the Philosophy of Education*. London: Routledge.

## LOGIC, ARGUMENTATION, AND RHETORIC

Besnard, P., and A. Hunter. 2008. *Elements of Argumentation*. Cambridge, MA: MIT Press.

Christensen, D. 2004. *Putting Logic in its Place: Formal Constraints on Rational Belief*. Oxford: Oxford University Press.

Crosswhite, J. 1996. *The Rhetoric of Reason: Writing and the Attractions of Argument*. Madison, WI: University of Wisconsin Press.

Crusius, T. W., and C. E. Channell. 2008. *The Aims of Argument: A Text and Reader*, 6th ed. New York: McGraw Hill.

Damer, T. E. 2000. *Attacking Faulty Reasoning: A Practical Guide to Fallacy-Free Arguments*, 4th ed. Belmont, CA: Wadsworth Publishing.

Das, S. 2008. *Foundations of Decision-Making Agents: Logic, Probability and Modality*. Singapore: World Scientific Publishing Co.

Fisher, A. 2004. *The Logic of Real Arguments*, 2nd ed. Cambridge: Cambridge University Press.

Freeley, A. J., and D. L. Steinberg. 2005. *Argumentation and Debate: Critical Thinking for Reasoned Decision Making*, 11th ed. Belmont, CA: Wadsworth Cengage Learning.

Herrick, J. A. 2007. *Argumentation: Understanding and Shaping Arguments*, 3rd ed. University Park, PA: Strata Publications.

Hurley, P. 2005. *A Concise Introduction to Logic*, 9th ed. Belmont, CA: Wadsworth Publishing Company.

Kahane, H., and N. Cavender. 2005. *Logic and Contemporary Rhetoric,* 10th ed., Belmont, CA: Wadsworth Publishing Co.

Maher, P. 2006. "A Conception of Inductive Logic." *Philosophy of Science* 73: 513-523.

Olmsted, W. 2006. *Rhetoric: An Historical Introduction*. Malden, MA: Blackwell Publishing Ltd.

Perelman, C. 1982. *The Realm of Rhetoric*. Notre Dame, IN: University of Notre Dame Press.

Perelman, C., and L. Olbrechts-Tyteca. 1969. *The New Rhetoric: A Treatise on Argumentation*. Notre Dame, IN: University of Notre Dame Press.

Ronald, K., and J. S. Ritchie, eds. 2006. *Teaching Rhetorica: Theory, Pedagogy, Practice*. Portsmouth, NH: Boynton/Cook Publishers.

Rybacki, K. C., and D. J. Rybacki. 2008. *Advocacy and Opposition: An Introduction to Argumentation*, 6th ed. Boston: Pearson Allyn and Bacon.

Saindon, J. E. 2007. *Argument and Argumentation*. Toronto: Thomson Nelson.

Tindale, C. W. 2007. *Fallacies and Argument Appraisal*. Cambridge: Cambridge University Press.

Tindale, C. W. 2004. *Rhetorical Argumentation: Principles of Theory of Practice*. Thousand Oaks: Sage Publications.

Toulmin, S. E. 2003. *The Uses of Argument*, updated ed. Cambridge: Cambridge University Press.

van Eemeren, F. H., and R. Grootendorst. 2004. *A Systematic Theory of Argumentation: The Pragma-Dialectical Approach*. Cambridge: Cambridge University Press.

Walton, D. N. 2008. *Informal Logic: A Pragmatic Approach*, 2nd ed. Cambridge: Cambridge University Press.

Walton, D. N. 2006. *Fundamentals of Critical Argumentation*. Critical Reasoning and Argumentation. Cambridge: Cambridge University Press.

Weston, A. 2000. *A Rulebook for Arguments*, 3rd ed. Indianapolis, IN: Hackett Publishing Co.

Wood, N. V. 2008. *Essentials of Argument*, 2nd ed. Englewood Cliffs, NJ: Prentice Hall.

## PHILOSOPHY OF SCIENCE

Boyd, R., P. Gasper, and J. D. Trout, eds. 1993. *The Philosophy of Science*. Cambridge, MA: MIT Press.

Cartwright, N., J. Cat, H. Chang, L. Fleck, and T. Uebel. 1996. *Otto Neurath: Philosophy Between Science and Politics*. Cambridge: Cambridge University Press.

Chalmers, A. F. 1999. *What Is This Thing Called Science?* 3rd ed. Maidenhead, UK: Open University Press.

Collins, J., N. Hall, and L. A. Paul, eds. 2004. *Causation and Counterfactuals*. Cambridge, MA: MIT Press.

Cover, J. A., and M. Curd, eds. 1998. *Philosophy of Science: The Central Issues*. New York: W. W. Norton & Company.

Giere, R., and A. Richardson, eds. 1996. *Origins of Logical Empiricism*. Minnesota Studies in the Philosophy of Science, Vol. XVI. Minneapolis, MN: University of Minnesota Press.

Giere, R. 1988. *Explaining Science: A Cognitive Approach*. Chicago: University of Chicago Press.

Godfrey-Smith, P. 2003. *Theory and Reality: An Introduction to the Philosophy of Science*. Chicago: University of Chicago Press.

Goldman, A. 1992. *Liaisons: Philosophy Meets the Cognitive and Social Sciences*. Cambridge, MA: MIT Press.

Goldman, A. 1993. *Philosophical Applications of Cognitive Science*. Boulder, CO: Westview.

Harding, S., ed. 1975. *Can Theories Be Refuted?: Essays on the Duhem-Quine Thesis*. Synthese Library. Dordrecht, Holland: D. Reidel Publishing Co.

Hesse, M. B. 1980. *Revolutions and Reconstructions in the Philosophy of Science*. Bloomington, IN: Indiana University Press.

Kitcher, P. 2001. *Science, Truth, and Democracy*. Oxford: Oxford University Press.

Kitcher, P. 1993. *The Advancement of Science: Science without Legend, Objectivity without Illusion*. Oxford: Oxford University Press.

Kitcher, P. 1982. *Abusing Science: The Case Against Creationism*. Cambridge, MA: MIT Press.

Lange, M., ed. 2007. *Philosophy of Science: An Anthology*. Blackwell Philosophy Anthologies, 25. Malden, MA: Blackwell Publishing.

Mosedale, F. E., ed. 1979. *Philosophy and Science: The Wide Range of Interaction*. Englewood Cliffs, NJ: Prentice Hall.

Nelson, L. H. 1990. *Who Knows: From Quine to Feminist Empiricism*. Philadelphia, PA: Temple University Press.

Okasha, S. 2002. *Philosophy of Science: A Very Short Introduction*. Oxford: Oxford University Press.

O'Hear, A., ed. 2007. *Philosophy of Science*. Royal Institute of Philosophy Supplement, 61. Cambridge: Cambridge University Press.

Popper, K. 1972. *Objective Knowledge*. Oxford: Oxford University Press.

Popper, K. 1963. *Conjectures and Refutations*. London: Routledge.

Psillos, S. 2007. *Philosophy of Science A-Z*. Philosophy A-Z series. Edinburgh: Edinburgh University Press.

Rosenberg, A. 2000. *The Philosophy of Science: A Contemporary Introduction*. London: Routledge.

Sokal, A. 2008. *Beyond the Hoax: Science, Philosophy, and Culture*. Oxford: Oxford University Press.

Strahler, A. N. 1992. *Understanding Science: An Introduction to Concepts and Issues*. Buffalo, NY: Prometheus Books.

## PSEUDOSCIENCE

Crossen, C. 1994. *Tainted Truth: The Manipulation of Fact in America*. New York: Touchstone.

Friedlander, M. W. 1998. *At the Fringes of Science*. Boulder, CO: Westview Press.

Gilovich, T. 1991. *How We Know What Isn't So: The Fallibility of Human Reason in Everyday Life*. New York: Free Press.

Hamblin, C. L. 1970. *Fallacies*. London: Methuen.

Humphrey, N. 1999. *Leaps of Faith: Science, Miracles, and the Search for Supernatural Consolation*. New York: Copernicus.

Lawson, T. J. 2007. *Scientific Perspectives on Pseudoscience and the Paranormal: Readings for General Psychology*. Upper Saddle River, NJ: Pearson Prentice Hall.

Rasmussen, S. C. 2007. "The History of Science as a Tool to Identify and Confront Pseudoscience." *Journal of Chemical Education* 84 (6): 949-951.

Rothman, M. A. 1988. *A Physicist's Guide to Skepticism: Applying Laws of Physics to Faster-than-Light Travel, Psychic Phenomena, Telepathy, Time Travel, UFO's, and Other Pseudoscientific Claims*. Buffalo, NY: Prometheus Books.

Schick, Jr., T., and L. Vaughn. 2008. *How to Think about Weird Things: Critical Thinking for a New Age*, 5th ed. Boston: McGraw Hill.

Shermer, M. 2003. *How We Believe: Science, Skepticism, and the Search for God*, 2nd ed. New York: Henry Holt.

Shermer, M. 2002. *Why People Believe Weird Things: Pseudoscience, Superstition, and Other Confusions of Our Time,* rev. and exp. ed. New York: Henry Holt.

Shermer, M. 2001. *The Borderlands of Science: Where Sense Meets Nonsense*. Oxford: Oxford University Press.

## REASONING

Adler, J. E., and L. J. Rips, eds. 2008. *Reasoning: Studies of Human Inference and Its Foundations*. Cambridge: Cambridge University Press.

Feeney, A., and E. Heit. 2007. *Inductive Reasoning: Experimental, Developmental, and Computational Approaches*. Cambridge: Cambridge University Press.

Kelley, D. 1998. *The Art of Reasoning,* 3rd ed. New York: W. W. Norton.

Lakoff, G. and M. Johnson. 1980. *Metaphors We Live By*. Chicago: University of Chicago Press.

Nisbett, R. E., K. Peng, I. Choi, and A. Norenzayan. 2001. "Culture and Systems of Thought: Holistic vs. Analytic Cognition." *Psychological Review* (108): 291-310.

Nisbett, R. E., ed. 1993. *Rules for Reasoning*. Hillsdale, NJ: Lawrence Erlbaum.

Norenzayan, A., E. E. Smith, B. J. Kim, R. E. Nisbett. 2002. "Cultural Preferences for Formal Versus Intuitive Reasoning." *Cognitive Science* (26): 653-684.

Peng, K. and R. E. Nisbett. 1999. "Culture, Dialecticism, and Reasoning about Contradiction." *American Psychologist* (54): 741-754.

Thomson, A. 2008. *Critical Reasoning: A Practical Introduction*, 3rd ed. London: Routledge.

Toulmin, S. E., R. Rieke, and A. Janik. 1984. *Introduction to Reasoning*, 2nd ed. New York: Macmillan.

Choi, I., R. E. Nisbett, and A. Norenzayan. 1999. "Causal Attribution Across Cultures: Variation and Universality." *Psychological Bulletin* (125): 47-63.

Dörner, D. 1996. *The Logic of Failure: Recognizing and Avoiding Error in Complex Situations*. New York: Metropolitan Books.

Feltovich, P. J., R. J. Spiro, and R. L. Coulson. 1993. "Learning, Teaching, and Testing for Complex Conceptual Understanding." In *Test Theory for a New Generation of Tests,* ed. N. Frederiksen, R. Mislevy, and I. Bejar, 181-217. Hillsdale, NJ: Erlbaum.

Fischhoff, B. 1975. "Hindsight = Foresight: The Effect of Outcome Knowledge on Judgment under Uncertainty." *Journal of Experimental Psychology: Human Perception and Performance* 1 (3): 288-299.

Grotzer, T. A. 2003. "Learning to Understand the Forms of Causality Implicit in Scientific Explanations." *Studies in Science Education* 39: 1-74.

Grotzer, T. A. 2002. *Causal Patterns in Ecosystems*. Cambridge, MA: Project Zero, Harvard Graduate School of Education.

Kahneman, D., P. Slovic, and A. Tversky, eds. 1982. *Judgment under Uncertainty: Heuristics and Biases*. Cambridge: Cambridge University Press.

Kahneman, D. and A. Tversky. 1979. "Prospect Theory: An Analysis of Decision under Risk." *Econometrica* 47 (2): 263-291.

Koslowski, B. 1996. "Disconfirming and Anomalous Evidence," 49-86, and "General Summary and Conclusions," 251-282. *Theory and Evidence*. Cambridge, MA: MIT Press.

Maher, P. 2006. "Confirmation Theory." In *Encyclopedia of Philosophy,* ed. Donald M. Borchert, 2nd ed. New York: Macmillan.

Ranney, M., with E. Munnich et al. 2003. "Policy Shift through Numerically-Driven Inferencing: An EPIC Experiment about When Base Rates Matter." In *Proceedings of the 25th Annual Conference of the Cognitive Science Society, 2003*, ed. R. Alterman and D. Kirsh. Boston, MA: Cognitive Science Society.

Slovic, P. 2000. *The Perception of Risk*. London: Earthscan Publications.

Sunstein, C. R. 2002. "Thinking about Risks." In *Risk And Reason: Safety, Law, And The Environment*, 28-52. Cambridge: Cambridge University Press.

## SCIENCE AND SOCIETY

Bauchspies, W. K., J. Croissant, S. Restivo, and J. Gregory. 2007. "Science, Technology, and Society: A Sociological Approach." *Isis* 98 (4): 882.

Bulger, R. E., E. M. Bobby, and H. V. Fineberg, eds. 1995. *Society's Choices: Social and Ethical Decision Making in Biomedicine*. Committee on the Social and Ethical Impacts of Developments in Biomedicine, Division of Health Sciences Policy, Institute of Medicine. Washington, DC: National Academy Press.

Cozzens, S. E., and T. F. Gieryn. 1990. *Theories of Science in Society*. Bloomington, IN: Indiana University Press.
Ede, A., and L. B. Cormack. 2004. *A History of Science in Society: From Philosophy to Utility*. Peterborough, Ont.: Broadview Press.
Fuller, S. 2002. *Social Epistemology*, 2nd ed. Bloomington, IN: Indiana University Press.
Gieryn, T. F. 1999. *Cultural Boundaries of Science: Credibility on the Line*. Chicago: University of Chicago Press.
Goldman, A. 1999. *Knowledge in a Social World*. Oxford: Oxford University Press.
Goldman, A. 1987. "The Foundations of Social Epistemics." *Synthese* 73 (1): 109-144.
Graham, L. R. 1983. *Between Science and Values*. New York: Columbia University Press.
Gregory, J., and S. Miller. 1998. *Science in Public: Communication, Culture, and Credibility*. New York: Plenum Trade.
Haack, S. 1996. "Science as Social: Yes and No." In *Feminism, Science, and the Philosophy of Science*, ed. L. H. Nelson and J. Nelson, 79-94. Dordrecht, Holland: Kluwer Academic Publishers.
Hardwig, J. 1988. "Evidence, Testimony, and the Problem of Individualism." *Social Epistemology* 2 (4): 309-321.
Hardwig, J. 1985. "Epistemic Dependence." *Journal of Philosophy* 82 (7): 335-349.
Irwin, A., and M. Michael. 2003. *Science, Social Theory and Public Knowledge*. Maidenhead, UK: Open University Press.
Irwin, A., and B. Wynne. 1996. *Misunderstanding Science? The Public Reconstruction of Science and Technology*. Cambridge: Cambridge University Press.
Jasanoff, S. 1997. "Civilization and Madness: The Great BSE Scare of 1996." *Public Understanding of Science* 6 (3): 221-232.
Kitcher, P. 1996. *The Lives to Come: The Genetic Revolution and Human Possibilities*. New York: Simon & Schuster.
Komesaroff, P. A. 1986. *Objectivity, Science and Society: Interpreting Nature and Society in the Age of the Crisis of Science*. London: Routledge and Kegan Paul.
Petto, A. J., and L. R. Godfrey. 2007. *Scientists Confront Intelligent Design and Creationism*. New York: W.W. Norton & Company.
Polanyi, M. 1964. *Science, Faith, and Society*. Chicago: University of Chicago Press.
Porter, T. M. 1995. *Trust in Numbers: The Pursuit Of Objectivity in Science and Public Life*. Princeton: Princeton University Press.
Rouse, J. 1987. *Knowledge and Power: Toward a Political Philosophy of Science*. Ithaca, NY: Cornell University Press.
Solomon, M. 2001. *Social Empiricism*. Cambridge, MA: MIT Press.

Stotz, K., and P. E. Griffiths. 2008. "Biohumanities: Rethinking the Relationship between Biosciences, Philosophy and History of Science, and Society." *Quarterly Review of Biology* 83 (1): 37-45.

Thurs, D. P. 2007. *Science Talk: Changing Notions of Science in American Popular Culture*. Piscataway, NJ: Rutgers University Press.

Zehr, S. 1999. "Scientists' Representation of Uncertainty." In *Communicating Uncertainty: Media Coverage of New and Controversial Science*, ed. S. M. Friedman, S. Dunwoody, and C. L. Rogers, 3-21. Mahwah, NJ: Lawrence Erlbaum Associates.

### SCIENCE EDUCATION

American Association for the Advancement of Science: Project 2061. 1993. *Benchmarks for Science Literacy*. New York: Oxford University Press.

Ayers, J. M., and K. M. Ayers. 2007. "Teaching the Scientific Method: It's All in the Perspective." *American Biology Teacher* 69 (1): 19-23.

Brem, S. K., M. Ranney, and J. E. Schindel. 2003. "The Perceived Consequences of Evolution: College Students Perceive Negative Personal and Social Impact in Evolutionary Theory." *Science Education* 87 (2): 181-206.

Carey, S. 2000. "Science Education as Conceptual Change." *Journal of Applied Developmental Psychology* 21: 13-19.

Chinn, C. A. and C. C. Hung. April 13, 2007. "Learning to Reason about the Methodology of Scientific Studies: A Classroom Experiment in the Middle School." Paper presented at the American Educational Research Association (AERA) Conference, Chicago, IL.

Erduran, S., and M. Jimenez-Aleixandre. 2008. *Argumentation in Science Education Perspectives from Classroom-Based Research*. Science & Technology Education Library, v. 35. Dordrecht, Holland: Springer.

Evans, E. M. 2006. "Teaching and Learning about Evolution." In *The Virus and the Whale: Explore Evolution in Creatures Small and Large*, ed. J. Diamond. Arlington, VA: NSTA Press.

Flick, L. B. and N. G. Lederman, eds. 2006. *Scientific Inquiry and Nature of Science: Implications for Teaching, Learning, and Teacher Education*. Dordrecht, Holland: Springer.

Gallagher, J. J. 2007. *Teaching Science for Understanding: A Practical Guide for Middle and High School Teachers*. Upper Saddle River, NJ: Pearson Merrill Prentice Hall.

Grotzer, T. A. 2004. "Putting Everyday Science within Reach: Addressing Patterns of Thinking that Limit Science Learning." *Principal Leadership*: 16-21.

Lavoie, D. R, ed. 1995. *Toward a Cognitive-Science Perspective for Scientific Problem Solving*. NARST Monograph Number Six. Columbus, OH: National Association for Research in Science Teaching.

National Committee on Science Education Standards and Assessment, National Research Council. 1996. *National Science Education Standards*. Washington, DC: National Academy Press.

Perkins, D. N. and T. A. Grotzer. 2005. "Dimensions of Causal Understanding: The Role of Complex Causal Models in Students' Understanding of Science." *Studies in Science Education* 41: 117-166.

Pierce, C. T. 2007. *Democratizing Science and Technology Education: Perspectives from the Philosophy of Education*. Ph.D. Thesis, UCLA.

Ranney, M., J. Gutwill, and J. Frederiksen. 1996. "Seeking the Causal Connection in Electricity: Shifting among Mechanistic Perspectives." *International Journal of Science Education* 18 (2): 143-162.

Reiser, B. J., and B. K. Smith. 2005. "Explaining Behavior through Observational Investigation and Theory Articulation." *Journal of the Learning Sciences* 14 (3): 315-360.

Reiser, B. J., B. Loh, J. Radinsky, D. C. Edelson, L. M. Gomez and S. Marshall. 2001. "Developing Reflective Inquiry Practices: A Case Study of Software, the Teacher, and Students." In *Designing for Science: Implications from Everyday, Classroom, and Professional Settings*, ed. K. Crowley, C.D. Schunn, and T. Okada, 279-323. Mahwah, NJ: Erlbaum.

Reiser, B. J., I. Tabak, W. A. Sandoval, B. K. Smith, F. Steinmuller, and A. J. Leone. 2001. "BGuILE: Strategic and Conceptual Scaffolds for Scientific Inquiry in Biology Classrooms." *Cognition and Instruction: Twenty-Five Years of Progress*, ed. S. M Carver and D. Klahr, 263-305. Mahwah, NJ: Erlbaum.

Rudolph, J. L. 2005. "Epistemology for the Masses: The Origins of 'the Scientific Method' in American Schools." *History of Education Quarterly* 45: 341-376.

Taylor, R. S. 2008 (forthcoming). *Understanding the Evolution vs. Intelligent Design Controversy: Epistemology and Science Education*. London: Routledge.

Tobias, S. 1992. *Revitalizing Undergraduate Science: Why Some Things Work and Most Don't*. Tucson, AZ: Research Corp.

Tobias, S. 1990. *They're Not Dumb, They're Different: Stalking The Second Tier*. Tucson, AZ: Research Corp.

## SCIENTIFIC METHODS

Achinstein, P., ed. 2004. *Science Rules: A Historical Introduction to Scientific Methods*. Baltimore, MD: Johns Hopkins University Press.

Bauer, H. 1992. "How Science Really Works" and "Other Fables about Science." *Scientific Literacy and The Myth Of The Scientific Method*, 42-87. Urbana, IL: University of Illinois Press.

Carey, S. S. 2004. *A Beginner's Guide to Scientific Method,* 3rd ed. Belmont, CA: Wadsworth Publishing Company.

Derry, G. N. 1999. *What Science Is and How It Works*. Princeton: Princeton University Press.

Frank, P. 1956. *The Validation of Scientific Theories*. Boston: Beacon Press.
Giere, R. N. 2006. *Understanding Scientific Reasoning*, 5th ed. Belmont, CA: Wadsworth Publishing Company.
Gower, B. 1996. *Scientific Method: A Historical and Philosophical Introduction*. London: Routledge.
Nola, R., and H. Sankey. 2007. *Theories of Scientific Method: An Introduction*. Montréal: McGill-Queen's University Press.
Shapin, S. 2008. *The Scientific Life: A Moral History of a Late Modern Vocation*. Chicago: University of Chicago Press.
Wilson, E. B. 1991. *An Introduction to Scientific Research*, rev. sub ed. New York: Dover Publications.

## SCIENTIFIC THINKING AND REASONING

Chinn, C. A., and W. Brewer. 2000. "Knowledge Change in Response to Data in Science, Religion, and Magic." In *Imagining the Impossible: Magical, Scientific, and Religious Thinking in Children*, ed. K. S. Rosengren, C. N. Johnson, and P. L. Harris, 334-371. Cambridge: Cambridge University Press.
Dunbar, K., and J. Fugelsang. 2005. "Causal Thinking in Science: How Scientists and Students Interpret the Unexpected." In *Scientific and Technological Thinking*, ed. M. E. Gorman, R. D. Tweney, D. Gooding, and A. Kincannon, 57-80. Mahwah, NJ: Lawrence Erlbaum Associates.
Dunbar, K., and J. Fugelsang. 2005. "Scientific Thinking and Reasoning." In *Cambridge Handbook of Thinking & Reasoning*, ed. K. J. Holyoak and R. Morrison, 705-726. Cambridge: Cambridge University Press.
Kuhn, D., E. Amsel, and M. O'Loughlin. 1988. "Summary and Conclusions," *The Development of Scientific Thinking Skills*, 219-235. San Diego, CA: Academic Press.
Ranney, M., and P. Schank. 1998. "Toward an Integration of the Social and Scientific: Observing, Modeling, and Promoting the Explanatory Coherence of Reasoning." In *Connectionist and PDP Models of Social Reasoning*, S. J. Read and L. C. Miller, eds. Mahwah, NJ: Lawrence Erlbaum.
Rosengren, K., C. Johnson, and P. L. Harris, ed. 2000. *Imagining The Impossible: Magical, Scientific, And Religious Thinking In Children*. Cambridge: Cambridge University Press.
Solomon, M. 1992. "Scientific Rationality and Human Reasoning." *Philosophy of Science* 59 (3): 439-455.
Stadler, F., ed. 2004. *Induction and Deduction in the Sciences*. Dordrecht, Holland: Kluwer Academic Publishers.

## TEACHING AND LEARNING

Ackoff, R. L., and D. A. Greenberg. 2008. *Turning Learning Right Side Up: Putting Education Back on Track*. Upper Saddle River, NJ: Wharton School Publishing.

Cross, K. P., and M. H. Steadman. 1996. *Classroom Research: Implementing the Scholarship of Teaching*. San Francisco, CA: Jossey-Bass.
Graham, P. A. Fall 1995. "Battleships and Schools." *Daedalus* 124 (4): 43-46.
Lave, J., and E. Wenger. 1991. *Situated Learning: Legitimate Peripheral Participation*. Cambridge: Cambridge University Press.
Lepper, M. R., M. Drake, and T. M. O'Donnell-Johnson. 1997. "Scaffolding Techniques of Expert Human Tutors." In *Scaffolding Student Learning: Instructional Approaches and Issues,* ed. K. Hogan and M. Pressley, 108-144. Cambridge, MA: Brookline Books.
Meyer, J. H. F., and R. Land, eds. 2006. *Overcoming Barriers to Student Understanding: Threshold Concepts and Troublesome Knowledge*. London: Routledge.
Perkins, D. N., and G. Salomon. 1988. "Teaching for Transfer." *Educational Leadership* 46 (1): 22-32.
Raudenbush, S. W., and J. D. Willms. 1991. *Pupils, Classrooms, and Schools: International Studies of Schooling from a Multilevel Perspective*. San Diego, CA: Academic Press.
Reiser, B. J. 2004. "Scaffolding Complex Learning: The Mechanisms of Structuring and Problematizing Student Work." *Journal of the Learning Sciences* 13 (3): 273-304.
Salili, F., and R. Hoosain, eds. 2007. *Culture, Motivation, and Learning: A Multicultural Perspective*. Research in Multicultural Education and International Perspective. Charlotte, NC: IAP.
Shulman, L. 2004. *The Wisdom of Practice: Essays on Teaching, Learning and Learning to Teach*. San Francisco, CA: Jossey-Bass.
Stevenson, H. W., and J. W. Stigler. 1992. *The Learning Gap: Why Our Schools Are Failing and What We Can Learn from Japanese and Chinese Education*. New York: Summit Books.
Strike, K. A., and G. J. Posner. 1985. "A Conceptual Change View of Learning and Understanding." In *Cognitive Structure and Conceptual Change*, ed. L. H. T. West and A. L. Pines, 211-231. New York: Academic Press.
Wagner, T. 2008. *The Global Achievement Gap: Why Even Our Best Schools Don't Teach the New Survival Skills Our Children Need—And What We Can Do About It*. New York: Basic Books.

## TEACHING REASONING AND CRITICAL THINKING

Anderson, H. K., and D. Weil, eds. 2000. *Perspectives in Critical Thinking: Essays by Teachers in Theory and Practice*. New York: Peter Lang.
Bailey, R. 1995. *Critical Thinking Skills: Language Arts*. Torrance, CA: Frank Schaffer Publications.
Bean, J. C. 1996. *Engaging Ideas: The Professor's Guide to Writing, Critical Thinking, and Active Learning in the Classroom*. San Francisco, CA: Jossey-Bass.
Brookfield, S. 1987. *Developing Critical Thinkers*. San Francisco, CA: Jossey-Bass.

De Bono, E. 1976. *Teaching Thinking*. London: Temple Smith.

Dill, B. 1995. *Critical Thinking Skills: Social Studies*. Torrance, CA: Frank Schaffer Publications.

Facione, P. A. 1990. *Critical Thinking: A Statement of Expert Consensus for Purposes of Educational Assessment and Instruction*. Millbrae, CA: California Academic Press.

Gunning, T. G. 2008. *Developing Higher-Level Literacy in All Students: Building Reading, Reasoning, and Responding*. Boston: Pearson Allyn and Bacon.

Hakes, B. 2008. *When Critical Thinking Met English Literature: A Resource Book for Teachers and Their Students*. Oxford: How To Books.

Halpern, D. F. 1997. *Critical Thinking Across the Curriculum: A Brief Edition of Thought and Knowledge*. Mahwah, NJ: Lawrence Erlbaum Associates.

Kurfiss, J. G. 1988. *Critical Thinking: Theory, Research, Practice and Possibilities*, ASHE-ERIC Higher Education Report No. 2. College Station, TX: Association for the Study of Higher Education.

Mason, M., ed. 2007. Critical Thinking and Learning: Special Issue of *Educational Philosophy and Theory* 39 (4): 375-474.

Nelson, J. 2005. *Cultivating Judgment: A Sourcebook for Teaching Critical Thinking Across the Curriculum*. Stillwater, OK: New Forums Press.

Nelson, J. 2002. *Cultivating Judgment: A Sourcebook for Teaching Critical Thinking in Community Colleges*. Danvers: North Shore Community College.

Nickerson, R., D. Perkins, and E. Smith. 1985. *The Teaching of Thinking*. Hillsdale, NJ: Erlbaum Associates.

Nosich, G. M. 2008. *Learning to Think Things Through: A Guide to Critical Thinking Across the Curriculum*, 3rd ed. Upper Saddle River, NJ: Prentice Hall.

O'Donnell, P. S. Spring 2006. "Collective Self-Examination: Thinking Critically about Critical Thinking." *Radical Pedagogy* 8: 1.

Olson, I. 2000. *The Arts and Critical Thinking in American Education*. Westport, CT: Bergin & Garvey.

Paul, R. W. 1995. *Critical Thinking: How to Prepare Students for a Rapidly Changing World*. Foundation for Critical Thinking, http://www.criticalthinking.org/.

Perkins, D. N., E. Jay, and S. Tishman. 1994. "Assessing Thinking: A Framework for Measuring Critical Thinking and Problem Solving at the College Level." In *The National Assessment of College Student Learning: Identification of the Skills to be Taught, Learned, and Assessed,* ed. A. Greenwood, 65-112. Washington, DC: The US Government Printing Office.

Perkins, D. N., E. Jay, and S. Tishman. 1993. "Teaching Thinking: From Ontology to Education." *Educational Psychologist* 28 (1): 67-85.

Perkins, D. N., with R. Swartz. 1989. *Teaching Thinking: Issues and Approaches*. Pacific Grove, CA: Midwest Publications.

Pluta, W. J., and C. A. Chinn. April 13, 2007. "Making Sense of Conflicting Studies: Can Students Build Complex Evidence-Based Models?" Paper presented at the American Educational Research Association (AERA) Conference, Chicago, IL.

Scheffler, I. 1973. *Reason and Teaching*. Indianapolis, IN: Bobbs-Merrill.

Semali, L., and A. W. Pailliotet. 1999. *Intermediality: The Teachers' Handbook of Critical Media Literacy*. Boulder, CO: Westview Press.

Seymour, D., and E. Beardslee. 1990. *Critical Thinking Activities for Grades K-3*. Palo Alto, CA: Dale Seymour Publications.

Swartz, R. J., S. Fischer, and S. Parks. 1998. *Infusing the Teaching of Critical and Creative Thinking into Secondary Science: A Lesson Design Handbook*. Pacific Grove, CA: Critical Thinking Press and Software.

Swartz, R. J., and S. Parks. 1994. *Infusing the Teaching Of Critical And Creative Thinking into Content Instruction: A Lesson Design Handbook for the Elementary Grades*. Pacific Grove, CA: Critical Thinking Press and Software.

Teays, W. 1996. *Second Thoughts: Critical Thinking from a Multicultural Perspective*. Mountain View, CA: Mayfield Pub. Co.

Tishman, S., D. N. Perkins, and E. Jay. 1995. *The Thinking Classroom: Learning and Teaching in a Culture of Thinking*. Boston: Allyn and Bacon.

## TECHNOLOGY AND EDUCATION

Goldin, C. D., and L. F. Katz. 2008. *The Race between Education and Technology*. Cambridge, MA: Belknap Press of Harvard University Press.

Grotzer, T. A. 2002. "Expanding our Vision for Educational Technology: Procedural, Conceptual, and Structural Knowledge." *Educational Technology* 42 (2): 52-59.

Harwood, P. G., and V. Asal. 2007. *Educating the First Digital Generation*. Westport, CT: Praeger.

Kritt, D. W., and L. T. Winegar, eds. 2007. *Education and Technology: Critical Perspectives, Possible Futures*. Lanham, MD: Lexington Books.

Palfrey, J., and U. Gasser. 2008. *Born Digital: Understanding the First Generation of Digital Natives*. New York: Basic Books.

Pea, R., M. Mills, and L. Takeuchi, eds. 2004. Making SENS: Science Education Networks of Sensors. Report from an OMRON-sponsored Workshop of the Media-X Program at Stanford University, October 3, 2003. Stanford, CA: Stanford Center for Innovations in Learning, http://makingsens.stanford.edu/.

Pea, R. D., and K. S. Sheingold, eds. 1987. *Mirrors of Minds: Patterns of Experience in Educational Computing*. New York: Ablex Publishing.

Roschelle, J., R. Pea, C. Hoadley, D. Gordin, and B. Means. 2001. "Changing How and What Children Learn in School with Computer-Based Technologies." *The Future of Children* 10 (2): 76-101.

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