TOWARD A RESEARCH AGENDA FOR

EPISTEMOLOGICAL STUDIES IN SCIENCE EDUCATION

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Abstract:

The purpose of this paper is to identify and describe research trends in epistemological studies in science education. Current reform in science education emphasizes the intersubjective processes of representation, communication, and evaluation of the evidentiary bases of knowledge claims. To understand better the pedagogical strategies oriented toward engaging students in these processes, research needs to be attentive to the social processes and criteria employed during knowledge production. We review theoretical and empirical studies of epistemological issues in science education. This review leads us to argue for an expanded research agenda that includes studies of epistemic practices associated with producing, communicating, and evaluating knowledge claims in everyday educational settings; of modeling and explanation formation in learning processes; and of critical perspectives on knowledge and science.

TOWARD A RESEARCH AGENDA FOR EPISTEMOLOGICAL STUDIES IN SCIENCE EDUCATION

The purpose of this paper is to identify and describe research trends in epistemological studies in science education. The "new" science education reforms suggest that students develop thorough understandings of conceptual knowledge of science, inquiry processes, the nature of science, historical development of scientific ideas, communication processes in science, and the role of science in society (AAAS, 1993; NCR, 1996). Through a review of these reform documents and other research-based pedagogies (Duschl, 1990; Driver, Asoko, Leach, Mortimer, & Scott, 1994) we classify the goals of such reform into four broad categories: conceptual, epistemological, communicative, and sociopolitical. These educational goals place importance on the intersubjective processes of representation, communication, and evaluation of the evidentiary bases of knowledge claims. We argue that to address the social basis of knowledge production under these conditions, epistemological studies in science education need to consider the epistemic practices associated with producing, communicating, and evaluating knowledge claims in everyday educational settings.

One important difference of current reform in science education with that of the past, is that "science for all" is now an explicit goal. Science and technology are becoming increasingly central to the economic, social, and cultural spheres of modern society, while at the same time equality of participation remains distorted, disadvantaging populations of students of lower socioeconomic status, of certain ethnic, racial, and gender groups, at least in the US context (Lynch, 2000). Nevertheless, equity in educational institutions is of fundamental importance for a liberal democracy and exemplary models for science education do exist (Warren, Ballenger, Ogonowski, Roseberry, & Hudicourt-Barnes, 2001). This requires analysis of knowledge production, communication, and appropriation to develop a progressively more democratic distribution of knowledge across the total population (Dewey, 1916). The significance of our argument is that it sets a research agenda aimed at identifying those epistemic practices central to such knowledge production, communication, and appropriation. Research focused on epistemic practices contributes to normative educational aims by demystifying access to the knowledge of legitimized and legitimating institutions.

Framing epistemological studies in the learning and knowing of educational processes

A recent trend in education research and development is that of employing the concept design. Initially led by the seminal paper of Ann Brown (1992) which examined the idea of design experiments as a focus for educational research, the concept of design can be found associated with design studies, design principles, and design research (Edelson, 2002). What is shared by the various considerations of design is recognition that there is a complexity and structure to learning in subject specific domains. Hence the notion of design experiments, design studies, designing learning environments, and design research is derived from a shared goal that what we have learned about learning, the conditions of learning and the structure of knowledge can through research and development be aligned and engineered to support learning. Two recently published books from the National Research Council on learning (Bransford, Brown, & Cocking, 1999) and on assessment (Pelligrino, Chudowsky, & Glaser, 2001) serve as examples of the how past research has been synthesized into recommendations for learning and the design of learning environments. Fundamental challenges are being made to the basic question concerning what to teach, how to teach, and when to teach.

The two books represent the deliberations and recommendations of two committees set up by the Social and Behavioral Sciences Committee for the National Research Council. One need look no further than the composition of the committees to see the dominance of the cognitive and social psychology communities. Surely, the learning sciences are critically important for understanding learning but we wish to take the position that when it comes to the design of learning environments, and specifically science learning environments, epistemological factors must be an important part of the deliberation. We are concerned that epistemological considerations for the design of science learning environments and assessment practices have not received the attention deserved. The purpose of this presentation is to initiate a discussion and propose a possible framework that will help frame research on how epistemological elements situated within curriculum, instruction, and assessment models can inform design thinking.

Research science studies and science education: Trends toward epistemic communities

The central theoretical basis for epistemological studies in science education stems from the philosophy of science (e.g., Brown, 1977; Longino, 1990; Suppe, 1977). Epistemology has been traditionally thought of as the branch of philosophy that investigates the origins, scope, nature, and limitations of knowledge (Boyd, Gasper, &

Trout, 1991; Sosa, 1991). This philosophical position sets epistemology as a discipline concerned with examining such issues as the nature of evidence, criteria for theory choice in science, role of theory-dependence in scientific research methodology, evolution and growth of theories, and the structure of disciplinary knowledge, etc. Such a view is largely normative in nature, and contrasts with some psychologically-oriented studies of epistemology. A psychologicalized view of epistemology both makes the study of epistemological beliefs empirical and focuses on individual minds rather than disciplinary communities. As noted by Duschl, Hamilton, and Grandy (1992) cognitive psychology considers the "nature, causes, and dynamics of internal representation of conceptual structures" (p. 28-29), rather than rationality, truth, and justification – typical epistemological issues. While epistemology as a discipline has examined disciplinary knowledge (Duschl et al., 1992; Strike, 1982), empirical studies from a psychological point of view tend to consider individual subjects' beliefs about knowledge (e.g., Duell & Schommer-Atkins, 2001; Hofer, 2001). Differences between the study of knowledge as justified, true belief (Strike, 1995) and beliefs about knowledge represent differences in ways of conceptualizing the phenomena of interest for research. While the study of both knowledge and belief have a role in educational studies, the confounding of knowledge with belief poses the problem of eliminating a thoroughly social view of justification (Southerland, Sinatra, & Matthews, 2001). Our focus shall be primarily on how epistemological issues related to knowledge construction and justification are manifest in educational settings.

The philosophically-oriented, normative considerations for knowledge construction and growth have offered many applications to science education. These include, but are not limited to: providing a rationale for supporting critical thinking in science teaching (Siegal, 1991), delimiting science for educational purposes (Kitcher, 1982), providing models for uses of theory and knowledge growth (Duschl, 1990), proposing theories of conceptual change (Posner, Strike, Hewson, & Gertzog, 1982), among others. This theoretical work in epistemology has been mined for frameworks and applications in science education. Nevertheless, while epistemology has been traditionally a normative à priori discipline, there is an emerging trend toward naturalism and description (Fuller, 1992) across disciplinary perspectives that have yet to be fully examined for their potential contributions to science education. These studies examine epistemological issues from an empirical point of view, but maintain an interest in the social and disciplinary considerations of knowledge construction (Lynch, 1992). Thus, in considering a research agenda for epistemological studies in science education, we propose maintaining epistemology's traditional interest in rationality, justification, and theory choice, but doing so from a descriptive perspective of the social processes constitutive of knowledge in the making. (Kelly & Crawford, 1997; Kelly & Green, 1998).

We consider some of these descriptive perspectives by reviewing studies centered on epistemic practices in the sciences from the fields of sociology/anthropology of science (e.g., Knorr-Cetina, 1999; Lynch, 1993), rhetoric of science (e.g., Bazerman, 1988; Gross, 1990; Perelli, 1989), and cognitive science applied to scientific reasoning (e.g., Giere, 1999; Gooding, 1992). In particular, three issues are particularly salient for their potential to inform epistemological studies in science education. These are representing data, persuading peers, and observing from a particular point of view.

First, we consider the role of data representation. Knorr-Cetina (1999) compared the cultural practices of two scientific communities, microbiology and high energy particle physics. For both of these communities, the role of signs and sign-creating technologies emerge as central to the knowledge generating processes. Knorr-Cetina noted that sign-creating technologies produce “verbal renderings, visual images, or algorithmic representations of objects and events” (p. 41) important for both experimentation and the transmission and publication of scientific results. She noted how experimental measurements achieve meaning, i.e., “turned into something useful” (p. 55), when considered by a community in light of other features of an experiment. These results corroborate results found by Latour (1987) as he examined how data inscriptions (e.g., graphical representations, photographs, diagrams) traveled through different rhetorical spaces achieving their final epistemic status through agonistic debate. For both Latour and Knorr-Cetina, data representations offer interpretative flexibility, and thus the social processes of seeing, displaying, describing, enter into deliberations about what counts as evidence for a relevant audience. Such considerations led Roth and McGinn (1998) to conclude that “A focus on inscriptions entails a shift from representing as mental activity to representing as social activity” (p. 54). Thus, such representational practices are situated within disciplinary norms, and while data and data representation are centrally important for the making of knowledge claims in science, the status of such claims depends heavily on the persuasiveness of the overall argument for which they support. The issue of persuasiveness is taken up in the field of rhetoric of science.

Second, considerations of audience and disciplinary norms and practices are prominent in rhetorical analysis of scientific texts. Couching a argument to potentially persuadable audience requires understanding the disciplinary norms for representation, the history of the rhetorical processes of the social group, and the particular problem solving context surrounding the question at hand (Bazerman, 1988; Gross, 1990). These rhetorical studies of science view knowledge as actively constructed and evaluated by scientists working individually or collectively on problems and being held accountable to public standards (Kelly & Bazerman, in review). The forms of expression, invention, and knowledge are responsive to the particular argumentative fields of the professions and disciplines (Knorr-Cetina, 1999; Myers, 1990). Thus, in making knowledge claims, scientists need to refine reasoning, limit theoretical claims, marshal evidence, and understand strengths and limits of their evidence so as to make credible and creditable such claims within their critical communities of peers (Gieryn, 1999; Latour, 1987; Myers, 1990; Pinch, 1986). A key feature of developing persuasive texts is the ties from specific instances of data to larger theoretical assertions and explanations. Analysis of debates in forming and reviewing claims to knowledge, particularly in written forms, demonstrates the high levels of accountability between detailed findings and theoretical claims enforced by the relevant community of peers (Bazerman, 1988; Myers, 1990). Thus, studies of knowledge claims processes evince the situated, local aspects of persuasion as well as the constraints posed by the norms of the relevant communities (Gieryn, 1999).

Third, learning to observe in a particular way has been the focus in Goodwin's (1994) studies of professional vision. The issue of observation has surfaced in many historical studies of scientific epistemology and the dismantling of the observational-theoretical distinction is a hallmark of the new view of science (Brown, 1977). However, the empirical study of the socialization processes leading to learning how to observe in a particular way offers a more nuanced way of understanding how data get viewed in the first place. For example, through close examination of the situated practices of archaeologists, Goodwin (1994) identified ways the discipline distinguished itself from other professions through the use of theories, artifacts, and application of particular expertise. Specifically, Goodwin (1994) examined how archaeologists come to learn how to observe particular shades of brown in dirt and make inferences about artifacts these shades represent (post supporting an ancient structure). New members to the community need to learn the “professional vision” – i.e., ways of observing what counts as archaeological – through participation in digs with other group members where disciplinary practices are communicated (e.g., demarcating a line in the dirt with a trowel). The categorization schemes for classifying shades of dirt, while central to the disciplinary practice, are not easily learned, nor automatic. Rather, through talk and gesture the perceptual field is defined leading observers to attend to certain features. Although noted specifically noted in Goodwin’s study, such forms of observation can become further nuanced by bringing soil samples back to a laboratory for carbon dating analysis. Thus, members of the group come to learn how to recognize ways of seeing; that is, attending to and distinguishing certain features relevant to the investigation at hand.

These three instances of epistemic practice in science (representing data, persuading peers, observing from a particular point of view) demonstrate the prominent role of the relevant practice-defining community in deciding “what counts?” for members of the group. These studies illustrate the value of examining situated practices of disciplinary communities and the ways that issues around knowledge creation, transmission, justification, and evaluation can investigated through close attention to social processes. Similarly a move toward empirical investigations of epistemic practices potentially opens new ways of informing practices in science education. Thus, in considering the value of epistemology for education, we need to draw from multiple points of view and disciplinary perspectives. By including both the normative and descriptive study of knowledge creation, science education can continue to benefit from considerations of disciplinary knowledge structure, reasoning patterns, evidentiary inference etc., as well as from investigations of such issues in science-in-the-making contexts (Kelly, Chen, & Crawford, 1998; Latour, 1987).

Epistemological research in science education

Like many research traditions, epistemological studies in science education are populated by histories, theories, methods, and persons. To organize our review of these research traditions we draw from the work of Strike (1989) who characterized educational research in terms of social science research programs (cf., Lakatos, 1970). Research programs as depicted by Strike are governed by a set of substantive assumptions that may be metaphysical, epistemological, ethical, or methodological. These assumptions have several roles in research programs that include: distinguishing relevant from irrelevant phenomena; providing standards of judgment for accounts of phenomena; identifying central foci of research; providing perceptual categories through which the world is experienced; and specifying problems that require solution (Strike, 1989, p. 6). In our review, we examined these assumptions for each identifiable research perspective focused on epistemology in science education. Applying this framework to epistemological studies in science education evinces features of current traditions in the field and points to emerging lines of inquiry which we describe below. After reviewing the history of integrating epistemological into science education we consider three established research programs: studies of theory-change models in science and education; studies of views about knowledge and science; and studies of learners' epistemological frameworks. We then turn to some new directions for epistemological studies in science education by considering three emerging research programs: discourse studies of knowledge construction, appropriation, and justification; modeling and explanation formation; and knowledge legitimation. In each case we consider some work to date and consider some possible new directions.

Historical perspectives on epistemological research in science education

While we view many fruitful ways to integrate cognitive psychology and epistemology (Duschl & Hamilton, 1992 & 1998), we argue that adherence to a strictly psychological interpretation of epistemology limits the role studies of knowledge construction processes may have for educational purposes. We are certainly not the first to be concerned about the dominance psychological perspectives have had on educational theory and practice. Joseph Schwab's (1960a&b) proposals to make science an 'enquiry into enquiry' were grounded in ideas that focused attention on the structure of the discipline, specifically the syntactical and semantic structures of knowledge. His proposals were a reaction to the then dominance behavioral psychology was having on educational theory and practice at the University of Chicago and then the national educational policy, e.g., Benjamin Bloom's (1956) Taxonomy of Educational Objectives and Ralph Tyler's (1949) Basic Principles of Curriculum and Instruction. For Schwab

(1960b), the important focus was to ask “what is it that scientists do?” His subsequent analysis of the biological sciences led him to the conclusion that scientists’ guiding conceptions (i.e., theoretical frameworks) impacted data gathering and data analysis processes. Hence, any sound implementation of making science education an ‘enquiry into enquiry’ would need to infuse into the instructional sequence careful and critical examinations of the ‘moves’ that occur when progressing from evidence and observation to explanation and theory. Such ‘moves’ for Schwab were, as just indicated, grounded in the structures of the discipline and the language of the disciplines. He was in a sense, providing guidelines for the design of science learning environments. However, the successful attainment of inquiry science learning has eluded us.

Studies of theory-change models in science and education

The first research tradition we consider is the ways epistemology has entered into science education as a theoretical referent, guiding curriculum decisions and providing a basis for science pedagogy and assessment. One example of this line of work would be conceptual change theory, which was based initially on theory-change models in scientific fields (Posner, Strike, Hewson, & Gertzog, 1982) and continues to benefit from epistemological analogies between scientists and science learners (Tyson, Venville, Harrison, & Treagust, 1997; Duschl & Hamilton, 1998). Drawing from descriptions of theory change in science (e.g., Kuhn 1996; Lakatos, 1970; Toulmin, 1972), educators sought to characterize students’ conceptual change by taking into account the conditions that may lead to conceptual change and the intellectual ecology within which reasoning about ideas and evidence takes place (Strike & Posner, 1992). Theories of conceptual change have continued to benefit from taking this epistemological point of view. Areas of continued investigation include the role of abstraction techniques (i.e., analogy, imagery, thought experiment, limiting case analysis) (Nersessian, 1992), the role of learners' responses to anomalous data (Chinn & Brewer, 1998), introduction of sociocultural psychology (Duschl & Hamilton, 1998), and the integration of epistemological, ontological, and affective dimensions for considerations of domain specificity, learner development, and status of students' initial conceptions (Tyson, Venville, Harrison, & Treagust, 1997). A developing line of research may include the ways local discourse communities provide intellectual ecologies for learners and ways that epistemological commitments, analogies, metaphors, etc. can be viewed as interactionally accomplished through discourse processes (e.g., Kelly & Green, 1998). Additionally, feminist, multicultural, social psychological, and postmodern perspectives can be found in Perspectives on Conceptual Change (Guzzetti & Hynd, 1998).

Another example of this application of epistemology is the development of increased understandings of theory change and science learning from an epistemological point of view as found in Duschl's (1990) Restructuring Science Education. Generally, this sort of work allows the scholarship of philosophy to inform educational practices, particularly curriculum and assessment design. The frameworks proposed by philosophers to explain or account for the growth of scientific knowledge, e.g., Kuhn's disciplinary matrix in scientific revolutions, Lakatos' novel facts and research programmes, Laudan's research traditions and triadic network and/or Giere's model-based view of science, can serve, in turn, as pedagogical frameworks for guiding the design, selection and sequencing of instructional tasks and topics. The goal is to move away from presentations of final form science in classrooms to a focus on the consensus building dynamics of scientific knowledge growth. Such dynamics are rooted in the argumentative nature of scientific discourse that links evidence to explanation via processes that progress from data to evidence to patterns in evidence and then to explanations of the patterns. Furthermore, and importantly, such dynamics are as much a process of moving away from one's established commitments about theory, methods and goals as they are a process of moving toward new commitments. This dual dynamic is often not considered in the design of inquiry learning environments. In both the conceptual change research and Duschl's emphasis on theories in science and science education, epistemology served as a valuable referent to consider changes in knowledge structure.

Studies of views about knowledge and science

In a second tradition, epistemology has been empirically investigated by examining teachers' and students' views about knowledge and science (Ryan & Aikenhead, 1992). These studies typically assess changes in epistemological position to be a measure of education effectiveness (e.g., Meyling, 1997), or consider how students' epistemological positions influence science learning (e.g., Edmondson & Novak, 1993). Studies of teachers' and/or students' views typically share a common orientation of examining the research subjects' views of knowledge with respect to normative views of experts. The importance of understanding students' learning about science has generated renewed interest as educators consider the understanding the nature of science as a content goal for science education (AAAS, 1993; NRC, 1996). While it will continue to be important to consider how well students learn about science and epistemological issues in particular, research relying on surveys and interviews presents methodological liabilities. Two recent reviews bear this out.

Kelly et al. (1998) noted that studies of the nature of science, many concerned with epistemological issues, had the following methodological weaknesses. First, there has been an overreliance on research surveys and interviews. These research methods situate the discussion on a limited discourse context and thus frame the issues following the researchers' point of view. Second, by probing individuals' beliefs about knowledge the social processes of knowledge creation, justification, and legitimation are collapsed into mentalistic entities (Lemke, 1988; Toulmin, 1979) capable of being categorized and compared. Such a view contrasts with the social practices leading to knowledge claims in the first place (i.e., Bazerman, 1988; Goodwin, 1994; Knorr-Cetina, 1999). In a review of research methods for studying the nature of science -- which considers many epistemological issues -- Lederman, Wade, & Bell (1998) noted the need to examine classroom practice rather continuing to document students' and teachers' conceptions. These reviews note that value can be had from studies of conceptions of knowledge and science, but missing are studies considering epistemological practices in everyday action.

Studies of learners' epistemological frameworks

A third tradition examines learners' epistemological frameworks and their influence on learning processes. This research traditional, while not exclusively focused on science education, has demonstrated a relationships between learners views of knowing and learning (e.g., Roth & Roychoudhury, 1993). Hofer and Pintrich (1997) reviewed research concerning students' thinking and beliefs about the nature of knowledge and their relation to learning. In this review they identified the central conceptual frameworks and methodologies of different research approaches examining such issues. Beliefs about knowledge for individual learners are the locus of investigation. A recent special issue of the journal Educational Psychology Review (Schraw, 2001) exemplifies this point of view. For example, Hofer (2001) characterizes this research as "personal epistemology" and notes the focus on "ideas individuals hold about knowledge and knowing" (p. 353). Duell & 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 (p. 44-445). The general theoretical issue centers on learners' beliefs and changes in belief. Methodologically, this research tradition is concerned with addressing the complexities of studies of learners' beliefs while developing questionnaires and instruments to measure beliefs about knowledge and learning (Duell & Schommer-Aikins, 2001; Schraw, 2001). The focus is on learner acquisition of knowledge and less on the social (Kelly, Crawford, & Green, 2001; Roth & Lucus, 1997) and epistemic (Grandy, 1997; Duschl, 2000) processes of inquiry, learning, and knowledge development.

In our view research of this sort has a role to play in understanding student learning in science education settings. However, examination of learning without consideration of the broader disciplinary practices of knowledge generation and justification falls short of delivering educational implications. A missing piece of this research is the ways epistemological issues manifest in discourse processes of learning situations – admittedly not a focus of this work. Through our review of some relevant issues from science studies, we found that the study of epistemic practices *in situ* has led to new perspectives about learning science (Kelly, Brown, & Crawford, 2000; Lynch & Macbeth, 1998; Roth, 1996). Interesting lines of development may occur by merging some of the sociocultural research that examines the appropriation of knowledge through discourse processes of learning with the personal epistemological research centered on how individuals' take up learning opportunities depends on extent beliefs about knowing and learning.

Missing elements: Studies of epistemic practice *in situ*

There has been significant theoretical and empirical research regarding epistemology and science education. In Table 1 we present a summary of the current research in these three research programs: (a) studies of theory-change models in science and education; (b) studies of views about knowledge and science; and (c) studies of learners' epistemological frameworks. For each case we considered the focus on current research as well as ways the research programs may integrate the emerging research issues of the role of language, the social basis for knowing, the importance of epistemic practice emanating from our review of science studies. As a general trend, the empirical work has generally conceptualized epistemology of an individual knower's understanding of knowledge issues. Thus, while the theoretical work identifies the importance of communication, argumentation, and community, the empirical work has tended to consider individuals' beliefs. This is not to denigrate work of this sort but rather to recognize the limitations it has in helping inform the design of science learning environments. There are many important reasons to consider learner's epistemological views. Nevertheless, little research has examined knowledge construction *in situ*, from an empirical point of view – precisely the sort of work that speaks to the social-interactional issues identified as pedagogically important in reformed-minded science pedagogy. This problem suggests future work consider such issues.

Future directions for epistemological studies in science education

Discourse studies of knowledge construction, appropriation, and justification

One future direction for epistemological studies in science education is to consider the situated, everyday practices that define science and knowledge in educational and other settings. Some initial work in this direction shows promise for respecifying important issues such as reason and evidence within a social context (e.g., Ballenger, 1997; Kelly & Chen, 1999; Lynch & Macbeth, 1998; Millar, 1989; Richmond & Striley, 1996; Roth, 1996). Studies of this sort focus on epistemic practices rather than epistemological beliefs. We use epistemic practices to refer to the specific ways members of a community observe, infer, justify, evaluate, and legitimate in the process of making knowledge claims.

One line of research concerned with knowledge construction and justification focuses on how students come to use evidence. Studies of how students formulate evidence in argument provide important examples of how epistemological issues occur through situated activity (for review, see Duschl & Osborne, in preparation). For example, in a study of bilingual Haitian students, Ballenger (1997) identified how students were provided with multiple points of entry to scientific discourses, such as interpreting evidence and making claims, and through the use alternative genres of talk, such as storytelling and joking. By allowing students to populate the science discourse with their own intentions and purposes, the teacher created conditions under which students were able to direct their claims and comments to other students. Thus students were able to engage in dialogical processes supporting science learning. Similarly, Warren, Roseberry, & Conant (1994) argue for the importance of argument and persuasion in the production of scientific knowledge. They drew from science studies to create analogies for constructing epistemologically rich experiences in science classrooms. Their study of language minority classrooms in a large urban high school demonstrated how students could engage in self-directed research of bacteria in a local pond, and subsequently in their homes and school. The authors found that students were able to appropriate new ways of knowing through their participation in the community of practice. These and other studies of classroom discourse (e.g., Carlsen, 1997; Kelly, Druker, & Chen, 1998; Patronis, Despina & Spiliotopoulou, 1999; Richmond & Striley, 1996) draw from argumentation theory to develop methods and theories for examining epistemological issues such as knowledge justification in the actions of participants in education settings.

Another direction for research concerned with the knowledge construction, appropriation, and justification in everyday activity examines the role of writing in science. Historically, writing has played an important role in defining, and being defined by, evidentiary norms within scientific communities (Atkinson, 1999; Bazerman, 1988). In science education, there has been renewed interest in the relationship of writing and inquiry. For example, the science writing heuristic [SWH] has been proposed a to promote science learning through writing during laboratory experiences (Keys, 1999;

Keys, Hand, Prain, & Collins, 1999). The science writing heuristic provides ways for students to learn how to use evidence by promoting "connections among investigation questions, procedures, data, evidence, and knowledge claims" (Keys et al., 1999, p. 1065). Studies of student use of writing science have shown student development of meaning about science concepts, links between observation and higher inference assertions, and metacognitive awareness. Two identified research issues emerged out of these studies. First, there is a concern for greater emphasis on student understanding of how knowledge claims are established in science. Second, there is a need to understand how through writing students can some to understand uses of evidence typical of scientific communities (Keys et al., 1999; Prain & Hand, 1999). Thus, much like learning to use evidence in laboratory work through spoken discourse, learning to write concerns some central epistemological issues around uses of data, inference, and evidence. The development of the science writing heuristic and its application in educational contexts leads us to suggest a closer examination of the epistemic practices tying between inquiry and writing.

One set of studies attempts to tie the relationship of community norms communicated through spoken discourse to the development of argumentation strategies in student writing (Kelly, Chen, & Prothero, 2000; Kelly & Takao, in press; Takao, Prothero, & Kelly, 2002). Kelly et al. (2000) used an ethnographic approach to examine how instructors, texts, and technologies (interactive CD-ROM with earth data) in interaction with students, came to frame epistemological issues around the writing of science in university oceanography. The analysis of spoken and written discourse identified ways teachers and students came to define particular views of disciplinary knowledge through the everyday teaching and learning practices. Specifically, results show that through discussions centered on writing in science, the course participants considered the socially constructed nature of science (e.g., issues of funding, audience, economic and political ramifications); the role of expertise (e.g., considering speakers' roles in framing arguments); the uses of evidence (e.g., supporting conclusions with an evidential base); and the importance of responsibility (e.g., citizens' role in the use and understanding of scientific knowledge). Discourse analysis of the discussions of these issues by the course teachers and students revealed two thematic stances toward scientific writing: (a) Writing in science was presented as a situated practice that required an understanding of the reasons, uses, and limitations of written knowledge; (b) what counts as writing in science was presented as being shaped by a community's procedures, practices, and norms. While this study identified some of the social practices associated with presenting ways of writing in science, and thus ways inquiry was framed in the discipline of oceanography, there remained questions about the students' perspective on such issues and the students' appropriation of the presented practices in their own writing.

The second study introduced an argumentation analytic to assess the university oceanography students' use of evidence in writing (Kelly & Takao, in press). Drawing from rhetorical studies of science writing (Bazerman, 1988; Latour, 1987; Myers, 1990) and studies of argumentation in science education (Kelly & Chen, 1999), a model for assessing students' arguments was used to analyze the relative epistemic status of propositions in students' written texts. Student arguments were analyzed through a process of sorting propositions by epistemic level and identifying the explicit links within and across levels. These epistemic levels were defined by discipline-specific geological constructs from descriptions of data, to identification of features, to relational aspects of features, to theoretically formulated assertions. This form of argumentation analysis allowed for assessment of each student's writing on normative grounds and for comparisons across students' papers. This analysis identified the ways students were able to engage in the epistemic practices tying specific data inscriptions to models and theories in geology.

Although a comprehensive review of studies of the situated practices around knowledge construction, communication, and evaluation is beyond the scope of this paper, the few illustrative examples we presented point to some useful directions to research in this area. One issue emerging is a need to consider how epistemological issues play out in four different domains: subject matter domains, problem solving situations, epistemological contexts, student populations. First, initial studies of everyday epistemic practice suggest the possibility of disciplinary variations, much like those found in science studies (cf., Knorr-Cetina, 1999). For example, Kelly & Takao's (in press) study of argumentation in physical oceanography may show disciplinary uniqueness as well as common practices across science subject mater areas. Such questions remain unanswered, and pose intriguing possibilities as research in science education continues to recognize the need for research in sciences education.

Second, variations may also exist in problem solving situations. For example, the problems posed for the study of student self-directed research of bacteria in a local water systems (Warren, Roseberry, & Conant, 1994) may offer opportunities for learning science concepts, communication, and epistemic practices that differ from other laboratory-oriented contexts (e.g., Keys, Hand, Prain, & Collins, 1999).

Third, different educational settings may pose unique epistemological contexts. For example, Duschl (in preparation) described the tensions of teaching biological conceptual frameworks in museum settings where the typically extended-time events of biology (growth, development, decay) are not conducive to the visitors relatively short visits to science exhibits. However, through the construction of carefully organized exhibits which included postcards, sent to visitors one month after their visit, the science learners could be involved in generating data, participating in community practice, and reporting results. As science is studied in a continually diverse group of settings (schools, science camps, museums, homeless shelters, field trips) epistemological contexts are likely to vary both within and across such settings. Descriptive study of how knowledge is proposed, communicated, appropriated, evaluated, accepted or rejected will contribute to understandings of how educational goals may be met.

Finally, there are potentially interesting variations in the epistemic practices brought to learning situations by different student populations. For example, Lee (1999) studied the response of three student populations (Caucasian, African-American, Hispanic) to the Hurricane Andrew natural disaster in south Florida. She found that students' previous knowledge, spiritual views, and world views influenced how students accounted for the event, with variations noted across ethnicity, gender, and socio-economic status. This research suggests that studies of epistemological issues in science education needs to consider the variation in students populations, particularly in those cases where students background may led to interpretations alternative to those of tradition science.

Modeling and explanation formation

A second major direction concerns the uses of sociocognitive modeling and explanation formation (Giere, 1999). Studies of this sort would focus on the epistemological dimensions of science conversations including ways teachers and students formulate ideas, construct arguments, debate evidence, model phenomena, draw, and write. To understand how this perspective can contribute to future work in epistemology and education, we need to consider some historical trends in science education. When we look back at science education curriculum, instruction, and assessment models over the last 50 years, there have been two perspectives that have dominated policy and practice. One is the focus on content and process (CP) and the other is the focus discovery and inquiry (DI). Employing ideas borne out of epistemology and sociology of science that inform the growth of scientific knowledge we wish to propose a third alternative focus, namely an evidence and explanation (EE) focus. An EE focus we will argue affords opportunities for the development of evaluative criteria to examine the status of knowledge claims that the neither the CP nor DI can. By focusing science education on a model that tracks both the construction and evaluation of knowledge claims, epistemological contexts and considerations become essential. For at the very heart of the enterprise is developing in learners a sense of the epistemological criteria for determining “what counts” as evidence and as explanation.

Each of us in our own ways, but with a great deal of commonality, has been engaged in research that examines the design conditions that support meaningful science learning. We are each committed to the ideal that design of effective science learning environments is fundamentally about the coordination of three goals – conceptual goals, epistemic goals, and communication/representation goals. Within this tripartite goal frame, we see language and language processes as critically important both for the learners and the teachers. However, we have each come to struggle with the subtle ways that scientific language and thinking can be nurtured in classrooms. Hence our concern for the epistemological structures of language. Consider the following framework for instruction proposed by Duschl (2000). If we take the EE focus and treat it as a continuum, there are specific decision making points along the continuum that require epistemic thinking. We fully recognize and embrace the philosophical positions that link theory to observation but wish for the purpose of argument to talk about the start of the EE continuum as beginning with a set of collected data. The first decision point in the EE continuum is the transformation of data to evidence. In Figure 1 this is indicated at T1. The second decision point is the transformation (T2) of the evidence into patterns and models. The third decision point is the transformation (T3) of the patterns and models into explanations.

Each of the transformations represents an opportunity for argumentative discourse or epistemic discourse/dialog since each transformation is asking learners/thinkers to come to terms with 'what counts' as appropriate evidence, patterns and models, and explanation for the scientific inquiry undertaken. In turn, then, we would argue there is a need to examine both the specific criteria learners employ and the criteria the structure of knowledge in the inquiry domain or context demands. Our concern is that considerations of the former psychologicalized versions of student's epistemologies has begun to weigh in more heavily than considerations for the latter.

Our position is that the complex relationship between evidence and explanation in science, a relationship that harbors conceptual, epistemological, and social discourse dynamics, warrants a systemic examination of understanding the development of the criteria learners employ to relate evidence to explanations. With regard to the three transformations in the Evidence-Evaluation continuum this would imply considering:

- criteria for assigning data to one of four categories: fact/evidence, artifact, irrelevant or anomalous;
- criteria for selecting strategies and tools for identifying patterns/models from selected data;
- criteria for developing or selecting theories or explanations to account for the patterns/models and after the completion of one inquiry and in preparation of the next inquiry;
- criteria for deciding if, and then what, new data are needed.

Each of the three transformations in Figure 1 presents a discourse opportunity where learners can begin to examine the dialectic between data and theory. The dialectics of theory informing us about the relevant facts and of facts telling us what are the significant theories is a central dynamic among scientists (Ackerman, 1985) but unfortunately has been and continues to be a missing dynamic in K-12 science education. One explanation for the exclusion of the data dialectic in science classrooms is the continued belief in deficit models of what it is that children cannot do as learners in science classrooms. A recent report of research by Smith, Maclin, Houghton, & Hennessey 2000), clearly demonstrates that with proper learning environment conditions elementary age children are capable of understanding complex aspects of the nature of science. Metz (1991, 1993 & 1995) has produced evidence that children in the very beginning of formal education are able to engage in formal reasoning tasks (e.g., design of experiments, testing hypotheses) when the learning environment is formatted to support reasoning about data. Lehrer and Schauble (2002) also report a set of impressive results on elementary school children reasoning with data in the pursuit of answering scientific and mathematical questions. Centrally important to the design of the learning environment is the use by students of various inscription devices that represent and communicate patterns of data and information.

These three research programs reveal how important it is to engineer learning environments that provide affordances for learners' engagement with the conceptual, epistemic, and social dynamics of science. While there are significant theoretical and programmatic differences among the three research programs, one common element is the use of colloquia or conversations around investigations. The idea of colloquia in science classrooms is taken from Landsdown, Blackwood, & Brandwein (1971). Grounded in Vygotsky's theory of learning that meaning and understanding is obtained through language, colloquia are 'speaking together' opportunities that begin with a "pooling of observations, getting a collection of facts into the arena, so to speak, to make individuals aware of common data seen from different viewpoints. This is the beginning of 'speaking together'" (Lansdown et al. 1971, p. 120). We see this quote as an example of a T1 discourse exchange (transformation of data to evidence).

We maintain that there is an imbalance in science learning environments between the use of scientific instruments and the opportunities to use and develop discriminating scientific language. As advances in scientific tools and instruments have been extended and refined and been brought to classrooms, either as data sets (e.g., worldwide earthquake data) or as tools for pupils to use (e.g., real time computer supported data gathering tools), the extension and refinement of the discriminating language found in the data texts has lagged far behind. While post-Sputnik curriculum efforts have been responsive in getting tools, techniques and instruments that extend human sensory apparatus into the hands of learners and teachers, these same curriculum efforts have been much less successful in creating instructional contexts for developing the scientific languages that refine and extend the discriminations that can be coded into ordinary language. In other words, discussion debates and arguments about understanding what counts, or more generally the discourse practices within an epistemic community, are missing from our instructional frameworks and science learning environments, as described by Grandy:

> What is missing are the epistemic connections that relate theory to supporting data, to conflicting theories, to anomalous data, to equivocal data . . . what can be taken as data and what is disqualified, what is strong evidence and what is weak evidence, is always judged against the background provided by the community's experience with the theories, the data domain, and the instruments in question . . . the demarcations between what counts and what does not . . . is critical to the ongoing enterprise." (Grandy 1997, pp. 49-50).

In school science, the enterprise of addressing epistemic connections is about carefully designed learning sequences and environments that engage students in both investigations and colloquia or conversations around investigations. Such learning environments pose important challenges for research in this area. Due to the lack of research examining how such epistemic connections are made in everyday instances of science learning, a specific research agenda is difficult to formulate. Nevertheless, as argued we envision some fruitful directions including developing and researching instructional approaches that engage students in knowledge construction, justification, and communication; studies of use of inscription-technologies as tools for epistemic activity; and evaluation of the unique constraints and possibilities for developing students' understanding in varied educational settings (classrooms, science centers, museums, field and laboratory experiences). We propose a set of research questions in Table 2.

Knowledge legitimation in education

A third tradition involves critical theories of knowledge, particularly those considered traditionally associated with science. Such critiques in science education have come from feminist perspectives (e.g., Barton, 1998), multicultural education (e.g., Krugly-Smolska, 1996), critical theory (e.g., Kyle, 1991) and from the point of view of indigenous knowledges (e.g., Aikenhead, 1997, 2001). Increasingly, science and scientific knowledge are being contested and subject to critique that centers on epistemological issues (Barton & Osborne, 1998; Harding, 1993). These critiques pose challenges for science education and offer possibilities for enhancing the views of science underwriting pedagogy and the pedagogies supporting differing views of science.

There are many examples of established and emerging research that contests one or more aspects of the epistemological positions taken to count as scientific. For illustrative purposes we review liberatory pedagogy and cultural border crossing. Osborne & Barton (1998) described a number of key features of liberatory pedagogy in science, informed significantly by feminist (Barton, 1998) and multicultural education (Barton, 2000). In an article entitled, Constructing a liberatory pedagogy in science: Dilemmas and contradictions, Osborne & Barton (1998) proposed a liberatory pedagogy for science education. Such an approach is guided by questions and interests of students and consider both how science is socially constructed and how particular views of science promulgated in schools may lead to different social identities for learners. This approach is motivated by the inequalities found in science and seeks to foster ways science can be interpreted in context of race, gender, and class. Thus, a liberatory approach stands to challenge some of the views of science as often presented in schools (i.e., science as objective, based on universal truths, and for a cognitive elite). Nevertheless, as argued by Osborne & Barton, the critical thinking associated with liberatory science education may include student understanding the content and processes of science (e.g., theorizing, observing, generalizing) as students develop a stance of critical toward science.

As another illustrative example we review some of the work concerned with cultural border crossing by students. Again, our intention here to bring forward a few illustrative examples of research that pose new questions for epistemology and science education, rather than say provide a comprehensive overview of the field. Aikenhead

(1997) proposes to treat various ways of knowing about nature from the point of view of different cultures. The knowledge and practices of Western science thus represents one way of knowing, i.e., an indigenous knowledge of a cultural group (Watson-Verran & Turnbull, 1995). For the example proposed, Aikenhead contrasts Western science with First Nations knowledge of nature. The contrast notes how the two perspectives can be mutually informing, while recognizing epistemological differences: first nations epistemology concerns knowledge derived from personal and tribal experiences; individual and collective perceptions, thoughts, and memories; and from the spiritual world evidenced through dreams, visions, signs and interpreted by elders (p. 221). Scientific epistemology, at least as presented in school settings, tends to be characterized as mechanistic, focused on eradicating mystery, objectively decontextualized, and analytic. Despite the cultural disconnect between first nations' peoples world views and that of Western scientific communities, Western science offers some practical ends related to economic development, environmental responsibility, and cultural survival. Aikenhead proposes that learning science be viewed as cultural border crossings, in which teachers act as facilitators as students learn to negotiate the different sub-cultures in their lives. Aikenhead thus explains:

> A cross-cultural perspective for the science curriculum suggests that learning results from the ever-changing interactions among: (1) the personal orientations of a student; (2) the subcultures of a student's family, tribe, peers, school, media, etc.; (3) the culture of his or her nation; and (4) the subcultures of science and school science. (Aikenhead, 1997, pp. 232-233)

In our review of science studies, we identified a few trends regarding how epistemological issues are being considered for those studying admittedly rather conventional science (e.g. high-energy particle physics, cultural archaeology). We noted that there is an increased recognition in the importance of understanding the role of language and communication in science, in the role of relevant social groups in defining what counts as science (e.g., through considerations of what counts as worthy of study, as evidence, as argument, as experimentally competent), and in the move toward the empirical study of everyday epistemic practices. Some of the issues raised by liberatory and border crossing science show similarities in those trends we found in science studies and these emerging new views in science education. The moves toward considerations of language, social knowledge, and epistemic practices suggests that issues of universalism and multiculturalism (Cobern & Loving, 2001; Stanley & Brickhouse, 1994;) may not be resolved by *à priori* demarcation criteria. Rather, the empirical investigation of ways that people construct ways of knowing may led to new forms of communication and further recognition of how different perspectives can learn from each other (Lewis & Aikenhead, 2001). Thus, through the study and comparison of situated practices, different perspectives may be examined in detail, rather than in the abstract.

A research agenda for epistemological studies in science education may take up the questions of knowledge legitimation (Habermas, 1975) and consider the ways different views of science contribute to pedagogy. We suggest that descriptive work analyzing the epistemic practices of knowledge construction, appropriation, communication, and justification can contribute to these ongoing conversations. Such an empirical point of view, however, needs to consider some normative ideals regarding what counts as science. For example, feminists such as Longino (1993) recognize various levels of bias in scientific practice, yet the argue for a normative view of science, one that considers expertise (Norris, 1995), but is open to democratic decision making and rational discourse (Brickhouse, 2001). Longino (1993) proposed ways of mitigating against bias in science by developing norms for deliberative processes of knowledge validation, i.e., critical dialogue within an interactive dialogic community. She was concerned both with mistakenly excluding those of alternative perspectives but with scientific merit, as well as establishing criteria for excluding as scientific those perspectives with little rational merit, for example, “new age ‘crystalology’ or creationism” (p. 118). Longino propose four criteria to achieve the “transformative dimension of critical discourse” (p. 112):

1. There must be publicly recognized forums for the criticism of evidence, of methods, and assumptions about reasoning.
2. The community must not merely tolerate dissent, but its beliefs and theories must change over time in response to the critical discourse taking place within it.
3. There must be publicly recognized standards by reference to which theories, hypotheses, and observational practices are evaluated, and by appeal to which criticism is made relevant to the goals of the inquiring community.
4. Finally, communities must be characterised by equality of intellectual authority. (Longino, 1993, p. 112)

This work suggests a line of research that examines theoretically contestable dimensions of science education as well as ways to develop transformative critical discourse within an interactive dialogic community – both in educational research communities and communities of learners in various educational settings.

Some possible directions for epistemological studies in science education

We proposed thinking about three new directions for epistemological studies in science education: (a) discourse studies of knowledge construction, appropriation, and justification; (b) modeling and explanation formation in educational settings; and (c) knowledge legitimation in education. While each of these new directions has its own unique foci and approaches there is a common trend toward examining science and knowledge from social and cultural points of view. In Table 2 we present a summary of such research considering the issues we identified from science studies: the role of language, the social basis for knowing, the importance of epistemic practice. The intersection demonstrates the numerous opportunities for new directions in epistemological studies.

Educational implications and research questions

We have argued in this paper that epistemology has an important role in education and that to the extent that epistemological issues are investigated empirically, they need not be reduce to studies of individuals' beliefs. Rather, the move toward descriptive study of knowledge producing communities, such as those in science studies, provides models for similar work in science education. Current science education reform suggests an increased focus on engaging students in group inquiry processes, formulating evidence, communicating scientific ideas to varied audiences, and understanding the social ramifications of science and technology. These pedagogical recommendations suggest a renewed need for studies of epistemology in science education, but with a view of epistemology that considers the importance of language and dialog; of the role of the relevant discourse community; and of the specific practices within a community that define what counts as science, knowledge, justification, etc. In these concluding remarks, we consider some educational implications, particularly as related to curriculum and assessment, for a sample of instructional approaches in science education. We then consider a set of research questions for each of the research program reviewed.

In our review of research programs concerned with epistemology in science we examined some epistemological implications of instructional approaches. To the extent that instruction purports to develop, transmit, reproduce, or communicate knowledge, all instruction has epistemological implications. Instruction in science entails some view of knowledge construction, justification, and evaluation, etc.; however, not all of the research programs reviewed necessary imply particular form of instruction. For example, studies of students' views knowledge and learning do not suggest an instructional approach; these studies document participants' views. So, while all instruction entails epistemological positions, not all research in epistemology concerns itself with instruction. Therefore for illustrative purposes we chose six instructional approaches with either historical or topical relevance and compared some central curriculum and assessment issues.

The six illustrative instructional approaches are content and process; discovery and inquiry; conceptual change models; evidence and explanation; border crossing; and liberatory pedagogy . Obviously, there are many other ways of teaching science, and even many other ways of naming the approaches. We considered some of the central foci, the overall aims, and implications for the nature of instruction. These comparisons are shown in Table 3. There are a few trends worth mentioning. First, as we move away from content and process and discovery and inquiry to those that consider more explicitly the nature, construction, and evaluation of knowledge, there is a greater emphasis on longer instructional sequences and on problem-based approaches. Second, the evidence-evaluation approach examines epistemological issues both in the knowledge construction, but also in knowledge evaluation. This approach suggests need for assessments directed to next steps in students' understanding. Third, there is a greater recognition is the evidence and explanation, border crossing, and liberatory pedagogy of the social processes of learning. Fourth, border crossing, and liberatory pedagogy bring to the foreground issues of students' identity and how identity lead to conflicts for students as they experience school science. These approaches tie science examine students' social and cultural backgrounds in interaction with the science being considered.

In our review we identified three research program in science education with a history of integration, or focus, on epistemological issues: (a) studies of theory-change models in science and education; (b) studies of views about knowledge and science; and (c) studies of learners' epistemological frameworks. In addition we noted three new directions for epistemological studies in science education: (a) knowledge construction, appropriation, and justification as situated in everyday activity; (b) modelling and explanation formation; and (c) knowledge legitimation in education. For each case we listed in Table 4 a set of possible research questions that either extend or define some new directions for research. We hope these questions may serve as starting point for thinking about new directions for epistemological studies in education.

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Table 1:
Comparison of three current science education research programs informed by epistemology. Shown are the current research issues in each research program and ways these programs may extend in new directions based on considerations of language, social basis of knowing, and a focus on epistemic practices.

Research Program	Current Research Foci:	Emerging research issues: emphasis on role of language, dialogue, & dialectics	Emerging research issues: social basis of knowing in science	Emerging research issues: focus on epistemic practices
Studies of theory-change models in science and education	Conceptual change models of historical changes in science disciplines and of individual learners' accommodation	Examination of concept use in discourse processes in varied educational settings	Consideration of not only disciplinary knowledge, but role of local social group in providing intellectual ecology fostering conceptual change	Examination of epistemological commitments, analogies, metaphors, etc. as interactionally accomplished through discourse processes
Studies of views about knowledge and science	Students and teachers views of epistemology of science as compared to those of experts	Acknowledgement that research instruments and interviews represent a discourse event establishing a context of elicitation for presenting views about science	Consideration of the role of the nature of science in classroom interaction, group affiliation, and views about the nature of science	Consideration of students' views about knowledge in the context of formulating arguments, evaluating evidence, examining justification etc. situated in social practice
Studies of learners' epistemological frameworks	Efficacy of individuals' views of knowing in learning new knowledge	Introduction of role of discourse processes in constructing epistemological frameworks	Integration of socio-historical research into examination of epistemological development and change	Examination of learners' epistemological frameworks across educational settings, social contexts, & learning situations

Table 2:
Comparison of three new directions for science education research programs informed by epistemology. Shown are the current research issues in each research program and ways these programs may extend in new directions based on considerations of language, social basis of knowing, and a focus on epistemic practices.

Research programs:	**Current research**	**Emerging research issues**		
		emphasis on role of language, dialogue, dialectics	social basis of knowing in science	focus on epistemic practices
Discourse studies of knowledge construction, appropriation, and justification	Examination of the lexical, rhetorical, and pragmatic dimensions of discourse in school science; argumentation analysis; uses of writing in science	Examination of role of language, discourse processes, and norms for talking science in learning to participate in epistemic community	Examination of role of discourse community in establishing and enforcing social norms for epistemic practices as related to posing questions, making valid inferences, justifying claims, etc.	Examination of epistemological issues as manifest in different subject matter domains, problem solving situations, and for diverse student populations
Modeling and explanation formation	Focus on content and process (CP) and/or discovery and inquiry (DI).	Consideration of the rhetorical and linguistic forms of language used in science settings, discourse processes of inquiry events, & roles of language in establishing explanation	Examination of evidence as the results of community norms and practices. Considerations of multiple epistemological contexts for student learning	Focus on evidence and explanation (EE): considerations of transformations from data to evidence, from evidence into patterns and models, and from patterns and models into explanations
Knowledge legitimation in education	Consideration of demarcation of science and non-science; importance of understanding multiple frameworks; multiculturalism in science	Examination of the role of norms for scientific discourse as potentially alienating, importance of discourse processes in issues of equity of access	Recognition of scientific knowledge as that of a social group; examination of epistemic and non-epistemic reasons for exclusion; multiple cultures of science	Focus on how specific inquiry processes, ways of knowing count as science in actual practice

Table 3: Comparison of epistemological issues across *selected*[1] science education instructional approaches

Instructional Approaches	**Curriculum and Assessment issues**
Content and process	• Focus on transmitting science concepts and processes • Short-term time frame (e.g., single lessons to 1-2 weeks of lessons)
Discovery and inquiry	• Focus on students' questions, making inferences from experience • Reconstruction of normative scientific knowledge through experience • Short-term time frame (e.g., single lessons to 1-2 weeks of lessons)
Conceptual change models	• Focus on students learning normative conceptual knowledge • Consideration of conceptual ecology, conditions for theory/concept change • Initially influenced by epistemological considerations, later brought in affective, motivational dimensions of learning • Short-term time frame (e.g., single lessons to 1-2 weeks of lessons)
Evidence and explanation	• Focused on opportunities for epistemic discourse and dialog • Centered on conceptual, epistemic, and communicative goals • Emphasis on science-in-the-making • Longer instructional sequences, frequently set in problem-based contexts. • Knowledge assessment for subsequent learning, over–time, centered around concepts, communication, and epistemic practices
Border crossing	• Focused on recognizing value of different (sub)cultural perspectives • Considers students' & teachers' cultural knowledge in relationship to cultural knowledge of science • Sets opportunities for exploration of multiple perspectives, border crossings, & mutual understanding • Instruction set in contexts of students everyday lives
Liberatory pedagogy	• Focused on science education oriented toward changing conditions of oppression • Guided by questions and interests of students, interpreted in context of race, gender, class inequalities • Critical examination of personal experiences; development of expression of identity • Includes critical thinking, content and processes of science (e.g., theorizing, observing, generalizing) • School science linked to understanding of power, inequality, and critique to develop collective sense of agency

1. The position we argue views all science pedagogy as either explicitly or implicitly entailing epistemological positions. We choose a few instructional approaches for illustrative purposes, Obviously, there are many other science pedagogies not represented (e.g, learning cycle, project-based, multicultural, etc.)

Table 4.
Research questions for epistemological studies in science education (page 1 of 2)

Research programs concerned with epistemology in science education:	**Possible research questions**
Studies of theory-change models in science and education	How can thinking about children's ideas integrate sociocultural views of knowledge and learning? In what ways can historical and philosophical literature continue to be mined for understandings about students' learning? What is the relationship of conceptual change to learning discourse features of science? What methodological implications can be drawn? How can theories of theory-change inform equity issues in science education?
Studies of views about knowledge and science	How can studies of students' views of science be investigated through the study of everyday educational processes? How can teachers' and students' views about the epistemology of science inform instructional practice? What are the explicit and implicit ways epistemological practices are communicated through educational practices? How are students' life experiences related to their views of science? How can such views impede or enhance learning opportunities?
Studies of learners' epistemological frameworks	What variations in learners' epistemological frameworks are tied to participation in social groups, cultural practices, particular language games? How can learning in social contexts be informed by the study of learners' epistemological frameworks? How do discourse practices in science education reflect epistemological positions that can be appropriated by students?

Table 4 (continued).
Research questions for epistemological studies in science education (page 2 of 2)

Research programs concerned with epistemology in science education:	**Possible research questions**
Discourse studies of knowledge construction, appropriation, and justification	What social activities define epistemic practices within relevant community? What are the uses of texts and inscription-technologies as tools for epistemic activity? What is the role(s) of students' understanding of substantive conceptual knowledge in engagement in relevant epistemic practices? How to the educational settings (classrooms, science centers, museums, field and laboratory experiences) pose unique constraints and possibilities for developing student understanding of epistemic practices?
Modeling and explanation formation	How do students distinguish fact from artifacts and patterned data from anomalous data? How do students recognize and interpret patterns of data? How do students explain patterns of data? How do students decide which of several alternative explanations is most plausible? How do students decide to change or alter an explanation? What are the unit design principles that promote student engagement along the evidence-evaluation continuum? How can instructional practices take into account the cultural and linguistic diversity of students while promoting student engagement along the evidence-evaluation continuum?
Knowledge legitimation in education	How and in what ways does science education de-legitimate students' personal, cultural perspectives? What relationships can emerge from potential conflicts? How does the perspective of knowers influence notions of evidence use, knowledge claim, inference etc.? Are these perspectives tied to group membership? How are epistemic practices embedded in the world view of knowers, and does this lead to systematic bias? How can science be taught in ways that contribute to students' own cultural knowledge? In what ways can multiple ways of viewing and knowing about nature be mutually informing?

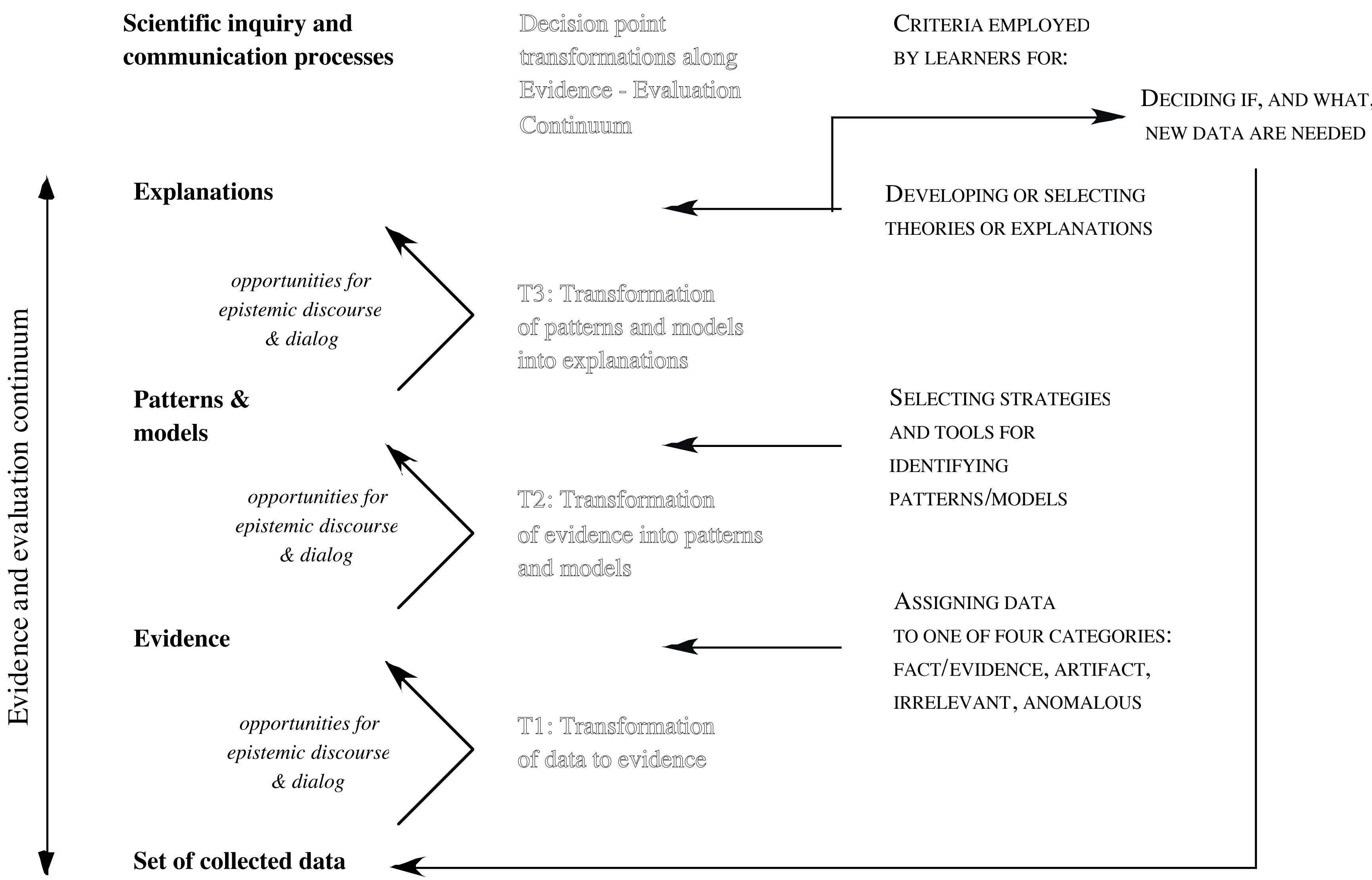

Figure 1. Schematic of Evidence-Evaluation continuum model for consideration of epistemic dialog opportunities