

Integrating Philosophy into Learning Sciences Research on Epistemic Cognition

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Abstract: The purpose of this symposium is to provide a forum for exploring how contemporary developments in philosophy can enrich learning sciences research on epistemic cognition (EC). In three papers, we discuss ways in which research on epistemic cognition can profit greatly from closer attention to the philosophical literature. The first paper reviews a broad range of philosophical literature to identify philosophical topics and subtopics which are potentially relevant to research on epistemic cognition but which have not yet been much investigated by EC researchers. The second paper discusses implications of philosophical work for the assessment of epistemic cognition. The third paper discusses implications of recent philosophical work on underdetermination for both assessment and instruction in science education.

Rationale for the Symposium

There has been rapid growth in psychological and educational research on epistemic cognition (EC)—by which we refer to research on people’s cognitions related very broadly to knowledge and knowing, including research on learners’ personal epistemologies, epistemological beliefs, and their understanding of the nature of science. However, research on epistemic cognition has made relatively little contact with relevant scholarship in philosophy, particularly contemporary philosophy. We think that this lack of contact has had negative consequences for research on epistemic cognition, because the philosophical analyses provide many insights that can enrich EC research.

To determine the extent to which educators cite philosophical works, we examined 128 articles addressing EC in six major educational journals from 2004 through 2008 (*Journal of Educational Psychology*, *Contemporary Educational Psychology*, *Educational Psychologist*, *Science Education*, *Journal of Research in Science Teaching*, *Journal of the Learning Sciences*, and *Cognition and Instruction*). The modal number of philosophical citations was 0; the average was about 1. Even fewer of the citations referred to recent developments found in contemporary epistemology and philosophy of science. Contemporary philosophical research raises a variety of important issues and problems that are relevant for research on EC, but it appears to us that EC researchers have not yet much considered this body of philosophical work.

The purpose of this symposium is to explore how contemporary developments in philosophy can enrich learning sciences research on epistemic cognition. We present three papers that highlight a variety of ways in which EC research could be improved by drawing on insights from philosophy.

With its strong commitment to multidisciplinary and interdisciplinary research, the learning sciences are the field of educational research that should be at the forefront of bringing insights from philosophy into research on epistemic cognition. This ICLS symposium will provide a forum for presenting and discussing critical implications of contemporary philosophy (epistemology and the philosophy of science) for educational research. The symposium includes three presentations, each discussing distinct ways in which philosophical research can help learning sciences researchers expand and improve research relating to epistemic cognition. The discussant will be James Blachowicz, a philosopher, who will comment further on implications of philosophy for educational research.

We think that philosophical insights have the potential to transform EC research in at least four different ways. We describe each below.

1. Scope of Issues Addressed in Research on Epistemic Cognition

In the first paper, we argue that philosophers have discussed *many* epistemological issues that should be of interest to EC researchers but that EC researchers have seldom or never addressed. For example, philosophers ask manifold questions about social dimensions of knowledge and about reliable processes for producing knowledge (e.g., Goldman, 1986, 1999), but researchers have not addressed human cognitions related to these and many other topics. Thus, attention to philosophy can dramatically expand the scope of dimensions of issues that EC researchers address.

2. Conceptualization of Important Epistemic Constructs

On many EC topics, philosophical work provides insights into how important dimensions of epistemic cognition should be conceptualized or analyzed. For example, we argue in the second paper that philosophical work indicates that relativism should be defined differently from the way in which EC researchers have defined it, and—as a result—EC research falls short of providing adequate evidence for their claims that people in certain stages of epistemic development are relativists.

3. Formats for Assessments

Recent developments in contemporary epistemology have strong implications for the development of assessments of personal epistemology and understanding of the nature of science. Many EC researchers have employed interviews or questionnaires that ask students to reflect on fairly abstract statements (see Hofer & Pintrich, 2002). Recent philosophical work, including new trends in experimental philosophy, challenges the usefulness of such measures and argues for more contextualized approaches to assessment. These issues are a main focus of the second paper.

4. Goals for Instruction

The philosophical literature provides insights into new goals for instruction. For example, we note in the first paper that social epistemologists have discussed processes in the media that reliably produce true beliefs as well as processes that do not (e.g., Goldman, 1999). Given the importance of the media in influencing the formation of beliefs in a society, this suggests that understanding the “nature of media” is an important form of epistemological knowledge, one that has been little studied by educational researchers. As another example, the review in the third paper of the philosophical literature on underdetermination suggests new goals for science instruction that will provide science students with more powerful tools for resolving conflicts between competing knowledge claims.

Overview of Session

A central goal of the session is to provide a forum to begin discussing philosophical work relevant to the learning sciences and the implications of this work for research on epistemic cognition. Our hope is that greater contact between philosophy, psychology, and education will inspire psychological and educational research both on new topics and subtopics relevant to personal epistemologies as well as on new approaches to addressing some of the topics that have already been investigated. We believe that this symposium could help spur the initiation of productive new lines of research on epistemic cognition.

The session will begin with three presentations reviewing philosophical research with a focus on applications to educational issues. Clark Chinn will present findings from a very extensive review of the range of epistemological topics addressed in contemporary philosophical research. He shows that philosophers have discussed many topics that are highly relevant to EC research but that have so far been neglected in educational research. Luke Buckland will review the same corpus of philosophical books and journals with a focus on implications for assessments of personal epistemology and understanding of NOS. Ala Samarapungavan will review the philosophical literature on underdetermination and discuss critical implications for the design of science instruction as well as the design of instruments to measure students’ understanding of the nature of science. The discussant will be James Blachowicz, a philosopher of science at the University of Loyola in Chicago. He will discuss further philosophical issues that educators may want to consider, as well as comment on the issues discussed by the three presenters. The session will conclude with a period of time for extended, in-depth discussion with the audience about these interdisciplinary issues.

Papers

Paper 1: Broadening the Scope of Research on Epistemic Cognition: Implications from Epistemology and Philosophy of Science

Presenter: Clark A. Chinn, Rutgers University

Goals

This paper presents a review of important topics addressed in philosophical literatures in epistemology and philosophy of science. An important goal is to identify important epistemological topics that have heretofore been neglected by research on epistemic cognition (EC). Currently, many researchers have focused on the following components of epistemic cognition: the nature and structure of knowledge (including theories and laws or the complexity of knowledge), the certainty of knowledge, and the sources and justification of knowledge (e.g., Hofer &

Pintrich, 1997; Lederman et al., 1992). Philosophical scholarship suggests other components that should be considered as part of epistemic cognition, and we aim to identify some of these components.

Philosophical Works Reviewed

The review of philosophical work surveys two voluminous literatures that discuss epistemological topics: analytic epistemology and the philosophy of science. To identify epistemological topics of potential interest to EC researchers, we analyzed epistemological topics and subtopics covered in 8 recent handbooks and anthologies of epistemology and 8 recent handbooks and anthologies of philosophy of science; in 5 years of each of 10 philosophy journals; and in 150 significant books in contemporary epistemology and philosophy of science. From all these sources, we compiled and structured a large list of epistemological topics addressed in the philosophical literature.

Topics Addressed in Philosophical Works and Some Implications for

The topics and subtopics identified in the review were grouped into six categories, which are summarized and discussed briefly below. Within each of these six broad categories, there are many new topics that are worthy of EC research but that have received little or no attention as yet from EC researchers. A few of these are discussed below.

1. *Knowledge and other epistemic attainments and their limits.* EC researchers have tended to define epistemic cognition as cognition related to the nature of knowledge and its justifications (e.g., students' beliefs about what knowledge is and how knowledge is justified). However, an examination of what epistemologists actually study reveals that their investigations encompass much more than just these topics. Epistemologists do not focus only on knowledge, but rather aim to explicate a large network of epistemic phenomena and their interrelationships, including *knowledge, belief, acceptance, understanding, wisdom, epistemic virtues and responsibilities, rationality, emotion, information, objectivity, meaning, explanation, model, theory, truth, "truthlikeness," consensus, memory, testimony, perception, observation, subjectivity, objectivity, justification, warrant, explanation, evidence, standards, inquiry, methods, aims*, and many others (e.g., Goldman, 1986, 1999; Kvanvig, 2003; Zagzebski, 1996). Thus, following the practice of philosophers, EC researchers can investigate students' ideas and practices related to many diverse concepts besides knowledge and justification. Philosophers treat these topics as highly interconnected. This suggests to us that epistemic cognition should be treated as a system of interconnected cognitions—or as an *epistemic network*. If we assume that different aspects of this network may be activated at different moments (Rosenberg et al., 2006), the network could be best viewed as a dynamic epistemic network.

2. *Epistemic and nonepistemic aims, values, and virtues.* One core topic discussed by philosophers is what kinds of epistemic *aims* there are (e.g., true beliefs, knowledge, understanding, good explanations that fit the data—whether true or not—and so on). Another topic is the extent to which people actually adopt epistemic aims. Some have argued that epistemic aims are of little interest to most people, who seek instead aims such as happiness and family welfare (e.g., Stich, 1990). Other philosophers argue that epistemic aims are important because they are highly conducive to achieving nonepistemic aims, as when accurate knowledge of how to eat healthily is conducive to family welfare (e.g., Bishop & Trout, 2005). Philosophers also investigate issues related to *epistemic virtues*, including what human traits should be regarded as epistemic *virtues* (e.g., intellectual courage) or *vices* (e.g., intellectual laziness) and what people's epistemic *obligations* are (Montmarquet, 1986; Zagzebski, 1996).

This set of topics discussed by philosophers raises many relatively unexplored issues for EC research. Few studies have examined students' epistemic aims or their epistemic cognition related to topics such as epistemic virtues, vices, and responsibilities. EC researchers could examine what epistemic aims students adopt and what kinds of epistemic virtues and vices students exhibit in their practices (e.g., whether they exhibit virtues such as intellectual courage and intellectual carefulness during inquiry experiences). EC researchers could also present students with vignettes posing dilemmas related to intellectual virtues and obligations, such as vignettes directed at finding out how well informed students think citizens are obligated to be about issues such as global warming.

3. *Sources and justification of knowledge and other epistemic attainments.* The third category of epistemological topics we consider include the *sources of knowledge* (and of other epistemic attainments) and *justifications* for claims of knowledge or belief. EC researchers have extensively investigated students' beliefs about the sources of knowledge, particularly authority and experience. Many philosophers frame these sources differently (e.g., they break *experience* into different kinds of experiences such as *perception, introspection*, and *reasoning*; and they view *authority* more broadly as *testimony*, which is often viewed as a necessary and positive source of most of human knowledge) (e.g., Lackey, 2008). This suggests new EC investigations that address sources such as these.

Philosophical research on justification addresses a wide variety of issues that go beyond the typical EC focus on whether people justify knowledge using experience, authority, evidence, and the like. Philosophical research addresses many other issues, including the foundations (if any) of belief, the role of coherence in justification, whether and how the validity of methods of inquiry can be justified, basic reasoning schemes such as

induction and abduction, contextual standards that may be used for justification, and the nature and varieties of evidence. Many of these topics are likely to be fruitful topics for EC research, as well. We think that a particularly useful avenue of research will be to investigate the standards or criteria that students employ and can articulate for evaluating theories, evidence, and arguments. (Paper 3 provides examples of criteria for evaluating theories.)

4. *Disagreement.* The category of disagreement encompasses philosophical work on the causes of disagreement and their prospects for rational resolution. Much of this work is in philosophy of science, where a large literature has arisen in response to the arguments of philosophers such as Thomas Kuhn (1962) that proponents of rival theories have different epistemic practices and standards that cannot be resolved by any rational means. Many of the philosophical works that are cited by EC researchers are works that tend to deny that rational, data-driven theory choice is possible in science. However, our review highlights the work of many different post-Kuhnian philosophers who have argued against radical views, and these philosophers are cited much less frequently in the EC literature (e.g., Boghossian, 2006; Haack, 2003; Kitcher, 1993). We therefore suggest that EC researchers could find new directions for EC research in a broadened exploration of post-Kuhnian philosophy of science. This research has developed new ideas about the strategies used by scientists to make rational decisions despite the threat that theories are underdetermined by data. It would be of great psychological interest to consider students' epistemic cognition in light of these new ideas. These issues are discussed in greater depth in Paper 3 of this symposium.

5. *Causal processes that produce knowledge.* *Reliabilism* is an influential contemporary epistemological theory which analyzes knowledge in terms of the reliable causal processes that produce true beliefs (e.g., Goldman, 1986). For reliabilists, epistemology investigates all aspects of the causal processes by which true beliefs are reliably produced, including the generation of new ideas (discovery or invention), inquiry methods (methodology and epistemic practices), methods of resolving disagreement and achieving consensus, and so on (Bishop & Trout, 2005; Kornblith, 2003). It would be difficult to overemphasize the degree to which reliabilism expands the scope of epistemology (and hence the potential scope of EC research). Reliabilism suggests that people's ideas about various processes that facilitate or impede true beliefs (memory processes, perceptual processes, processes by which groups and institutions produce knowledge, etc.) should be viewed as part of epistemic cognition. In line with these ideas, EC researchers can examine students' ideas about topics such as when the processes underlying vision are and are not trustworthy, how to make observations in a reliable way, how research should be conducted in order to reduce chances of erroneous findings, when people's testimony can be trusted and when it cannot, and so on (Goldman, 1986; Haack, 2003). Research into people's ideas about such matters may illuminate much about how they endeavor to produce knowledge and how they evaluate knowledge claims.

6. *Social epistemology.* The final category of epistemological topics discussed by philosophers addresses the social dimensions of knowledge and other epistemic attainments (Coady, 1992; Goldman, 1999; Kusch, 2002). The subtopics in this category are too numerous to enumerate in this brief summary. One topic of particular interest concerns students' understanding of reliable social processes for producing knowledge, such as people's understanding of journalistic and media processes that tend to enhance knowledge of significant truths in a society versus those that tend to spread falsehoods. More generally, EC researchers can investigate people's epistemic cognition in relation to a wide variety of putative knowledge-producing processes, ranging from how groups can be best organized to generate knowledge to how the formal policies and sanctions of institutions affect knowledge-producing processes of their members. Despite the intense interest by educators in social and sociocultural theories of learning, it seems to us that most EC research has focused on individualistic dimensions of epistemic cognition, so that there is a great need for research into the social dimensions of epistemic cognition.

Our research suggests that epistemic cognition encompasses a broader diversity of topics than many previous researchers have considered. We propose as a working hypothesis that students' epistemic cognition be viewed as a network of interconnected cognitions clustered into these categories: (a) epistemic aims, (b) cognitions related to the nature and structure of knowledge and other epistemic achievements such as understanding, (c) the sources, and justification and certainty of knowledge; (d) epistemic virtues, vices, and responsibilities; (e) good and poor processes of achieving epistemic aims (including cognitive processes, methods of inquiry, and social processes); and (f) social as well as individual features of epistemic cognition.

Paper 2: Implications of Philosophy for Assessing Epistemic Cognition

Presenter: Luke A. Buckland, Rutgers University

Objectives & Theoretical Framework

Educational researchers in the fields of "Personal Epistemology" (PE) and the "Understanding of the Nature of Science" (UNOS) suggest that attending to learners' ideas about the nature, sources and limits of knowledge promises a better account of cognitive development and real prescriptions for improving educational practice (e.g.

King & Kitchener, 1994; Hofer and Pintrich, 2002; Lederman et al., 2002). These research efforts share at least three central aims: (1) Expose the epistemic frameworks implicit in cognition and learning; (2) Ascertain the relations between these frameworks and the activities of formal and informal learning environments; and (3) Design targeted instruction for the effective and reliable improvement of students' epistemic cognition. The assessments used to investigate epistemic dimensions of learning are clearly crucial to the achievement of each of these goals—both for accurately charting psychological attitudes and dispositions, and for measuring instruction-driven change. In paper 1, we explored ways in which the contemporary philosophical literature might represent a considerable yet under-exploited resource for research on new components of epistemic cognition. This study focuses on the design of the instruments used in this research, reviewing these in light of insights from philosophical practice.

Methods

A broad range of PE and UNOS research assessments are reviewed, with a particular focus on written and verbal questionnaire formats. Assessments are critically analyzed in terms of the scope of the philosophical issues they address, as well as in terms of the ways in which their constituent questions are formulated. New and modified assessment items are suggested for both PE and UNOS research, as informed by consideration of the psychology of survey response and the philosophy literature described in Paper 1 of this symposium. Finally, alternate methods for eliciting and measuring epistemic cognition are considered.

Results

The assessments used in UNOS research cover a very broad range of topics, many of which overlap in complex ways and resist straightforward classification. Although PE instruments do present students with a fairly diverse set of questions, there are fewer of them, and correspondingly fewer dimensions of epistemic attitudes surveyed (e.g., the role of experience and authority as sources of knowledge, the certainty of knowledge attributions, etc.). PE assessments generally do not display the scope and fine-grained coverage of UNOS assessments, and would particularly benefit from a much greater engagement with research in epistemology. Paper 1 in this symposium canvasses a very large number of topics and subtopics that epistemologists have considered important, and many of these have not yet been subject to psychological investigation.

Resources from philosophy provide for the improvement of several existing educational research constructs. For example, consider a student who hears about two sets of experts with persistent disagreement on the safety of a food additive, and who concludes that “both groups of experts are right” (King & Kitchener, 1994). This kind of response is traditionally identified as “relativist.” However, variation in the semantic role of “safe” may well influence the student's pattern of responses, with any sensitivity to the interest-relative meanings of “safe” leading to the ascription of relativism. Further, assessment items are insufficiently sensitive to *ontological relativism* (i.e. that there is no objective fact, or truth, of the matter) versus *epistemological relativism* (i.e. that it is not possibly to objectively compare methods, reasons, and justifications). Finally, students may well commit to an uncontroversial *descriptive relativism* (i.e., that different communities can disagree about what is true or justified) without also committing to a fully *normative relativism* (i.e., that there are no objective facts regarding what is true or justified), yet would still be characterized by this research program as “relativist.” Alternatively, students might take an approach to knowledge based on verisimilitude, or “truthlikeness” (Niiniluoto, 2002), such that the views of each of the disagreeing expert groups are considered to approximate the truth to some degree, and so to “both be right.” This example of a problematic construct is of particular interest, given the popularity of epistemic developmental trajectories in which students are considered to progress from “absolutist” to “relativist” to “evaluativist” stances (e.g., Kuhn & Weinstock, 2002).

A number of items used in UNOS and EC assessments also seem likely to confound ontological, semantic, or social aspects of cognition with epistemic aspects. For example, Greene et al., 2008 correctly note that there is an ontological dimension associated with beliefs about the simplicity of knowledge. However, there is evidence from philosophical practice that beliefs about the simplicity of knowledge have a significant epistemic dimension, as well. Philosophical work provides resources for disentangling epistemological, ontological and semantic dimensions of cognition, and suggests that students' responses to survey questions might imply philosophical stances that may be quite different from what EC researchers have previously assumed.

Assessment items can also be considered in terms of three general levels at which they are presented: (1) reflection on general questions or statements about the nature of science and knowledge; (2) metacognitive reflection on epistemic practice; and (3) engagement in actual epistemic practice. Assessments in both UNOS and PE research are dominated by abstract questions from level 1 (e.g., “What is science?”) and so assume that participants have a high degree of introspective access to the epistemic underpinnings of their own cognition. They also assume that students can engage in some fairly sophisticated philosophizing, and that their explicit beliefs about

knowledge and science align with their actual epistemic practices. These assessments therefore neglect the role that implicit epistemic attitudes might have on natural deliberation (i.e., deliberation in authentic contexts of inquiry and belief formation) rather than in contexts of involving the rating of agreement with abstract statements about science or knowledge. While a considerable amount of research has been directed at level 3—at revealing students’ actual epistemic practices—far less has been directed at level 2, for example, asking students to justify their selection of the better theory and to explain why their justification is a good one.

Perspectives on survey design are also drawn from work in experimental philosophy, a nascent field of study in which surveys are used to explore traditional philosophical problems as well as to map the philosophical attitudes and assumptions of the “folk” (i.e. non-philosophers). Weinberg, Nichols, and Stich’s (2001) study is a representative example, assessing variation in epistemic norms within and across cultures. The experimentalist movement in contemporary philosophy has involved a shift from a focus on normative, a priori, and intuition-driven practices in philosophy, towards more descriptive, a posteriori and empirical practices. In particular, this research has downplayed the degree of introspective access participants have to the philosophical underpinnings of their own cognition. Experimental philosophers thus expect that people might engage effectively in an epistemic practice without being able to articulate a good understanding of it; for example, nonscientists might exhibit facility with some of the reasoning practices of science without being able to reflectively articulate what these practices are. This therefore represents a challenge to the educational research communities’ reliance on questionnaires that elicit general, abstract beliefs.

Assessments from both UNOS and PE research would thus benefit from a shift in focus from what learners can articulate about their epistemic commitments, towards the study of their epistemic practices when engaged in authentic inquiry. Real benefits are likely to flow from a greater reliance on more detailed vignettes, thought experiments, case-based reasoning, rich and intensive interviews, and real inquiry tasks for both PE and UNOS research.

Conclusions

The philosophical literature represents an excellent and under-utilized resource for educational researchers, both for improving assessments of epistemic cognition and for better interpreting participants’ responses. A richer and more authentic set of tasks and environments is likely to enhance assessment, revealing the influence of both implicit and explicit epistemic attitudes during real learning, reasoning and decision-making. An explicit focus on “enacted,” contextualized epistemic cognition is therefore likely to enrich research in this area.

Paper 3: Underdetermination in Philosophy of Science and Science Education

Presenter: Ala Samarapungavan, Purdue University

Objectives

The goal of this paper is to provide a theoretical review of the post-positivist literature in the philosophy of science on the underdetermination of theories by evidence. The results of this analysis have implications both for the scope of issues discussed in EC research and for the goals of science instruction.

Modes of Inquiry, Sources, and Theoretical Framework

The methods comprise a theoretical analysis of underdetermination arguments in the philosophy of science and the application of these ideas in science education. A wide range of contemporary philosophical works on underdetermination including recent books and anthologies that address issue related to underdetermination are included in the review. Philosophers of science and sociologists of scientific knowledge whose works are reviewed include Achinstein, Bloor, Cartwright, Clough, Cole, Collins, Daren, Fuller, Galison, Giere, Haack, Hacking, Harding, Kitcher, Knorr Cetina, Kuhn, Latour, Laudan, Longino, Machamer, Mayo, Newton-Smith, Niiniluoto, Pickering, Popper, Solomon, Staley, Thagard, van Fraassen, Wylie, and Zammito. The paper draws especially on Nersessian’s work (2002, 2008) on conceptual change in the history of science and on Laudan’s (1977, 1990) arguments against the claim that scientific theories are so underdetermined by evidence that the rationality of science is in doubt (e.g., Bloor, 1981; T. Kuhn, 1962). Grounded in these works, the paper discusses postpositivist arguments against the epistemic relativism implied by strong forms of underdetermination in philosophy and identifies situations in which rational theory choice is possible. The theoretical analysis developed from the philosophy of science literature is then applied to the science education literature.

Results and Conclusions

Analyses in the philosophical literature (buttressed by historical case studies) show how disagreements among competing scientific paradigms might be rationally resolved. For instance, Laudan (1977) used historical examples (such as the disagreement between the Cartesians and the Newtonians with regard to whether the earth was a perfect sphere or an oblate spheroid which bulged at the equator and was flattened at the poles) to show that rival paradigms often resolve disagreements at the factual level on methodological grounds because they agree on the relevant methodological rules. Nersessian (2002, 2008) argued that incommensurability arguments of the kind advanced by Thomas Kuhn (1962) are mistaken in focusing excessively on a comparison of the products (i.e. end theories such as Newtonian theory) rather than the cognitive processes of generating and evaluating theoretical alternatives (see also Kitcher, 1993). Boghossian (2006) and other philosophers have argued that there are epistemic standards that can be used to adjudicate between competing theories in situations in which theories are underdetermined by data. The problem that the data themselves may be theory-laden can be ameliorated by strategies that increase the independence of data and theories (Haack, 2003). In short, the review of the philosophical literature discloses many strategies used by scientists to avoid underdetermination in actual practice.

The implications for science education are complex. On the one hand, the normative content of formal school science may be even more underdetermined for students than competing scientific theories are for practicing scientists. For example, while scientists who favor rival paradigms often share methodological norms, the typical science novices in the classroom probably do not. Moreover, students are aware of much less data that constrain theories than scientists are. Thus, available theories may often be genuinely underdetermined for science students. Although many science educators recognize the problem of underdetermination, there has been less success in developing instructional strategies that might reduce specific forms of underdetermination for science learners. There has also been little work on helping students learn epistemic practices that they can use to try to resolve disagreements between competing theories. Our review of the philosophical literature identifies learning goals and instructional strategies for science classrooms. For example, developing and applying methodological standards and epistemic values to theory evaluation and choice should be a specific focus in the design of science learning environments.

Philosophical scholarship provides analytic tools that science educators can use to identify specific forms of underdetermination faced by science learners, to design ways of reducing underdetermination in instruction, and to teach students strategies that can ameliorate problems of underdetermination. In addition, philosophical work points to existing work in cognitive development and conceptual change that successfully addresses problems of underdetermination. For example, cognitive research points to effective instructional strategies that help students understand radically new and incompatible knowledge frameworks that can contribute to problems of underdetermination. Examples of these strategies include refining student intuitions through progressive abstraction (Nersessian, 1992), using bridging analogies (Clement, 1993), and facilitating model articulation with the use of electronic visualization and simulation technologies.

As noted earlier, one way in which scientific theories may be underdetermined for students during science learning is that unlike practicing scientists, students may not share or even be aware of the existence of certain epistemic and methodological standards and practices. For example, the work of cognitive psychologists has shown that non-scientists, especially children, typically do not use methodological strategies such as the control of variables strategy (e.g., Chen & Klahr, 1999) and often focus on gathering confirming evidence in hypothesis evaluation instead of trying to systematically build and evaluate a comprehensive body of evidence that includes a search for potentially disconfirming evidence. Philosophical analyses suggest a wide range of standards for evaluating and choosing among theories in the face of uncertainty; these include evidential criteria (e.g., explaining the broadest array of data), consistency criteria (e.g., internal coherence of the theory; coherence with other accepted theories), criteria concerning the theoretical precision of terms and measures, criteria of testability, methodological standards, simplicity, relevance to practical human needs, and so on. These criteria could be explicitly discussed by students as a way of helping them develop strategies for dealing with situations in which theories are partly underdetermined by data. This is an area that is currently under-analyzed and under-researched in science education. One problem is that many science education researchers fail to pay attention to important differences in methodological and epistemic norms and practices within different areas of science (Samarapungavan, Westby & Bodner, 2006). Helping students understand the epistemic and methodological norms and practices that form the foundation of normative scientific knowledge in different areas of science is critical to reducing underdetermination for students.

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