

Chapter 20

Science Learning and Epistemology

Gregory J. Kelly, Scott McDonald, and Per-Olof Wickman

This chapter examines the relationship of science learning and epistemology. We begin with the assumption that theories of learning necessarily presuppose views of knowledge. We consider how different theories of learning draw on epistemology, and how through the process of investigating science learning, researchers define their respective theories of knowledge. Traditionally, epistemology is a branch of philosophy that investigates the origins, scope, nature, and limitations of knowledge (Boyd et al. 1991). Thus, the interpretation of what is learned, how it is learned, and by whom, and under what conditions, poses epistemological questions for research in science learning. While this is a traditional definition of epistemology, studies of learning conceptualize epistemology in different ways for different purposes. We consider the ways that history and philosophy of science have informed learning theory (disciplinary perspective), ways that students' personal epistemologies influence learning (personal ways of knowing perspective), and emerging studies of practical epistemologies that consider ways that disciplinary practices are enacted interactionally in learning contexts (social practices perspective). We will consider how conceptions of knowledge are operationalized in science learning research and draw implications for research in science education.

In our review, we identify how these three different conceptualizations of epistemology are seen to influence science learning. Each view allows the respective researchers to view knowledge in a unique way and inform research from these perspectives. These views of knowledge are not necessarily mutually exclusive,

G.J. Kelly (✉) • S. McDonald
Department of Curriculum and Instruction, College of Education,
The Pennsylvania State University, University Park, PA, USA
e-mail: gkelly@psu.edu; smcdonald@psu.edu

P.-O. Wickman
Department of Mathematics and Science Education,
Stockholm University, Stockholm, Sweden
e-mail: per-olof.wickman@mnd.su.se

but rather, each perspective places emphasis on certain aspects of epistemology, with less attention to other aspects. One view (*disciplinary perspective*) considers the important role of disciplinary knowledge for science learning. This position conceptualizes epistemology as a discipline concerned with examining issues such as the nature of evidence, criteria for theory choice in science, role of theory-dependence in scientific research methodology, and the structure of disciplinary knowledge (Duschl 1990; Grandy and Duschl 2008). The disciplinary perspective is a philosophical view of epistemology, largely normative in nature (i.e., it considers the reasons for theory change and the evidence relevant to such changes), focusing on knowledge within practicing scientific communities (Kelly 2008).

A second view of knowledge emanates from psychologically oriented studies of learning (*personal perspective*). These studies are concerned with the ways that individual learners conceptualize knowledge and how such personal views of knowledge influence their learning (Hofer 2001). Rather than offering a normative point of view, this psychologicalized view of epistemology, treats theories of knowledge as personal, empirical, and contingent. The focus is centered on internal representation of cognitive structures (Duschl et al. 1992), and personal views of truth, rather than on disciplinary considerations of rationality, truth, and justification. Studies consider normative approaches about how education should foster epistemological development and empirical studies that examine how personal theories of knowing influence further learning.

The third view of epistemology considers the social practices that determine what counts as knowledge in local, contingent contexts (Knorr-Cetina 1999). These studies do not view theories of knowledge as either extant disciplinary entities or solely personal views, but rather view knowledge as accomplished through social interaction. This *social practices* view of epistemology examines how, through particular learning events, questions of justification, reasonableness, and knowledge claims are negotiated among members of a group. This view describes the ways that being a member of an epistemic culture, observing from a particular point of view, representing data, persuading peers, engaging in special discourse, and so forth, locally define knowledge (Kelly 2008; Wickman 2004).

Each of the three perspectives offer expressive potential that defines the research programs in particular ways (Kelly and Green 1998). While the perspectives may show some overlap and mutual recognition, they represent some unique contributions to research in science education.

Disciplinary Perspectives on Science Learning

Philosophy of science has served as an intellectual referent for the development of science curricular materials and weighed heavily in thinking about the aims of science education (e.g., Duschl 1990; Schwab 1962). One example of this line of work would be conceptual change theory (Posner et al. 1982), which was based initially on theory-change models in scientific fields, and continues to benefit from epistemological analogies between scientists and science learners (e.g., Tyson et al. 1997;

Duschl and Hamilton 1998). Theory change in science offers ways to conceptualize the learning tasks for students and suggests ways of organizing knowledge to support learning. These perspectives are typically normative in nature, that is, they consider how rationality is defined and how concepts change through reasoning. For example, Nancy Nersessian (1992) identified a number of epistemologically relevant abstraction techniques (i.e., analogy, imagery, thought experiment, limiting case analysis) that can support student learning. The history and philosophy of science were central to the focus on conceptual change theory, and studies of science learning continue to progress toward interests in the ways that theories and models are developed, examined, and evaluated in both science and learning contexts.

A second way disciplinary perspectives have informed science education, concerns the process of legitimation. Both intended science curricula and their enactment are often informed by views of the discipline. While some curricula may be created with implicit views of science, or various disciplines within science, others specifically rely on philosophy of science. Obvious in this respect are efforts to teach about the nature(s) of science to change students' conceptions or images of the epistemology of science (Lederman 2007). A number of scholars, including Sherry Southerland, Gale Sinatra, and Michael Matthews (2001) and Derek Hodson (1988), have implored the field to consider the epistemological bases for choices about science curricula. For example, John Leach, Andy Hind, and Jim Ryder (2003) used the history of science as a framework to design units in electromagnetism and cell membranes to help students understand the status of scientific theories. Through careful curriculum design they were able to improve some students' epistemological ideas – that is, to a limited extent, the students were able to engage with scientific models and not just focus on collecting empirical data.

The disciplinary view of epistemology continues to be informed by a number of fields, beyond just history and philosophy of science, that consider the ways that scientific theory and knowledge evolve. Known collectively as science studies, these fields offer ways of reexamining and reevaluating science learning (Kelly 2008). Science studies include examining scientific communities from an empirical point of view through the study of practices in situ. The central contribution has been to move away from the presentations of final form science in classrooms to a focus on the consensus building dynamics present in knowledge-building communities (Duschl 2008). Such dynamics are rooted in the argumentative nature of scientific discourse, where evidence is considered within theoretical traditions. Science studies research points to the very social nature of consensus building in science fields and offers a valuable referent to consider changes in knowledge structure. Thus, while a focus on scientific theories and models developed in philosophy of science offers opportunities for students to understand certain aspects of the epistemology of science, science studies offer a view into the social and epistemic practices determining what counts as science. For example, Duschl (2008) identified how science studies can inform science learning by noting that scientific actions include building theories and models, constructing arguments, and engaging in the social languages of special communities. A shift to the practical actions of scientific communities offers the opportunity to integrate various cognitive and sociocultural views of

learning into the design of science learning environments and curricula (Leach and Scott 2003). The focus on learning poses epistemological issues for personal ways of knowing and disciplinary practices, perspectives we examine in the subsequent sections.

Personal Epistemologies and Learning Science

The notion of personal epistemologies developed out of the work by William Perry (1970) regarding the intellectual development of college students. Personal epistemology research has since evolved in two primary veins: developmental stages and patterns of beliefs. Recently, there has been a movement to unite the stages and patterns of beliefs models and also to reconceptualize personal epistemologies. In general, the vein focusing on developmental stages examines the progression of beliefs from simple, certain, and dualistic (right/wrong) notions of knowledge, through relativist or uncertain subjectivity, and on to beliefs allowing for multiple views whose validity is considered in relation to context. Patricia King and Karen Kirchner's (1994) reflective judgment, for example, contains seven stages covering this continuum. In contrast, the research examining patterns of epistemological beliefs tends to take a broad view and include beliefs about intelligence and learning (Ken Lodewyk 2007), but views them as individual factors impacting a variety of correlates including motivation, cognitive development, conceptual change, self-efficacy, and task performance. Barbara Hofer (2004) has recently described epistemic metacognition, an attempt to unify the views of personal epistemology, which characterizes epistemic beliefs as theory-like patterns of belief that develop over time and are drawn on in more context-dependent ways.

Science learning has been informed in many ways by research from both the developmental and patterns of beliefs perspectives. Much of the focus of science learning has traditionally been on students' alternative conceptions and how, through systematically designed learning sequences, students can come to richer, more reason-based ways of understanding natural phenomena. Within this research framework, learners' ways of conceptualizing knowledge has been shown to influence science learning. Hofer (2001) characterizes this research as "personal epistemology" and notes the focus on "ideas individuals hold about knowledge and knowing" (p. 353). Within the focus on personal epistemologies, Orpha Duell and Marlene Schommer-Aikins (2001) identified five directions of research for personal epistemology studies: justification of knowledge, coping with uncertainty, gender issues, multiplicity of epistemological beliefs, and academic domain specificity. The general theoretical issues concern learners' beliefs about knowledge and how these beliefs change. Methodologically, this research tradition focuses on developing instruments to measure learners' beliefs about knowledge and learning (Duell and Schommer-Aikins 2001; Schraw 2001) and correlating them to a variety of other student factors.

In science learning contexts, learners' views of knowing and knowledge acquisition have been used to develop a framework for evaluating the authenticity of classroom

science inquiry tasks (Chinn and Malhotra 2002). There have also been examinations of the alignment of students' personal epistemologies of science with those of their science teachers (e.g., Roth and Roychoudhury 1993). Furthermore, Andrew Elby and David Hammer (2001) noted that philosophically correct epistemological positions do not necessarily align with the heuristic value of certain epistemological beliefs. They identified how a sophisticated epistemology needs to consider relevant contextual information to make judgments about inquiry processes involved in learning through engagement with nature. It is clear that attention to students' epistemological views is important to an understanding of science learning; however, both the nature of these views and the relationship to science learning are not unambiguous.

Hammer and colleagues (e.g., 2003, 2008) have attempted to ontologically reconceptualize epistemic beliefs in much the same way that Andrea diSessa's (1993) knowledge in pieces did for misconceptions. Hammer suggests that epistemology should be considered in finer grained and context-specific form – epistemic resources. Students' views of knowledge are thus manifestations of those parts of the raw material activated within a particular context. Data from elementary school students' beliefs in physics are used to support this view (Hammer et al. 2008). Hammer's epistemic resources can be seen as a bridge from a highly situated, contextually bound personal view of epistemology to a sociocultural approach to epistemology – the notion of epistemology as a social practice.

Epistemology as Social Practice

Studying epistemology as social practice entails seeing epistemology as constituted through situated interaction. The aim is to describe actual epistemological practice, that is, how people proceed in action to accomplish certain purposes. This definition of epistemology is close to that of Richard Rorty (1991, p. 1), who maintained that we should not “view knowledge as a matter of getting reality right, but as a matter of acquiring habits of action for coping with reality”. Studies of epistemology as social practices draw on sociocultural, ethnographic, and pragmatist studies of learning as talk and action in science classrooms. Jay Lemke (1990) is an early example of an analysis of the meaning given to science in classrooms through talk. Another example is Wolff-Michael Roth (1998), who studied the significance of social networks and artifacts for the meaning made in science classrooms. Also important are those experimental and interview studies examining the significance of artifacts and the communicative context for what students know (Edwards 1993; Schoultz et al. 2001). Although studies like these are not explicitly concerned with students' epistemologies, they demonstrate the holistic and empirical stance the social practice perspective has toward knowledge and learning and so toward epistemology. Within the social epistemology perspective, there is great variation regarding the nature and extent of the social in developing scientific knowledge, from relativist positions to those dedicated to examining the social basis for evidence use (Kelly et al. 1993).

Within this perspective, knowledge is seen as competent action in a situation rather than as correct, static representations of the world. To decide on what ways student actions are competent, they need to be examined in an activity with some human purpose. Hence, communication and action primarily has meaning within purposeful practice, in doing something (Kelly 2005; Wickman 2006). This tenet from Ludwig Wittgenstein (1967) is central for the epistemological analysis from this perspective (Lynch 1993). Epistemology as social practice is a description of how a community must continually construe what counts (Knorr-Cetina 1999). This means that we must study both science proper and school science as “science-in-the-making” (sensu Latour 1987, p. 4) to describe their epistemologies (Kelly et al. 1993). Only when we have these descriptions of how the participants themselves go about making sense can we suggest meaningful improvements from the educational researcher’s outside perspective (Kelly 2005; Wickman 2006). In science education research, description starts from that of school science-in-the-making without beforehand imposing outside analytical constructs such as positivism or constructivism on the patterned actions of students (Kelly and Crawford 1997).

Knowledge when studied in this way is encountered in transition as part of practice; continual learning is needed to transform knowledge to the contingences of each situation. Knowledge in this way is not propositional but enacted. However, the patterns of actions are not entirely contingent. They form certain jointly constituted discursive ways of dealing with people, objects, and events, and in particular ways of deciding what and whose knowledge counts (Kelly et al. 1998). Crawford et al. (1997) followed two bilingual high school students and studied the presentation of their science project across different audiences. The students’ descriptions varied across audiences such as teachers, classmates, and fifth-grade students. What counted as knowledge was construed depending on the communicative setting, suggesting that different communicative contexts afford students different ways of understanding what may first seem to be the same subject matter content. Hence, an ethnographic study from a first person perspective, although not normative in itself, can be used to inform our decisions in science education.

Studying epistemology as social practices can be used more directly to study how meanings concerning the nature of science are negotiated in science class. Gregory Kelly, Catherine Chen, and William Prothero (2000) developed such a method drawing from sociological and anthropological studies of scientific communities. Using this approach they analyzed talk and writing in a university oceanography class to examine such epistemological issues as the uses of evidence, role of expertise, relevance of point of view, and limits to the authority of disciplinary inquiry. Their study has implications for how epistemological issues can become an integrated part of science courses at the university.

Per-Olof Wickman and Leif Östman (2002a) and Wickman (2004) have developed a so-called practical epistemology analysis to study how certain meanings are made through interactions in science class as discursive practices. This approach can be used to study how different encounters with the teacher, among students, and between students and artifacts influence the direction learning takes through talk and action in a science class. Malena Lidar, Eva Lundqvist, and Östman (2005) examined how different kinds of epistemological moves by a teacher influence the

learning of middle school students. An epistemological move is how the teacher directs the students in ways that determine what counts as knowledge and appropriate ways of getting knowledge in a specific school science practice. Wickman and Östman (2002b) studied the practical epistemologies of zoology students at the university to see to what degree students could use induction and deduction to produce testable hypotheses when making observations of real pinned insects. This study demonstrated that students' practical epistemologies were more experiential and holistic, using whatever they could apply from previous experiences to understand the structure of the studied insects. The situated and locally construed epistemology was shown to be more functional than the typical inductive and deductive stances to learning about insects. An analysis of high-school students' practical epistemologies in chemistry lab (Hamza and Wickman 2008) showed that learning was more influenced by local and contingent aspects of the situation than by the cognitive constraints implied from interview studies of students' misconceptions. It has also been demonstrated that the learning of science is not a merely a cognitive affair. When epistemology is studied as social practice it is clear that aesthetic judgments play a crucial role for what counts as knowledge. This was found in elementary school science, as well as in university science (Jakobson and Wickman 2008; Wickman 2006). Studying epistemology as social practice thus opens up possibilities to study learning processes that the personal perspective sees as mental entities (e.g., aesthetic experience, misconceptions) and to analyze how knowledge as action develops and is changed by the various experiences and other circumstances that meet in education.

In the social practice approach, conceptions and views are not primarily seen as something that determines action, but rather as units of action themselves. That a student repeatedly argues that 'science is tentative' is seen as a habitual way of reasoning, rather than a propositional personal understanding that causes certain ways to talk and act, which could be described by this propositional statement. William Sandoval (2005) borrowed the term practical epistemology from Wickman and Östman (2001) to designate a belief about knowledge in school science that influences students' ways of doing science inquiry in school. However, approaching epistemology as social practice or as practical epistemology in the original sense of the word does not assume that beliefs necessarily are the reasons why people have certain habitual ways of doing things (Wickman 2004). It might simply be the way they do things, without further reflection. It then becomes an empirical question as to why certain social practices develop and how they might be made more purposeful based on what we value in science education (e.g., McDonald and Kelly 2007; Sensevy et al. 2008).

Evolution of Epistemological Perspectives on Learning in Science Education

Learning theories in and informing science education recognize the importance of epistemology. Disciplinary, personal, and social practice views each offer unique and potentially complementary views about how knowledge and learning interact in

science settings (Sandoval 2005). Across the different perspectives some common themes emerge. First, increasingly, science education researchers are viewing meaning as public, interpreted by participants (and analysts) through interaction of people via discourse including signs, symbols, models, and ways of being. Second, learning is increasingly examined through the everyday social practices of members of a group, for example, school settings, museums, research laboratories, and so forth. This research draws on the social knowledge of analysts to consider the ways that science is framed through discourse practices (Lundqvist et al. 2009). Thus, the measure of learning is not the results of student performance on tests, but rather how students are able to use language in authentic social settings (e.g., McDonald and Kelly 2007; McDonald and Songer 2008). Third, the epistemology is interpreted, not only in the traditional sense, concerning the origins, scope, nature, and limitations of knowledge, but as an interactional accomplishment among members who define for themselves what counts as knowledge in a particular context. Thus, the interactional nature of competent actions taken by members of a group in a situation comes to define knowledge. This view suggests that knowledge be examined as it occurs in practical actions, rather than as measured by students' decontextualized views of epistemology, nature of science, and so forth. Thus, through interaction with the world and each other, members of communities come to define what counts as knowledge, evidence, explanation, and so forth, and embody an epistemology through such actions. Finally, across the perspectives, the evolving nature of disciplinary knowledge and the confluence of perspectives on learning, suggest a focus on the epistemic moves made by teachers (Lidar et al. 2006). Further study of the different ways the teacher directs the students regarding what counts as knowledge is needed to develop desired learning situations for their students (Hammer and Elby 2003; Jiménez-Aleixandre and Reigosa 2006).

Future Directions for Studies of Epistemology and Learning

Our review of research involving epistemology and learning suggests that the emerging research directions draw from and are informed across perspectives. These perspectives may be mutually supportive, or in some cases, offer divergent directions for research and importantly, research methodology. There is fertile ground for additional studies in each area. However, there are also numerous directions that could plausibly emerge from the current knowledge base. We propose three for consideration. First, sociohistorical activity theory (CHAT) offers a direction that takes serious disciplinary knowledge and the acculturation associated with learning, and recognizes the need to examine knowledge in practice (Leach and Scott 2003; Van Eijck et al. 2009). Van Eijck et al. (2009) provide a cogent view of how measures of "students' 'images of science'" (p. 612) represent a snapshot of students' responses to research instruments and offer little insight into how students can engage in collective practices. In contrast, drawing from CHAT, they examine instead the coproduction of students' images of science at a moment in

time, embedded in a particular context. This view suggests a methodological focus on the interactional accomplishment of science in an activity system. Second, drawing from the learning sciences, Duschl (2008) proposed a shift away from the unitary goal of conceptual understanding to a more balanced set of goals focused on the conceptual, epistemic, and social goals for science learning. Central to this view is the development of learning progressions, centered on the most core and generative concepts of the respective science disciplines – concepts that are learned through engagement in situated scientific practices (Leach et al. 2003). Importantly, these learning progressions include social and epistemic goals for assessing and evaluating the status of knowledge claims, methods, tools for measurement, and representations or models (Duschl 2008). Third, theories tying the epistemological moves of teachers to consequences for what counts as science for students offer a way to develop practical epistemologies in classroom conversations (Lundqvist et al. 2009). Across perspectives, we envision research that considers seriously the social, contextual, and contingent nature of epistemic activity associated with learning science.

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