# Chapter 5
# Epistemic Practices and Science Education

**Gregory J. Kelly and Peter Licona**

This chapter draws from the empirical studies of scientific practice to derive implications for science teaching and learning. There has been considerable empirical work from multiple disciplines (cognitive science, sociology, anthropology, rhetoric) informing perspectives about science and the inner workings of scientific communities and institutions. These interdisciplinary science studies examine the practices, discourses, and cultures of scientists and scientific communities. While the empirical study of science has a considerable history, including informing a naturalized philosophy of science, it is an area often less emphasized for informing education. Such empirical studies of science offer insights about science, provide implications for science learning, and model ways of investigating knowledge in action. These studies of disciplinary practices have parallels in education where ethnographic studies of the everyday work of teaching, learning, and schooling have a long tradition. Such studies examine the cultural practices of educational phenomena in various settings, and similarly provide insights into the ways that knowledge is proposed, communicated, evaluated, and legitimized through sociocognitive practices.

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G.J. Kelly (✉)
College of Education, The Pennsylvania State University, State College, PA, USA
e-mail: gkelly@psu.edu

P. Licona
Elizabethtown College, PA, USA
e-mail: liconap@etown.edu

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A key contribution of this empirical work on the practice of knowledge construction is the shift in the consideration of the epistemic subject from the individual knower to that of a relevant social group. This research adds to the work in philosophy identifying limitations of epistemologies based in, or assuming, a Cartesian subject. This shift suggests the need to examine the social processes determining what counts as knowledge, to consider a communal understanding of meaning, to evaluate ideas set in historical and public contexts, and to recognize the importance of the assessment of knowledge claims by relevant groups. Such social processes can become routinized and patterned over time becoming epistemic practices. These epistemic practices include public reasoning and adjudication of competing claims for knowledge.

Epistemic practices are the socially organized and interactionally accomplished ways that members of a group propose, communicate, evaluate, and legitimize knowledge claims. Drawing from studies of science and education, this chapter argues that epistemic practices are interactional (constructed among people through concerted activity), contextual (situated in social practices and cultural norms), intertextual (communicated through a history of coherent discourses, signs and symbols), and consequential (legitimized knowledge instantiates power and culture). Through application of these epistemic practices, communities justify knowledge claims.

Through a review of research from education and science studies, the argument for the relevance of a focus on epistemic practices is developed. From this point of view, a number of implications for developing conceptual understanding, for learning, and for research methodology in science education are derived. The chapter shows how the use of empirical studies of scientific knowledge and knowledge construction processes in schools offers contributions to thinking about science education. This perspective complements the important normative work in epistemology to provide a balanced view of history, philosophy, and sociology of science in science education.

## 5.1 Education Goals for Science and Engineering Education

In a review of major reforms in science education over the past 50 years, Duschl (2008) drew from learning science and science studies to propose that science education be organized around conceptual, epistemic, and social learning goals. While these goals can be delineated, they do not appear as separate objectives of a given science lesson. Rather, they are to be integrated into lessons and experiences with each building off and supporting the others. For example, Duschl notes the importance of building models, constructing arguments, and using specialized forms of language in scientific communities. Such social practices involve and are dependent on cognitive processes and a history of conceptual knowledge that is brought to bear on decisions about argument and models (Toulmin 1972). Recognizing these goals are integrated and central to effective science education makes a shift away from only the products of science, to a view of science that includes the evidentiary bases for knowledge and need for participation in the cultural practices leading to knowledge construction (Kelly 2008, 2016; Longino 2002). The construction and assessment of models, reasoning, and communication each entail use of specialized discourse (Kelly 2014a), and lead to ways that educational goals for science instruction tie to scientific literacy.

Debates about scientific literacy have a history with many educational goals and purposes (DeBoer 2000). Conceptual, epistemic, and social goals all entail the uses of discourses (spoken, written, symbolic) and pose communicative demands on students. Building on these goals for science education is a set of considerations around the uses of language for learning. Norris and Phillips (2003) identified two broad forms of scientific literacy, fundamental and derived. Derived scientific literacy refers to the knowledge to be an informed citizen about science and socioscientific issues. These authors argue that to develop effective knowledge about socioscientific issues (derived sense of literacy), students need to be proficient in reading and writing scientific texts (fundamental sense). The argument we develop builds on this importance of language, but further considers how discourse processes are central to the work of constructing, communicating, evaluating, and legitimizing knowledge claims (Kelly 2011). Discourse refers to language-in-use, including verbal and non-verbal communication and uses of inscriptions, signs, and symbols. Discourse positions people in social groups and identities. Social norms, expectations, and practices are constructed through such discourse processes over time, and in turn shape uses of discourse; thus, discourse both shapes and is shaped by sociocultural practices. Discourse practices are central to the processes of seeking, building, and refining knowledge claims in science.

Across views of scientific literacy there is a common commitment to the need to develop understandings of science in context and to bring ethical and moral considerations to bear on socioscientific decision-making. For example, Aikenhead et al. (2011), aim to develop capacity to engage with issues from a scientific perspective. They suggest that this capacity focus on knowing how to learn and developing knowing-in-action. From this perspective, propositional knowledge of science is too limited a goal. They propose rather that curricular goals for science build on a triad of content, processes, and contexts. Through a review of perspectives on scientific literacy, Norris, Phillips, and Burns (2014) characterize intended outcomes of scientific literacy into three categories: values regarding states of knowing, values regarding capacity to engage with science in context, and values regarding moral and intellectual development of learners.

These arguments for scientific literacy build a view of learning that entails a "mastery of a range of epistemic practices" (Saljo 2012, p. 10) that require knowing how to draw from the texts, signs and symbols of relevant communities and employ concepts in the processes of knowledge construction. Learning the discourse processes of epistemic cultures occurs through acculturation into the ways of being instantiated by members of local communities (Kelly and Green 1998). Such local communities develop social language with unique features. For science, there are commonalities across social languages, for example the formalization of certified

**Table 5.1** Variation in foregrounding of the articulation of three educational goals across three approaches to teaching science

| Disciplinary approach: | Science | Engineering | Socioscientific issues |
|---|---|---|---|
| Educational goals: | | | |
| Conceptual | Construction and understanding of plausible models for representing and making sense of natural world | Design, analysis, and construction of models and technologies for specified purposes | Construction and understanding of science concepts and moral, personal, religious perspectives |
| Epistemic | Understanding of the reasons, evidentiary bases for conceptual knowledge and models | Understanding and optimizing the functioning of technologies and evidentiary bases for measures of success | Understanding the multiple perspectives (e.g., scientific, moral, personal, religious) for the construction of coherent line(s) of reasoning supporting a position(s) on a controversial issue |
| Social | Recognize the procedures used by epistemic cultures to generate, communicate, and evaluate knowledge claims | Recognize the procedures used by design and analysis teams and role of client in generating, communicating, and evaluating technological designs | Recognize the procedures for generating, communicating, and evaluating arguments supporting particular position(s) on an issue |

propositional knowledge, and variations, such as ways such knowledge is talked into being in local contexts (e.g., field-based ecology research group, after school science club). Learning science requires participation in a community of more knowing others that provides contexts for use of social languages where acquisition of scientific social languages is possible (Leach and Scott 2003).

Such participation holds regardless of the diversity of emphases in science learning—products or processes of science. Different science curricula will place emphasis on different aspects of the conceptual, social, and epistemic goals for education. To illustrate some of these differences we consider three types of curricula, science as inquiry (Kelly 2014b), engineering education (Cunningham and Carlsen 2014), and socioscientific issues (Sadler 2004; Zeidler 2014). These orientations toward knowledge and products of knowledge across the three types of educational goals (conceptual, epistemic, social) are presented in Table 5.1. This table demonstrates the ways educational goals vary across three approaches to teaching science. In each disciplinary approach, different conceptual, epistemic, and social practices are foregrounded.

Developing knowledge, values, and capacity to apply knowledge in action requires a recognition by educators of a commitment to "certain paths and goals of development and growth" that are more valuable than others (Norris et al. 2014, p. 1319). The argument we develop here is that this commitment is not just to learning the products of science, but rather involves understanding the importance and value of the disciplinary nature of science and engineering fields. This means that our view of epistemology is not one of a personal way of knowing, but rather that there are disciplinary ways of knowing that can be empowering for learners and recognized by legitimizing institutions. Thus, we turn to studies of science in action (history, philosophy and sociology of science, plus anthropology and rhetoric of science), to examine the processes and values associated across four categories of epistemic practices - proposing, communicating, evaluating, and legitimating knowledge claims.

## 5.2 History, Philosophy, and Sociology of Science (HPS) and Epistemic Practices

Studies in the History, Philosophy, and Sociology (HPS) of science and science teaching have drawn largely from the fields of history and philosophy. For example, a recent comprehensive HPS handbook (Matthews 2014) leaves sociology out of the title and largely out of the series of chapters. The perspectives in this handbook and elsewhere drawing from history and philosophy of science are valuable and have advanced thinking in education in a number of ways (e.g., Duschl 1990; Matthews 2015), including setting a prominent role for disciplinary knowledge in considerations of educational aims. To complement such perspectives, in this chapter we draw from an alternative body of literature that sets scientific knowledge and practice (i.e., science-in-the-making, Kelly et al. 1998) as the foci of empirical investigation. Studies from anthropology, sociology, and rhetoric of science have been introduced into conversations about science education in a number of ways over an extended period of time.[1]

Studies from the sociology of science have been ignored and often criticized in science education (e.g., Koertge 1998; Slezak 1994a, b; for alternatives, see Allchin 2004; Kelly 2005). Such criticisms often focus on the ways that sociology of science can be interpreted to offer a debunking critique of science. The emphasis on the social, causal explanations for the success for scientific theories and scientists by sociologists (Collins 1985) appears to run counter to not only the value of epistemology as a discipline, but also to a central educational goal of developing rationality among students. In a more recent book, Collins (2014) noted how a sociological understanding of science has identified the unique values, commitments, and expertise of scientific communities (p. 124), which cohere with educational goals. While we recognize problems in the sociology of science, we make three counter arguments to such criticisms, and in doing so leave open the possible value of the empirical study of scientific practices.

First, it is important to differentiate normative from descriptive accounts of social practice. Translating descriptions of actual practice to normative goals misses the central point of the empirical studies of practice. Normative goals may be informed

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[1] See: Collins 2007; Ford 2008; Heckler 2014; Kelly and Bazerman 2003; Kelly et al. 1993; Kelly and Crawford 1997; Roth et al. 1996; Stewart and Rudolph 2001.

by studies of everyday life in social settings, but such educational goals are dependent on deontological arguments that include a range of considerations beyond a replication of current practice. Empirical studies of practice identify how knowledge is constructed *in situ*; this may expand the range of understanding about knowledge construction, but not every behavior needs to contribute to normative goals. Second, for the purposes of educational theory, sociology of science and other empirical studies of science need to be read and understood from an educational point of view. Such studies may expand the range of knowledge about science, bring to light inner workings of epistemic cultures, and identify ways that claims are modified through experimental and textual work. These valuable insights can contribute to the development of educational programs without suffering from excesses of a relativist epistemology (Allchin 2011). Third, ethnographic studies of science from sociology and anthropology offer a range of methodological orientations and approaches to understanding cultural practices of science. The overall stance of investigating science-in-the-making through inquiry into how knowledge is produced offers a model for studies of education (Kelly et al. 1998). This approach asks similar questions about what counts as knowledge in school settings. The examination of the ways that groups produce knowledge offers a model that can be taken up in education.

### *5.2.1 Illustrative Examples of Epistemic Practices from Education Informed by Science Studies*

We define epistemic practices as the socially organized and interactionally accomplished ways that members of a group propose, communicate, evaluate, and legitimize knowledge claims (Kelly 2008, 2016). Social practices are patterned actions that are recognizable among members of a group. Epistemic practices are central to both science and education. Practices are learned through participation and often entail extended interactions with members already familiar with the ways that practices are recognized as socially significant. Such practices are not static over time and may be contextualized to relatively local groups – for example, a laboratory technique may be invented and used in a local context of research before being spread with various dissemination activities. Thus, epistemic practices are defined and acknowledged in a group that can be very localized and mutable, or extend to large membership through formulation (e.g., Hamiltonian function, standardized laboratory protocols). These epistemic practices are formed in endogenous communities and may be constructed and extended, modified and changed, and are based in substantive assumptions, such as the ontological categories of a discipline. Furthermore, in education, there are various forms of epistemic practice that vary with relevant pedagogical goals. For example, epistemic goals of an inquiry lab may be significantly different than those of a debate regarding socioscientific issues.

Since epistemic practices are field- and time-dependent (changing due to the challenges of knowledge production), there is not a limited set of “science practices.” This contrasts with how “the scientific method” is often interpreted in education as a set of linear steps. Rather, there are disciplinary (and other!) ways of knowing that vary across the multiple ways that humans make sense of their experience. The point is not to define a given set of eight practices (NGSS Lead States 2013), or the five steps of the scientific method. Rather, the idea is to identify the ways people come to know and recognize the value of making sense in systematic ways that render evidence open for public scrutiny and evaluation.

To illustrate the four categories of epistemic practices (ways of proposing, communicating, evaluating, and legitimizing knowledge), we draw from a series of education studies of Kelly and his colleagues. These studies represent an empirical program of epistemology – that is, they focused on what counts as knowledge, reasoning, justification, and representation in science education settings. The studies were informed by science studies and educational ethnography.

One dimension of epistemic practices concerns the value of *proposing knowledge claims*. Kelly et al. (2001) examined the discourse processes of four physics groups studying oscillatory motion. The student discourse was analyzed from a sociolinguistic perspective that considered the verbal and non-verbal communication, which included the signs and symbols, proxemics, and prosody of the conversations (Green et al. 1988; Gumperz 2001). The student groups made a series of knowledge claims. In this example, students needed to make interpretation of the physical events (oscillating masses), symbols (real-time, computer generated graphs), verbal and written prompts (student talk, teacher lab guide sheet), and embodied motion (student imitation of motion through physical movement of hands). The basis for much of the generation of knowledge claims was produced by the data acquisition and representation technologies. The computer generated visual texts were a consequence of the live complex physical phenomena and offered sufficient interpretative flexibility (Knorr-Cetina 1995) to provoke sustained conversation. Thus, a series of knowledge claims, often as false starts and initial thinking, were central to the activity by providing a focus for the students' processes of deliberation about the phenomena. The knowledge gleaned from the educational experience was supported by these knowledge claims – that is, ways of proposing assertions about the physical phenomena.

The methodological orientation was supported by studies of scientific practice, including Garfinkel et al. (1981) analysis of the "local, interactionally produced, recognized, and understood embodied practices" (p. 135) of astronomers through the processes of discovering, naming, and textually identifying a pulsar. Much like the astronomers, the physics students made sense of the phenomena by proposing a series of claims that were considered and modified over time by the group members.

Kelly and Brown (2003) examined the communicative demands of learning science through technological design. In this case, third grade students were tasked with using science to inform the design of functioning solar energy devices. *Communicating knowledge claims* is central to the development of knowledge generation. In this instance, the knowledge claims emerged from a series of events that required the students to work together in teams to study designs, brainstorm ideas, negotiate and renegotiate design strategies, and test and evaluate their solar devices. The students participated in multiple speech situations, where knowledge of science, materials, and phenomena were in question. Knowledge claims were forwarded to multiple audiences (e.g., small student groups, presenting ideas to classmates, student "scientific" reporter). The technological design challenge offered students multiple forums for drawing from extant knowledge and for advancing their own thinking. In this study, the students were situated in forums where discourse was central to the academic and scientific task. They needed to use sense making, persuasion, and representation of their thinking. While the substance of the communication differed from the formalization often found in scientific texts, the epistemic practices and the need for formulating evidence in particular ways is analogous to the discursive work of scientists (Bazerman 1988; Traweek 1988). The inquiry processes and engineering designs necessitating communication and, in particular, forwarding knowledge claims deemed persuasive by the relevant audience.

Takao and Kelly (2003) applied rhetoric of science and argumentation analysis to consider ways of recognizing and evaluating adherence to scientific genres in writing. *Assessing the merits of the presentation of evidence* is one way that knowledge claims can be evaluated. Drawing from rhetoric of science (Bazerman 1988; Gross 1989) and theories of argumentation (Kuhn 1992), this study first reviews key features of evidentiary-based arguments in science. Scientific evidence is presented in particular genres (patterned uses of language) with unique features—that is, knowledge claims are justified through socially accepted ways of presenting evidence. The study focused on methods of assessment of university students' uses of evidence regarding plate tectonics. Through a review of the literature and the analysis of the students' written arguments, key features of the situated nature of the genre of writing evidence were examined. In this case, the formulation of evidence entailed building from low inference claims to progressively higher order theoretical claims, while identifying coherence across epistemic levels of generality. The analysis of the students' papers identified this genre-specific feature of using evidence in geology. These features were difficult for even experienced graduate student instructors to recognize in others' writing. The example shows while the assessment of knowledge claims is important in science, the processes often remain tacit and unrecognizable for participants. This is an example of how science studies can make visible the epistemic practices associated with assessment knowledge claims.

In a study by Reveles et al. (2004), the teacher (Cordova) positioned his students to *legitimize a scientific point of view* amidst competing ways of thinking about natural phenomena. In this third grade classroom the students are introduced to a set of epistemic practices (organized around investigating, communicating, and using evidence). In this case, the goal of developing improved scientific literacy required more than learning the conceptual knowledge of science, or even the abilities to read and write science (Norris and Phillips 2003) – although the uses of language was an important component. In this example the teacher made reference to science and scientists in an effort to develop students' knowledge of disciplinary practices. He was able to accomplish this through meta-discourse, talk about the classroom talk. In doing so, he built on students' initial ideas and made reference to how they were using scientific concepts to understand phenomena. This is an example of how fostering epistemic practices among young students differs from the uses of such practices in science fields.

In the educational context, a key piece of the learning experience entailed developing students' identities as science learners capable of participating and making sense of scientific practices. This is just one way that knowledge can be legitimized in and through classroom discourse. There are multiple ways that knowledge can be legitimized in science and engineering fields (Pinch 1986). These legitimation processes often entail uses of texts and peer review and many agonistic struggles and competition (Latour 1987; Myers 1989, 1997). Knowledge claims can be proposed, communicated, and assessed, without entering into the socially recognized public knowledge and thus through the processes of legitimation such knowledge claims can become scientific knowledge.

## *5.2.2 Emerging Themes from Study of Epistemic Practices in Science and Education*

### 5.2.2.1 Contexts of Knowledge Claims

Across the four studies mentioned in the previous section, and others in education building on science studies (Jiménez-Aleixandre 2014), an important feature of the learning process is a focus on knowledge across three types of contexts. In philosophy of science, there was a distinction made between the (often messy and confusing) context of discovery and the (inferentially tight) context of justification. Both of these are important for science learners. The context of discovery provides opportunities to learn about instrumentation, how ideas connect to phenomena, and how knowledge claims change through inquiry. The context of discovery also provides opportunities to learn about how seemingly subject-dependent processes such as observation, require cultural knowledge to learn how to observe (Norman 1998). The context of justification remains important, not only to understand how theories change over time (e.g., Duschl 1990; Matthews 2015), but also to understand the ways that evidence gets marshaled in science (Duschl and Grandy 2008). Another context of equal importance is the context of communication and presentation. This context does not occur after the inquiry processes, when the knowledge claims are completed, but throughout the contexts of discovery and justification, as knowledge claims are conceived, put forth, debated, formulated, reviewed, critiqued, and revised. For this, context issues of persuasion and audience play a central role.

### 5.2.2.2 Epistemic Subject as Local Endogenous Community

Studies of epistemology in science education have been based on the epistemology of scientific knowledge (e.g., views of theory change and rationality), or personal epistemologies of individual learners (e.g., how views of knowing influence learning). An alternative view informing this chapter emerges from studies of epistemology *in situ*, focusing on the situated contextual practices of knowledge construction (Kelly et al. 2012). From this point of view, the locus of attention centers on how participants in an epistemic culture decide what counts as evidence, knowledge, and justification. The practices view of epistemology can be informed by both the study of disciplinary knowledge or of learners' views of knowing, but also reorganizes the research approaches to actual practices of knowledge construction. From this point of view, a key feature of knowing is the recognition of the local endogenous community as the relevant epistemic subject (Kelly 2008; Longino 1993).

Situating the epistemic subject in a relevant community of knowers suggests a view of learning as socialization into ways of being, knowing, interacting, and participating. Learning occurs through participation and engagement. Central to such participating is developing social meanings for terms, concepts, processes, and ways of being in a field. Under this orientation, teachers aim to engage students in epistemic practices through knowledge constructing activities. From theories of language socialization, it is clear that it takes significant socialization and acculturation to have meaningful conversations about substantive scientific concepts and procedures (e.g., s and p orbitals in atoms, mass spectroscopy).

As proposers of knowledge claims seek greater generality, claims migrate through increasingly broader levels of critique and legitimation. Longino (1990, 2002) proposed a set of social norms for the development of social (scientific) knowledge. Longino recognized the important role of social processes and values in the evaluation and legitimation of knowledge claims. The four norms are the following: The *venue* refers to the need for publicly recognized forums for the criticism of evidence, methods, assumptions, and reasoning (e.g., research meetings, conference presentations, and publications). *Uptake* refers to the extent to which a community tolerates dissent, and subjects its beliefs and theories to modification over time in response to critical discourse. A basis for criticism of the prevailing theories occurs through *publicly recognized standards*. These standards frame debates and criticism and evolve over time as research groups, communities and disciplines develop new knowledge and practices. Finally, Longino (2002) argued for communities characterized by *equality of intellectual authority*, tempered by relevant levels of expertise and knowledge.

Longino's argument is that such social norms are prescriptive – offering a normative account for public discourse in science. Such norms may be adaptable for learning contexts in education (Kelly 2014b). Longino's perspective offers ways of integrating the results from the practices of inquiry into the social knowledge recognized and legitimized by an epistemic culture, thus showing the importance of normative considerations for epistemology.

## 5.3 Epistemic Practices in Science and Engineering Education

Studies of scientific and engineering practices offer a number of implications for science and engineering education. These studies contribute to the important dimension of curriculum validity by considering the epistemological dimensions of education. By identifying what counts as science, design, engineering, experiment, and so forth, these studies open a range of possibilities for inventive, creative curriculum development. The study of professional practice and the epistemic cultures producing knowledge provides insights into not only how science and engineering are conducted, but also the ways in which knowledge is proposed, communicated, evaluated, and legitimized. Furthermore, ethnographic, sociological, and rhetorical studies of the actions, practices, and texts of professional practice offer models for the study of knowledge in education settings. These implications are noteworthy and complement the work that has emerged from the history and philosophy of science. Nevertheless, studies of professional practices cannot be taken without careful consideration of the educational contexts (McDonald and Songer 2008). Students often have considerably less knowledge and fewer and less developed habits of mind to bring to bear on issues of inquiry. Although when working under conditions with proper scaffolding, students have been shown to engage in knowledge building and reasoning (Lehrer and Schauble 2012), ethnographies of science also identify the highly competitive and sometimes ruthless rivalries in professional communities that would be detrimental to educational purposes. So, while HPS, and in particular the empirical study of science and engineering practice, has demonstrable value for science education, such studies must be read from an educational point of view where issues of ethics, pedagogy, and human development outweigh views of authenticity. There are a number of emerging research programs in education that build on science studies, taking carefully considered readings of this work into the study of epistemic practices in education.

## *5.3.1 Research Programs Regarding Epistemic Practices in Science Education*

Science studies have been taken up and applied to science education in a number of contexts and across a range of educational purposes (e.g., Kelly et al. 1993; Kelly and Crawford 1997; Roth et al. 1996). We now turn to research in science and engineering education that brings science studies perspectives to education. These studies have a common orientation to consider epistemological issues as interactionally accomplished among members of an educational community for specific goals (Kelly et al. 2012). In this section we answer the question: What does a focus on epistemic practice contribute to the field of history, philosophy, and sociology of science and science teaching (HPS&ST)?

### 5.3.1.1 Nuanced Understandings of Language and Its Relationships to Meaning

As we view epistemic practices as the socially organized and interactionally accomplished ways that members of a group propose, communicate, evaluate, and legitimize knowledge claims, engaging in epistemic practices involves making meaning among people through discourse. Discourse is language-in-use and includes spoken and written language, uses of signs and symbols, and non-lexical elements of communication such as body language and eye gaze. A number of studies in science education address epistemological questions through the study of discourse processes. One such research program follows an approach labeled the practical epistemology analysis (Lidar et al. 2010; Ostman and Wickman 2014). Rather than consider the epistemology of science as a known entity, and seeking to inculcate students into this perspective, a practical epistemology analysis focuses rather on the everyday practices of students and teachers making sense of phenomena and developing knowledge. This view takes epistemology as situated "in on-going communication, action, and practice" (Ostman and Wickman 2014, p. 375) and is consistent with the view of epistemic practices developed in this chapter. These studies examine meaning making, in situ, through analysis of the talk and action of members of a group. As the focus is on the work of deciding what counts as knowledge, the authors refer to the perspective as practical epistemologies.

Practical epistemologies focus on what counts as knowledge and how participants construct knowledge in educational events (Wickman 2004). To examine such issues in learning contexts, the researchers draw from Wittgenstein (1958) and focus on the language games of science learning. In this case, language games identify how meanings are constructed in situated actions and tied to ways of life (Heckler 2014). That is, the meanings of key terms are not taken for granted, but examined as either plausibly assumed or at stake in any given conversation. To examine practical epistemologies the research group has developed practical epistemological analysis (PEA). This approach considers those concepts that stand fast (assumed communal meaning) and the gaps (lack of initial understanding) that occur when students encounter challenges through talk or action (Wickman 2004). Students build relations with understood and effectively useful constructs across gaps in understanding. This approach allows for a close examination of how students' epistemologies in action account for the development of meaning. An example of this approach is provided by Lidar et al. (2010) who examined children's discussion about gravity and the shape of the Earth. The study showed how children made different meaning from a shared situation. These meanings were mediated by relevant artifacts such as a celestial globe and maps, and were varied in their adherence to normative interpretation.

#### 5.3.1.2 Disciplinarity and Variation in Epistemic Practices

Science may refer to a body of knowledge, a set of disciplines, or even a way of making sense of nature. The potential for commonality and differences across different substantive disciplines remains an open question for considerations of epistemic practices. That is, we would expect commonality, at least in a family resemblance manner, for some portions of science disciplines, but also recognize that considerable variation is likely. In this section we review some of the ways that epistemic practices are manifest in various science disciplines. Our purpose is to provide illustrative examples of how different disciplines make sense of those aspects of nature studied, and what can be learned by looking across such perspectives.

The individual scientific disciplines – across the life sciences, physical sciences, and earth and space sciences – are often conveniently grouped as “science” and naively assumed to represent common ways of knowing and epistemic practices. While there may be some commonality among general epistemic practices, each of the individual sciences may require students to engage in different ways of making sense and building knowledge (Rudolph 2000). For illustrative purposes we consider some of the research around the disciplinarity in science education and examine the commonalities, but, more importantly, the differences across disciplines. Three examples make the point.

Ault (1998) used the term “domains of inquiry” in order to acknowledge that the different sciences ask different questions and use different data sets. What counts as a legitimate question, evidence, and reasoning varies according to each domain of inquiry. For example, Ault noted that the earth and space sciences seek to retrodict, or answer questions about the past, as opposed to other domains that seek to predict. What counts as data, evidence, and reasoning about past geological events differs from the data, evidence, and reasoning relevant to development of knowledge about biological organisms. Given such disciplinary differences, the epistemic practices in these domains may vary. This is evident in a set of discipline-specific criteria geology education derived by Ault (1998). To engage in geological inquiry students need to draw from specific epistemic practices such as understanding constraints on ambiguity; drawing from independent, converging lines of inquiry; identifying proper taxonomies; extrapolating systems through time; and integrating across temporal and spatial scales. This attention to domain specific epistemic practices would necessitate different pedagogical methods.

In the life sciences, Jimenez-Aleixandre (2014) sought to examine the connections between science learning and the epistemology of science and noted three interrelated dimensions: domain-general and domain-specific features of epistemologies, correct versus productive students’ epistemological positions, and complementary approaches to the relationships between epistemology and science learning. Relevant to our work is her attention to domain-general versus domain-specific epistemologies, most specifically her treatment of genetics and the three aspects of relevance for engaging students: understanding what counts as acceptable science, identifying patterns in data, and recognizing the differences between probabilism and determinism. Such understandings develop through student engagement with genetics and in particular, learning to use and critique evidence through argumentation. Her argument is that the goal of teaching genetics is to support students in developing the capacity to understand and evaluate pieces of information related to genetics. Thus, building the capacity to use and evaluate evidence develops in students the abilities to learn and decipher socioscientific issues such as cloning, genetic screening, and commercial interests in genetics. This study shows how ways of engaging students in epistemic practices can develop scientific literacy in students.

Erduran (2007) and Erduran and Duschl (2004) argued for domain specific epistemological considerations in the analysis of specific features of laws in sciences and models in chemistry. Erduran (2007) made the case that laws in chemistry, such as the periodic law, are not exact and deducible in the ways that laws, such as Newton's law of gravitation, in physics are. She recommended a consideration of the application of philosophy of chemistry to chemical education in three distinct ways. First, she sought to develop ways that an epistemology of chemistry can be related to developmental patterns in students' thinking with respect to understanding how laws in chemistry are generated and evaluated. Second, she found ways that disciplinary-specific epistemology can be used to inform curriculum design. And third, epistemology of chemistry can be used to inform current and future chemistry teachers about how knowledge is structured in the discipline and how this structuring is related to the teaching of chemistry.

While epistemic practices such as argumentation and evidence-based explanations do indeed cross the boundaries of the science domains, such practices may be taken up and applied in domain specific ways that distinguish science and engineering disciplines from each other. Furthermore, the individual science subsumed under the large umbrellas of the life, physical, and earth and space sciences may also differ. Erduran (2007) made an argument noting the difference of the term "law" between chemistry and physics, both physical sciences. Similar inspection is needed in the individual life sciences (e.g. botany, zoology, mycology) as well as within earth and space science in order to consider how what counts as knowledge differs between the sciences.

#### 5.3.1.3 Student Learning About Science Through Engagement in and with Science

One advantage of engaging students in epistemic practices of science and engineering is that they may be able to learn about the nature of the disciplines through participation. This is not to suggest that merely going through the motions of laboratory procedures develops knowledge. Rather, the processes of inquiry, reasoning, and engineering design, among other ways of knowing, offer students insights into disciplinary approaches to knowledge construction if properly organized and reflected upon (Rudolph 2000). We have argued throughout this chapter that the epistemic practices we describe are illustrative examples of the kinds of ways various science and engineering disciplines construct knowledge.

Irzik and Nola (2011) have applied Wittgenstein's notion of family resemblances to the nature of science, or more properly, the natures of the sciences. They argue that across multiple disciplines of science there is a family resemblance of the kinds of activities, values, methodologies, and products. This approach has the advantage of not limiting the nature of knowing, recognizing the value of disciplined approaches to knowledge construction, and combined with reflective practices about activities, values, methodologies, and products may improve students' understandings of and about science. Our examples of epistemic practices have largely fallen into the category of activities, but this does not mean that values, methodologies, and products do not need to be examined and integrated into education as well. Furthermore, any choice of representation of epistemic practices requires a selection of the range of real-world practices of science (Rudolph 2002).

Science learning often situates students in sense making situations, with goals of developing propositional and procedural knowledge. The focus on knowledge construction in student reasoning has led to the practical epistemology employed by students through engagement (Wickman 2004; Sandoval 2005). Wickman (2004) identified the ways that students learned what counted as a valid observation in chemistry. Students drew from the chemical phenomena, prior experience, and the expertise of the teacher. Through these processes, the students addressed gaps in their understanding by patching together meanings derived from use in the contexts of the learning situations. Sandoval (2005) took a similar approach, noting the ways that teaching about science (nature of science) has not been successful at developing robust understandings about science. He noted that engagement in inquiry does not develop an understanding about the epistemology of science. Rather, students are guided by the practical experiences of their locally relevant situation. They develop ways of knowing, or a practical epistemology, that are unlikely to be coherent and explicitly recognized by learners.

Other studies consider how students can learn about science through engagement in scientific activities. Ford (2008) drew from science studies and the psychology of learning to show how students come to understand roles as “constructors and critiquers” (p. 159) of claims. These are important roles that embody epistemic practices of scientists, and may help students take on the role of a skeptical observer. Ford is concerned with developing students’ capacity to assess claims as citizens. He argued that through engagement, students develop a grasp of practice, and while this may not develop immediately into declarative knowledge about science, it can inform reasoning in the public sphere about science issues.

One important dimension of constructing and critiquing claims is the epistemic criteria brought to bear on the decisions regarding evidence. Pluta et al. (2011) examined middle school students’ criteria for judging the quality of scientific models. The students were shown to be able to generate epistemic criteria such as the explanatory functions of models, the role of evidence in making decisions about uses of models, the inclusion of appropriate details in the models, and the accuracy of the models as related to empirical observations. Given the prominent role of models in scientific reasoning (Giere 1999), these criteria are important parts of learning how to engage in the construction and critique of knowledge claims.

A number of studies of epistemic practices in education consider the ways that messages about science are communicated through engagement in activity. While such messages about science may not lead to robust understandings of professional practice (Sandoval 2005), often misconceptions about science are promulgated (Lemke 1990). For example, Oliveira et al. (2012) examined teachers’ uses of hedges and boosters in conversations that implied different levels of certainty in science and thus reflect an implicit view of the nature of science. As teachers often followed the stepwise progression of ideas in textbooks, students received messages about the authoritarian nature of science. In this study, the teachers' choices of how to frame knowledge and draw on only specific practices limited students' understanding of science. Interestingly, while science often publically views itself as open to revision and evidence, this value co-exists with the need to acculturate novices into the ways of being and knowing of the relevant epistemic community (Fleck 1935/1979; Kuhn 1962/1996). While messages are communicated about science through practice, across these studies and others (Akerson et al. 2000), students are shown to need reflective meta-discourse about inquiry activities to develop understandings about science (Reveles et al. 2004). Engagement in epistemic practices provides a basis for such discussions and can offer insights into the processes of knowledge construction.

#### 5.3.1.4 Broadening Uses of Knowledge to Social and Ethical Domains

Inquiry science and socioscientific issues are two approaches to science education that have gained prominence in recent years. These approaches share a common goal in the move away from a traditional approach in which science content is delivered from the teacher to the students with little attention to how this content was produced. While both of these approaches share a common goal, the epistemic practices necessitated by each approach differ. In order to focus on the different epistemic practices promoted by these approaches, it is necessary to consider the separate goals of each approach. Goals of an inquiry approach include promoting students to ask authentic questions, plan authentic investigations, and use the results of the investigations to provide answers to the questions. As students attempt to answer a scientific question, they bring to bear scientific evidence and reasoning. Engineering education is another approach that engages students in science, but for the purposes of technical design or analysis. Across these approaches are variations in the extent of the scope of the relevant ethical domains. In inquiry science, issues of ethics and values often center on the integrity of the research approach. Engineering entails ethics around the application of design and analysis to serve a human purpose, and often the concerns are safety, function, and cost.

The goal of a socioscientific approach is to develop scientific literacy by promoting the exercise of informal reasoning in which students are compelled to analyze, evaluate, discuss, and argue varied perspectives on complex issues that are ill-structured but fundamentally important to the quality of life in social and natural spheres (Sadler 2009; Zeidler 2014). As students consider and attempt to respond to the issue at hand, they may bring scientific, ecological, moral, religious, personal, and/or economic perspectives to bear on the issue. In contrast to an inquiry science approach, a socioscientific approach does not constrain explanations, arguments, evidence, or reasoning to only a scientific perspective. In addition, a socioscientific approach often requires students to take a position on or make a decision about a specific issue. In contrasting across approaches, we can consider the concept of genetically modified organisms (GMO), in this case GMO corn. An inquiry approach might ask, “Does genetically modified corn grow better than wild corn?” On the other hand, a socioscientific issues approach might ask, “Should genetically modified corn be introduced into the natural ecosystem?” An engineering question might be “how can corn be modified to conform to a set of social and economic constraints?” While these approaches use the concept of genetically modified organisms, each asks a different question, thus promoting different epistemic practices in answering the different questions.

In considering the epistemic practices promoted by these approaches we return to the four epistemic practices of proposing, communicating, evaluating, and legitimating knowledge as proposed by Kelly (2008). While an inquiry approach focuses on the use of scientific knowledge, a socioscientific approach also considers knowledge from other domains (e.g., ethical, economic, and religious). As such, students are required to engage in epistemic practices from various perspectives, some of which may be competing. The epistemic practices foregrounded by an inquiry approach would center on the construction, communication, evaluation, and legitimization of a scientific explanation that answers a scientific question. The epistemic practices foregrounded by a socioscientific approach would require students to engage in these practices while attempting to answer the original socioscientific question that often involves taking a position. These arguments are multiple and originate from not only the scientific perspective but also ethical, moral, economic, and religious perspectives. In this way, each perspective may require students to construct, communicate, evaluate, and legitimate (or not) multiple and often competing arguments.

What counts as evidence or reasoning from each perspective may vary, thus requiring students to engage in epistemic practices that go beyond the scope of the scientific content of the argument. For example, a student arguing from the scientific perspective may provide an argument regarding the ecological implications of introducing a GMO into the natural ecosystem. On the other hand, another student may provide an argument from a purely economic perspective regarding the increased yield of GMO crops. In yet a third case, a student may provide an ethical argument stating that it is wrong to introduce an organism produced in a lab into the ecosystem. Each argument originates from a different perspective and would require students to consider what counts as a strong (or weak) argument in each of these perspectives. While both inquiry science and socioscientific issues approaches to science education promote a move away from content-delivery pedagogy, each approach differs in the epistemic practices foregrounded. Engineering provides yet another set of practices that concern identifying the problem, assessing constraints, considering multiple solutions, and providing analysis. In each of these ways of drawing from science and engaging in knowledge building require that students appropriate and take up various epistemic practices.

## 5.4 Characteristics of Epistemic Practice in Science and Engineering Education

Epistemic practices may be appropriated and taken up differently across a range of educational goals for STEM education. While there is no finite set of epistemic practices characterizing science or engineering, we present some illustrative examples across a range of educational goals in Table 5.2. For comparison sake we consider inquiry science (Kelly 2014b), engineering education (Cunningham and Carlsen 2014), and a socioscientific issues approach (Zeidler 2014). Some key differences in educational goals and the nature of epistemic practices are evident in

**Table 5.2** Illustrative examples of epistemic practices three orientations toward science and engineering education

| Disciplinary approach: | Inquiry Science | Engineering | Socioscientific issues |
|---|---|---|---|
| Epistemic practices: | | | |
| Propose | Posing scientific questions<br>Designing scientific investigations to answer questions<br>Making observations<br>Envisioning relevant evidence based for an investigation<br>Building and refining models | Identifying problems<br>Considering problems in context<br>Applying scientific concepts and reasoning<br>Applying mathematical reasoning<br>Envisioning multiple solutions<br>Persisting and learning from failure<br>Using systems thinking | Posing questions – scientific, economic, moral, religious, ecological<br>Designing investigations to answer questions<br>Balancing multiple lines of reasoning<br>Constructing a rebuttal |
| Communicate | Developing a scientific line of reasoning<br>Providing disciplinary-specific justification for knowledge claims<br>Writing a scientific explanation (lab report)<br>Communicating a verbal scientific explanation<br>Constructing a scientific explanation based on evidence and reasoning | Communicating effectively in working teams<br>Justifying project designs for given constraints<br>Communicating to the client | Constructing evidence based on investigations<br>Taking a position<br>Constructing (multiple) arguments based on evidence and reasoning<br>Presenting an argument<br>Engaging in a debate or role-play |

(continued)

**Table 5.2** (continued)

| Disciplinary approach: | Inquiry Science | Engineering | Socioscientific issues |
|---|---|---|---|
| Evaluate | Assessing merits of a scientific claim, evidence or model<br>Assessing a line of scientific reasoning<br>Evaluating scientific explanation<br>Considering alternative explanations | Making tradeoffs between criteria and constraints<br>Using data to drive decision making<br>Placing value on constraints and client needs | Assessing merits of a scientific claim<br>Evaluating evidence (what counts as evidence – moral, ethical, scientific, etc.)<br>Assessing lines and types of reasoning<br>Evaluating arguments holistically |
| Legitimize | Building group consensus for scientifically sound explanations<br>According value to the explanation that most closely matches the preexisting scientifically accepted theories<br>Recognizing knowledge by relevant epistemic community | Considering implications of solutions<br>Making evidence-based decisions<br>Acknowledging evaluation of successful technology by client | Building consensus or acceptance of the most convincing argument<br>Recognizing value of positions taken in debate |

this table. For example, inquiry science generally seeks to develop students' capacity to conduct investigations and, through this process, learn the knowledge and practices of a disciplinary community. The approach situates the students as inquirers and seeks to develop ways of building knowledge through engagement, thereby developing over time the capacity among students to make sense of their world. Engineering education focuses on developing the knowledge of design and analysis through project-based approaches that require understandings of relevant science, math, and the cultural contexts of the client. This approach finds its solution in real world applications that are optimized given a set of constraints. A socioscientific issues approach situates science in a social problem and requires that students draw from current knowledge, build on this knowledge, and apply moral and ethical reasoning to taking a position regarding a controversial issue. In each of these three orientations to learning science, there are shared and mutually exclusive epistemic practices. As previously discussed (Kelly 2016), epistemic practices are interactional, contextual, intertextual, and consequential.

Each action in the world occurs in a time and place. As these actions are developed and routinized, they can be recognized as patterns. Such patterns begin as actions members of a group take through social interaction. Engaging in social practices defines what counts as knowing and knowledge, such as proposing ideas, testing hypotheses, representing concepts, evaluating merits of candidate solutions, recognizing alternatives, justifying knowledge claims, and legitimizing conclusions (see Table 5.2). Thus, in any instance, epistemic practices are constructed in the moment, as they are *interactionally* accomplished, among people, texts, and technologies. While each interaction is situated and contextualized, participants of a group draw from common knowledge, and make reference to previous knowledge and ways of participating. Research in science education has demonstrated how discourse processes are central to knowledge construction (e.g., Kelly and Crawford 1997; Wickman 2004). The ways of talking and being, including uses of signs and symbols are characteristic of epistemic cultures (Kelly 2014a, b).

Epistemic practices are *contextualized* in time, space, social practices, and cultural norms. Knowledge is constructed through specific processes with variations across disciplines and ways of knowing (Knorr-Cetina 1999; Longino 1990). Knowledge construction occurs over time through a series of interactions from interactions around data collection, to conversations about interpretation, to forms of representation, and to processes of communication, evaluation, and legitimation (Bazerman 1988; Lynch 1992). Engaging in epistemic practices thus occurs in various venues and settings and such practices need to be examined as they occur in the making (Kelly et al. 1998). Thus, the study of epistemic practices needs to be situated in specific contexts. This suggests that the study of knowledge construction needs to occur in situ, through an examination of the processes leading to socially agreed-upon knowledge. The study on such micro-moments of interaction needs to take into consideration the ways that cultural practices are established over longer time scales and how such cultural practices enter into moments of interaction. This suggests looking across time scales to consider how epistemic practices emerge, vary, change, and influence social processes (Kelly 2008; Lemke 2000; Wortham 2003). Events constructed in the moment (e.g., a decision regarding anomalous data, consideration of ethical implications regarding a socioscientific issue) draw from contexts, practices, texts, and artifacts created at longer time scales (Goodwin 2000). For example, the genre of an experimental article in science (Bazerman 1988) becomes a cultural model that can be taken up and used to create new texts within this patterned use of language (Kelly and Bazerman 2003; Takao and Kelly 2003).

Discourse processes make use of and reference to previous discourse, both spoken and written texts, including the various signs and symbols characteristic of disciplinary knowledge, and are thus *intertextual* (Bazerman 2004; Green and Castanheira 2012). Reference to previous texts builds continuity and common knowledge as members of a social group (e.g., student laboratory group, professional research team, environmental activists) define and make use of shared assumptions of meaning (Wittgenstein 1958). Intertextuality serves as a method to identify socially salient concepts comprising common histories and cultural experiences (Vygotsky 1978). For example, students taking a stand regarding a socioscientific issue (Licona and Kelly 2015) may make reference to relevant published facts of the matter (e.g., characteristics of the ecology of an endangered species) and to definitions and policies (e.g., legal definitions). These texts serve as reference to decisions regarding how to use science to reason through a problem.

Knowledge claims are proposed, communicated, evaluated, and legitimized through social processes. Thus, epistemic practices have *consequences* for what knowledge counts for participating members of a group. Members entering into a knowledge generating culture bring ways of knowing with them that may or may not count or be recognized (Traweek 1988), as often in science and education knowledge claims need to be modified to build acknowledgement as legitimate (Kelly et al. 2001; Myers 1997). The empirical study of ways that knowledge is legitimized identifies how power, culture, and social processes are tied to what gets taken for knowledge in certain contexts (Kelly 2016).

## 5.5 Research Directions for the Study of Epistemic Practices in Education

We have argued that a focus on epistemic practices should be part of the pedagogy for science and engineering education across a range of educational goals. Education seeks to develop knowledge, skills, values, and ways of knowing and learning. Importantly, while substantive, conceptual knowledge plays a role in learning ways of knowing (i.e., epistemic practices depend on substantive knowledge), developing the capacity to learn and know should be a major goal of education. In this section we draw from the literature considered in previous sections of the chapter to consider plausible research directions for the study of epistemic practices in education. We propose following four directions: (a) development of learning of epistemic practices, (b) disciplinarity and learning, (c) cultural and linguistic diversity and learning epistemic practices, and (d) learning about science through engagement in practice.

A number of studies have begun to show the value of a focus on epistemic practices for science education (Manz 2014; Sandoval 2005; Wickman 2004). This positive direction opens up questions for further research. Kelly (2014b) argued that the learning of epistemic practice in science inquiry settings depends on and requires understanding of relevant concepts to the problem at hand. This means that, rather than learning domain general science process skills, students learn epistemic practices (e.g., posing questions, justifying claims) through engaging in problems where conceptual knowledge is evoked and applied. This poses research questions for the field. For example, what is the interaction of particular types of epistemic practices with substantive, disciplinary knowledge? What knowledge do students need to effectively employ epistemic practices in inquiry settings? How can the development of conceptual and epistemic knowledge co-occur and develop synergies?

We know that students bring a variety of experiences and knowledge to educational situations (González et al. 2006). These previous experiences may be resources for developing and learning epistemic practices.

Questions relevant to this topic include: What knowledge do students bring? How are students' outside of school ways of knowing relevant and helpful for developing disciplinary practices? Each learner and group of learners brings different experiences and thus offers a unique set of opportunities for learning, both for individuals within a group, but also how the group learns over time to function and become an epistemic community (Kelly 2008). Finally, there may be ways that maturation and development are related to ways that students learn to engage in epistemic practices: What are the learning progressions for epistemic practices? How can school science and engineering be designed to gauge students' development trajectories and potential?

Scholars focusing on epistemology and learning have identified the ways that disciplinary knowledge and ways of knowing vary across the sciences (Ault 1998; Erduran 2007; Jimenez-Aleixandre 2014). While often grouped together, each of the sciences, and even more so, fields of engineering, vary in the ways that they investigate and solve relevant problems in their respective fields. While we recognize these differences, and acknowledge that such differences should not be glossed, science teachers face the problem of developing the knowledge, inquiry abilities, values, and applications of science and engineering in real settings. Furthermore, nuances in disciplinarity may be lost on students. This poses a number of research questions about disciplinarity and learning: What are the ways that understandings about the sciences and engineering fields can be refined through empirical inquiry? How is knowledge gained about such practices relevant to teaching? To what extent do students learn to transfer epistemic practices gained in one discipline (e.g., recognizing anomalies to a distribution of data) to another discipline with different substantive knowledge (e.g., epidemiology and atmospheric sciences)?

We live in an increasingly multilingual and multicultural world. Different ways of knowing offer opportunities to learn about and draw from alternative ways of making sense and learning (Varelas et al. 2008; Varelas et al. 2012). Students bring ways of sense making to educational events that can be drawn into school activities, thus serving as resources for learning. Furthemore, various sciences produce their own cultural ways of being with particular ways of communicating, producing knowledge, and being a member of the group (Knorr-Cetina 1999; Watson-Verran and Turnbull 1995). Thus, learning science or engineering can be viewed as a process of acculturation in which new members both learn the extant ways of being and doing, but also transform the current practice through innovation and change. Research questions emerging from this area include: What sorts of ways of knowing do students bring to educational events? How can these ways of knowing contribute? How can access to the practices of epistemic cultures be made visible and opened to learners?

Finally, engaging in epistemic practices offers contexts for discussion and reflection about science and engineering fields (Akerson et al. 2000; Kelly 2014a, b). While it is generally recognized that merely engaging in activity does not produce propositional knowledge about science (Abd-El-Khalick 2012; Sandoval 2005), learning to propose, communicate, evaluate, and legitimize knowledge claims can provide a basis for discussions, reflection, and further reading about how science and engineering operate, the values in these disciplines, and limitations of these ways of approaching problems. Research in these areas may consider the following questions: What are the relationships between competency in certain epistemic practices and learning science and engineering? How are epistemic practices generative of new knowledge of and about science and engineering? What sorts of engagement and reflection leads to learning of and about science and engineering that support decision making for socioscientific issues?

## 5.6 Conclusion

Our argument in this chapter is that engagement in epistemic practices is an important part of a robust science education. Part of the need to engage in epistemic practices is to learn values of knowledge-producing communities – the value of persuasion over force, open-mindedness over dogma, and consideration of alternative solutions, and so forth (Rorty 1991). Scientific explanation and argument are not technical procedures, as they do not have specific formulas that can be translated easily to the pedagogy of science education. We drew from three types of educational approaches (inquiry, engineering, socioscientific issues), each with different goals, to identify illustrative examples of epistemic practices across these contexts. Each of these approaches can support goals for scientific literacy, suggested by Aikenhead et al. (2011): developing the capacity to engage with issues from a scientific perspective. Central to such engagement is an understanding of the disciplinary ways of proposing, communicating, evaluating, and legitimizing knowledge claims. Through such engagement, connected to carefully organized pedagogy, students may build capacity to participate as informed citizens in the public sphere.

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