2. Thematic Chapter: Epistemology and Systems Design

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Abstract. This is a brief tutorial on epistemology and its relevance to systems design. First, I will sketch what epistemology is and how it relates to the task of designing systems. Then I caricature six contrasting epistemological positions, both professional and "common sense" based, to show how differences of epistemological orientation may critically affect design.

2.1 What is Epistemology?

Epistemology is a somewhat esoteric pursuit. It is much less familiar than education, psychology or even systems design. You won't find *Epistemology Today* at your local magazine stand. Yet epistemology stands as one of the three pillars of systems design in this book (the others being psychology or pedagogy, and cultural studies), and you will find reference to it in many of the chapters. How do we think about this?

Etymologically, epistemology is transparent. *Episteme* is Greek for knowledge, and *logy* is the common suffix for study of, or discourse on. The dictionary says epistemology is the study of methods and grounds of knowledge. Traditionally, philosophical epistemology has been preoccupied with truth and absolute certainty. But, especially since the middle of the twentieth century, several strands of inquiry have developed to bring epistemology into more practical contexts.

Into what sorts of questions does epistemology inquire?

What is the nature of knowledge?
- Does it come in diverse forms? If so, how are these related?
- Is knowledge the same as know-how; how does knowledge relate to intuition?

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How is knowledge possible?
- From what source does it flow; are there laws that govern its development?
- Is knowledge inherent in the world, or is it a relatively unconstrained construction of humans?
- Can people know without speaking or meaning? Is knowledge applied or constructed only when things go wrong?

How does knowledge work?
- Can we see how or when people deploy it, as opposed to simply "acting in the world"?
- Can machines "know" the same way people do?
- What is the relation of knowledge and symbols?

The relationship of epistemology and psychology is not easy to describe. At least in part, this is because the relationship is unsettled. Broadly, psychology investigates the workings of the human mind, whether or not these involve knowledge. Depending on how one thinks about them, emotion or perception may not be important to epistemology. It is remotely possible that knowledge is nothing more than a particular function of the human mind, and that eventually epistemology will be only a branch of psychology. On the other hand it is also possible that there are general laws of epistemology that determine a lot about how humans (or any knowing entities) develop and use knowledge, with a bunch of little filigrees and parameters that are filled in for the particular case of humans—or particular cultures or individuals—by psychology. Epistemology may then be the quickest way to get to the real heart of the matter in learning, for example.

Epistemology is also frequently confused with an even more obscure *ology.* Ontology considers the forms and nature of existence—what does it mean *to be?* In that knowledge exists (let us suppose!), its ontological status is important. But of course, many other sorts of things exist. And it is likely many other aspects of knowledge are worthy of study besides its existential status. The possible confusion between epistemology and ontology is worse in that a special focus of ontological studies has been the nature of abstract ideas, going back to (and probably before) Plato's consideration of *forms*, the supposedly real and "tangible" form of pure knowledge.

A rough but serviceable litmus test for the validity of epistemology as a point of view (and to determine whether a colleague has epistemological leanings) is the question of whether or not epistemological forces exist. Epistemological forces stem from the very nature of knowledge and how it is used, or they emerge from what people know about knowledge. These forces push and guide the development of knowledge in certain directions, and not others. Epistemological forces are controversial to the extent that one believes factors other than epistemological ones determine the knowledge people acquire and how they acquire it. For example, it is more commonsensical to believe that the world somehow directly impresses knowledge of itself on us, or that knowledge is imparted in a straightforward way by teachers than to acknowledge epistemological forces.

I believe that under a broad range of circumstances, which I will not describe here, humans are led to construct essentially the same knowledge no matter how diverse their experience or instruction. I also believe only epistemological forces can account for this fact. Of course, there are clearly limits to the strength of epistemological forces. But if there is any fragment of validity in the concept, epistemology has a future.

Mathematics seems a particularly good arena in which to investigate epistemological forces. It seems that if one plays the mathematical game at all, one is drawn to make remarkably uniform constructions. Piaget and his successors have shown how surprisingly regular are young children's constructions of quantity and numerosity. The world of professional mathematics shows an agreement on the nature of the game and of what constitute results that is striking (compared, for example, to education or systems design). Are there epistemological forces behind both children's and mathematicians' constructions of mathematics?

In this volume, John Mason argues for the systematic use of students' powers of closure and construal, which I interpret as one version of epistemological forces, to overcome problems of didacticism in instructional technology. He says, don't try to tell children everything, but allow their natural knowledge-building capabilities (sensitivity to epistemological forces) to work. To play a different tune, the power of the homily that *you learn what you are taught* may make epistemological forces seem implausible and, perhaps, Mason's exhortations seem romantic. From still a different point of view, the enterprise of defining epistemological forces may seem like just another excuse to extol the virtues of those who "get it" and denigrate and disenfranchise those who see things differently. My own feelings are in line with Mason's. While we must acknowledge that teachers are, in a sense, responsible for a significant part of what is learned in classrooms, and while we must certainly understand and encourage diversity in ways of knowing, still we must acknowledge and capitalize on the fact that knowledge naturally bootstraps on itself.

2.2 The Relevance of Epistemology to Systems Design

There are three ways in which epistemology is important to systems design. The first is completely obvious: We want students to understand the systems that we design—to acquire knowledge of them. To the extent that we have anything interesting to say about the forms of knowledge involved in understanding and operating systems, and the development of such knowledge, epistemology is relevant to our designs.

One important trend in thinking about knowledge in recent years, the revaluing of intuitive or metaphorical forms of knowing in comparison to articulate or logical forms of knowledge (the latter traditionally considered the *only* forms of *true* knowledge) has found a real home in system design. It seems unmistakable that people can build substantially on metaphors and other suggestive forms provided in systems, and that they operate as much or more by intuitive instinct than by articulate rules.

The second relevance of epistemology comes into play the moment we want our systems to be educational—when we want students to learn something in using the system as well as how to operate it. Here, the educational world polarizes and flares into fundamental disputes. What is the fundamental nature of mathematical (or physical or biological...) knowledge? Is it "facts and algorithms" or a cultural and gradually accumulated instinct and capability to mathematize the world? Our epistemological orientations help answer the very first instructional question: What do we want to teach? Do we want to build a system to "teach fractions" or to support collaborative discourse about measuring, parts and wholes?

After deciding on the nature of what we want to teach, what comes next in fostering learning? What do we make, for example, of the many false starts and "misconceptions" students show in beginning to learn what we want them to know? From one epistemological perspective (the dominant orientation of those willing to say "genetic epistemology"—see below) our attitude toward student mistakes is relatively clear, if slightly disquieting. False steps are inevitable and will occur whenever students start to make progress. That is, learning without building on prior knowledge is nonsensical, and prior knowledge cannot be perfectly adapted to the new contexts in which we place learners. From contrasting points of view, mistakes and missteps are just that. They have no status as necessary, and, in fact, they are things to minimize or eliminate. Real, true knowledge stands apart.

While there are important differences that will be evident in other parts of this volume, there is a family resemblance among the epistemological beliefs of those contributing here. Indeed, this is one sense in which the contributors are members of a community, rather than an ad hoc collection of educational technologists. Talk of open learning environments and exploratory learning bespeaks a commitment to knowledge that transcends "facts and algorithms." It bespeaks a serious concern for the naive knowledge of learners, and perhaps even for the belief that a large part of teaching is arranging for epistemological forces optimally to do their work—as opposed to *telling*. (These commitments may sound suspiciously like values, rather than scientifically debatable contentions. But who said politics and epistemology don't mix?)

The above two relevances of epistemology to systems design probably depend on the ultimate success of epistemology as a scientific pursuit. The better we solve issues of what constitutes the essence of knowledge and what are the laws that govern its development, the better will be our recommendations about what and how to teach with computer systems—and how comprehension of the systems themselves may be fostered. The third relevance of epistemology, surprisingly, is independent of the success of scientific epistemology and does not depend on the belief that there are epistemological facts on which we may draw. The fact is—and I believe it is indisputable—students, teachers and systems designers all have implicit assumptions about what constitutes knowledge and how it is built. Systems designers have methods of laying out knowledge. Teachers and students have methods of ferreting it out, collecting and refining it. Broadly I refer to these spontaneous assumptions and predilections as constituting *intuitive epistemologies.*

To help systems designers (ourselves), I project we will always have to understand their (our) intuitive epistemologies and how to evolve them toward more effective and productive stances. This is true even if (which seems doubtful to me) we can replace all scientific epistemological talk with appropriate results from psychology, pedagogy or whatever. Similarly, intuitive epistemology is a well-documented phenomenon among students. Some students believe knowledge is facts and formulas and others dismiss these as inessential (diSessa, 1985; Hammer, 1993). If we cannot help students find a productive intuitive epistemology, or at least match designed systems to their expectations, they will disparage what is supplied to them and systematically miss its point as an aid to learning. So, understanding intuitive epistemologies will be an enduring issue.

The remainder of this chapter caricatures six positions that will help draw out many of the epistemological issues to be encountered in this volume. These are, indeed, caricatures, for the exposition needs to be far shorter than a responsible intellectual presentation requires. Also for reasons of accessibility, I present multiple epistemological positions rather than take a single position and argue its validity, or even to lay out a systematic set of issues and results. I won't particularly hide my own commitments, or what I feel to be central issues and results. But a presentation of a spread of epistemological positions (with some comment on related generic issues) serves better as an introduction.

The first three caricatures are of intuitive epistemologies that might well mirror the histories and practical concerns of the contexts in which they developed. I caution, I hope unnecessarily, that any belief in contextual determinism—that beliefs follow reliably and rigidly from the contexts in which people find themselves—should easily be dispelled by talking to a few inhabitants of the contexts named. Nonetheless, echoes of the caricatured epistemologies can easily be heard in the corridors of design and seen in the artifacts designed. The second set of three caricatures highlights three respectable themes in professional epistemology, complementing the first three intuitive epistemologies.

Intuitive Epistemology #1: School

One might think schools would foster rich and vital epistemological views. After all, their prime business is knowledge and its development. But amid the voices, one detects a central, if not dominant, tone of a decidedly schoolish epistemology. It is conservative, shallow and authoritarian.

> What we should teach is what we have taught; and that is what is in the textbook. Say it clearly, and they will "get it." (Some won't, of course, but that is what we have to deal with.) The teacher's art and responsibility is in methods and motivation; it is not, for example, in understanding students' ideas and, least of all, in deciding the epistemological type of what is taught.

As many people do, I see school's institutional context as pressing hard in these directions. Consider the following three factors.

Historical entrenchment: Institutions have a vested interest in (indeed, responsibility for) reproducing themselves. This typically lends a strong conservatism to them, which is as strong epistemologically as in other planes. Not only do participants do what they have done and see what they have seen, but novel views, from inside or out, appear implausible if not threatening. For example, ideas of problem solving, per se, as a prime part of mathematics have been very slow to spread in the U.S. As a second example, for all the energy in the reform movement and some of its constructivist rhetoric (e.g., in U.S. mathematics teaching), students' ideas are still strongly marginalized in most classrooms. See Hoyles, this volume, for a more extended treatment of these issues.

Bureaucratic infusion: Big institutions frequently develop bureaucratic structures to organize themselves. Bureaucracies are conservative by nature. They keep things in line—the same line. Bureaucratic responsibility is frequently at the lowest common denominator, in keeping things objective and simple, only the most accessible measures are observed. This holds both for assessing teachers and, perhaps more prominently, in assessing students. What's easy to see and say is what's tested. Unfortunately, the lowest common denominator of knowledge and its most evident forms (e.g., facts) may be least important.

Institutional lockstep: The ties between schooling and other institutions propagate conservatism, shallowness and authoritarianism. Schooling's proper responsibility to the broader public and to the government that funds it, along with its low institutional status, leads to external powers deciding what and even how things should be taught. Teachers understand their mediating role and must position themselves as knowledge authorities in the classroom. Further, public and political accountability presses again a lowest common denominator epistemology—if teaching goals are not immediately plausible to parents and politicians, they are threatened. Other institutional connections also press conservatism and shallowness.

Textbook publishers and domain experts have sanctioned stakes in the process of deciding what is taken for knowledge in schools. Neither have strong innovative tendencies and, to some extent, they cancel each other out with respect to any hope for epistemological finesse and style.

In this volume Kynigos provides an account of how these institutional forces impinge on students and teachers attempting innovative instruction in Greece. I believe he shows the struggle is largely epistemological in nature, not about teaching methods per se. The issue is what counts as knowledge and some very basic assumptions about where it comes from and how it develops. Noss (this volume) provides a broader, more theoretical account of social and institutional forces in education and educational change, many of which are at the epistemological level.

Intuitive Epistemology #2: Work

Work contexts these days are so diverse—from assembly line production, to farming, to academia and high technology research and development—that there is even more danger in picking out one epistemology that belongs to work than for school. In part to complement the somewhat negative sketch I make below, I note there have been a succession of very positive characterizations of learning properties of "real work" situations in recent years. For example, Sylvia Scribner produced compelling accounts of perhaps surprising in-context mathematical expertise of milk workers. Jean Lave has shown similar competence in grocery shoppers. Following on this, many have extolled the virtues of apprenticeship and other learning processes typical of workplaces and other "real world" situations. One of the central epistemological themes of this work has been the value (or even necessity) of rich *authentic* communal activity for the development of knowledge. I'll follow up on this shortly.

These notwithstanding, there are pressures in industrial and commercial settings that lead toward certain views of knowledge. In the first instance knowledge, per se, is less central than in either of the other two contexts described here (school and academic disciplines). So knowledge may be both less valued and less interesting in industrial work. Indeed, perhaps the prime goal and value in these contexts is production, leading to a practical epistemology—*knowledge is as knowledge does.* Skill and competence, for example, are likely to be appealed to rather than knowledge to explain successful negotiation of circumstances, narrowing the niche for which knowledge is considered relevant.

A prominent phenomenon in work contexts is the imperfect correlation between school learning and accomplishment. Virtually everyone knows that even highly (school) knowledgeable neophytes need experience to become really productive. And schoolish entry and promotion standards perpetuate an antagonistic relationship both between workers and management, and also between workers and "school learning."

Fischer (this volume) discusses *the production paradox* that further accentuates the marginalization of knowledge and knowledge-developing activity. Because getting things done is paramount, lack of knowledge is not a concern unless an impasse in production is encountered. But then there is little time to consider learning an effective remedy. Even less is there opportunity to expand the learning that might be occasioned by an impasse beyond immediate concerns. This is true despite the fact that such expansion might forestall a future impasse.

Popular culture provides an interesting category of knowledge that is appealed to in work situations. Competence is frequently assumed to arise from *common sense.* Managers and more experienced workers want people with common sense who will do things in ways that accord with their own sense of sensible and logical. From certain perspectives (mine, in particular), this is a key recognition of some forms of knowledge not given much play in schools. On the other hand, workplace epistemology may not accord these capabilities the status of knowledge, and their teachability may be suspect.

The discussion at the conference that led to this volume provided an interesting validation of a workplace epistemology as described, if only in the eyes of outsiders to the commercial workplace. Fischer developed in his presentation the notion that systems can and should be organized around "learning on demand." He wants to develop systems that highlight a wish or need to achieve an outcome but provide learning support whenever the user runs into a problem or simply wishes further information. Learning on demand sounds like a concept out of the workplace, and, indeed, Fischer has been inspired, in part, by positive accounts of learning on the job by Lave and others. Learning on demand at first met with skeptical reactions at the conference. Providing dollops of knowledge, and only when needed and for the purpose of getting things done (it seemed to some) trivialized knowledge. It violated epistemological assumptions—about the diversity of knowledge forms, their complex relationship to accomplishment, and how one cultivates deep knowledge—that were broadly held in the group. In his chapter Fischer makes clear that he shares these worries and that he does not espouse the workplace epistemology described here. Instead, Fischer wishes to contextualize knowledge better and keep learning from becoming an artificial activity that one does only at school. The broader lesson of this anecdote is, once again, that epistemological assumptions are real, the locus of deep commitments, and a vital part of understanding systems design.

Intuitive Epistemology #3: Academic Disciplines

I will treat this last intuitive epistemology very briefly, doing little more than giving it a name that may be useful in understanding issues that appear in several contexts in this volume. The official keepers of various disciplines (mathematicians, physicists, biologists, and so on) have a dramatically different experience with the knowledge of their field than workers, teachers, or students. The most relevant part of this is how they experience the codified knowledge that is introduced in school, as opposed to how they experience knowing and developing new knowledge in their professional work. Disciplinary experts are likely to feel the school version of their domain is simple, clear, logical, objective, strictly cumulative and compelling. They are likely to project this as the way learners and teachers will experience it, or should be pushed toward experiencing it. They don't see knowledge as problematic and possibly threatening, or in need of interpretation. In my terms, discipline experts are likely to miss the contextual essentials of their own lives that strengthen epistemological forces to the point that knowledge can feel sharp and compelling.

A subtext in several of the contributions to this volume is that the designers of computer environments, armed with different epistemological views, are challenging discipline experts' sole right to determine what counts as learning a discipline. To exaggerate, knowledge that is unteachable and inadequately bootstrapped is not a candidate for a student's introduction to a subject matter, no matter whose sense of "necessary" it satisfies.

Having treated three formidable intuitive epistemologies, I now give the professionals a chance. The following three sketches are intended to capture important trends in the thinking of those who consider knowledge on its own terms a focal, professional concern.

Professional Epistemology #1: Genetic Epistemology

Genetic epistemology names the most important of Twentieth Century innovations in conceptualizing knowledge. Genetic, here, refers to genesis—a developmental view of knowledge. The central commitments of genetic epistemology are both substantial and methodological.

Substantially, a genetic view of knowledge entails a commitment that the structure, forms, and possibly the content of knowledge is determined in major respects by its developmental history. Development, itself, may be conceived either phylogenetically (with respect to the macro-history of cultures or species) or ontogenetically (with respect to the development of individuals). A contentious claim that organizes a lot of genetic epistemological work is that the development of an individual's knowledge must follow the same patterns as the far longer time-scales of its historical development: Ontogeny recapitulates phylogeny. A weaker and more plausible claim is that onto- and phylogenetic development follow the same epistemological principles, but with different contextual influences. Piaget, who coined the term genetic epistemology, pressed hard to uncover universal epistemological principles that would explain both ontogenetic and phylogenetic patterns.

Methodologically, a genetic stance on knowledge may be as superficial as believing that developmental information provides excellent data on knowledge issues. Or it may be as deep as claiming that there is no other way to understand knowledge except through its development. Piaget and following genetic epistemologists emphasize clinical interviewing and detailed interpretive accounts of knowledge development as methodologies. This made Piaget and some successors appear to be "child psychologists" or the like, a view that Piaget strongly resisted.

Constructivism is a well-represented view in the contemporary educational scene that recognizes the important influence of prior conceptions on students' interpretations, and hence on their learning. This is consonant, if not synonymous, with a genetic epistemological point of view. Unfortunately, widespread commitment to constructivism has skewed toward a trivial version in which prior conceptions must be "respected" rather than a commitment to articulating a full genetic theory of knowledge (Smith, diSessa, and Roschelle, 1993). Perhaps the prevalence of schoolish epistemology has undermined a deeper interpretation of constructivism.

Broadly, the commitments of contributors to this volume are constructivist, even if genetic epistemology per se is an acknowledged pursuit of few of them. This sometimes puts this group in opposition to other groups. For example, I previously mentioned a grappling with discipline experts over what should count in schools as domain knowledge. As a group, contributors are also more venturesome with respect to what they intend to teach with their computer environments than, for example, more psychologically oriented researchers and developers. The latter are less likely to have professional commitments to epistemological principles strong enough to override their own intuitive epistemologies or those of colleagues like textbook writers or domain experts to whom it is all too easy to defer. It is important to place these differences of opinion in the context of often implicit but real epistemological issues, in contrast to seeing them as accidental and possibly trivial differences. For example, disciplinary experts frequently comment that new instructional techniques don't get to the heart of the mathematics (or other areas). Problem solving and collaborative instruction may be fine, but where are the basics? While it may be that some educational designers just don't know their subject well enough, it is also sometimes the case that they have arrived at different epistemological principles to determine what is most valuable to teach.

Professional Epistemology #2: Social Epistemology

Educational research and development has seen a boom in the last decade in attention to social concerns. Small group work has become almost a *sine qua non* of reform techniques in the classroom. Collaborative learning is an inescapable buzz word. Educational researchers tout building communities of learners (Brown and Campione, 1990) as a fundamental goal. Systems design itself has shifted impressively from designing single-user systems from a psychological perspective to designing multi-user, collaborative environments on sociological principles. There is even a journal now devoted to the design of *computer supported collaborative work.*

No one can doubt there may be effective group methods of instruction, that people need to work together, hence need computer tools to suit, or that sociology, perhaps at the level of institutions, is a critical perspective in education. But these trends are relevant here only to the extent that they reflect epistemological issues. Claims that group learning is the only or best method of instruction are by themselves, epistemologically boring. So what might social-epistemological claims be like?

One level might involve the origins of all, or at least important parts of, the knowledge we intend to teach or that accounts for competence with systems. Lev Vygotsky is a critical reference in this regard. He is famous, if not notorious, for his claim that the origins of all higher-level thought are social. Crudely put, patterns of intelligence or knowledge arise first in communities and then become internalized by individuals. One can read this as a matter of reproduction. But it is deeper as a phylogenetic claim that this is the ultimate origin of all higher level knowledge.

A more radical social account of knowledge involves not only its origin but also its very nature. Jean Lave sets a relevant standard by claiming that cognition is intrinsically spread over individuals and the world. (Be patient—the world will enter this tutorial shortly.) Her work emphasizes that much of cognition (and, *a fortiori,* of knowledge) cannot be sensibly located in individuals, for it is only communities that define and allow the accomplishments that knowledge is supposed to account for. One can state a similar claim in terms of epistemological forces. If causal paths that enter into the manifestation of epistemological forces intrinsically involve interpersonal paths (feedback from others, for example) then the knowledge hewn by these forces must reflect the social world in some measure.[1]

Social views of the nature of knowledge emphasize language, a patently social and cultural creation. To the extent that language confers form, reach and possibly limitations on our knowing, the social world is inextricably part of each of our "personal" worlds.

How might a social epistemology affect systems design? For one, it may make no sense to design individual software, even if the software designed is only for individuals! Instead, one must in a genuine sense be designing communities and social niches (diSessa, 1990) at the same time that one specifies artifacts in those communities. In jointly designing communities, activities and artifacts, the designer's role and expertise is importantly different. Perhaps in this context, "designer" is even the wrong word, and "facilitator" is more apt. Knowledge hasn't disappeared, but its fit into an operating context is so important that one can't facilitate one without facilitating the other. Along a different dimension, a social epistemology may emphasize collaborative patterns of communication in a discipline as an essential part

[1]Of course, it is open to dispute whether these forces are epistemological at all. Perhaps it is not knowledge that is hewn in communities, but only participation.

of learning that discipline. So some look to foster, for example, "mathematical ways of speaking."

The contributors to this book are socially aware in many respects. See especially Noss' contribution. By and large, it is a conservative group in the sense that it believes epistemological forces may sometimes act within an individual working with a computer environment (as opposed to always mediated by community interchange). The overall goals of the Boxer Project (diSessa, this volume), however, include the creation of a new literacy based on computational media, a manifestly social design (or facilitation) issue. Nevile, as well, speaks about her own Boxer experience as the inhabitant of an emerging culture predicated on the existence of computational resources of a certain sort. Nevile's and diSessa's concerns are culturally phylogenetic issues. Individuals can be "smarter" or come to know in different ways only if communities succeed in transforming themselves.

Professional Epistemology #3: Material/Enactive Epistemology

In our everyday dealings with the physical and social world, one sees knowledge and intelligence of an unusual form. People "know" to pull harder to move heavier objects. Similarly, people take cautious stances toward individuals who display hostility. Most of this knowledge is clearly not articulate or propositional. By many definitions, this cannot even count as knowledge. It is not, for example, "justified, true belief." But within an enactive epistemological perspective, knowledge-in-action is a fundamental form, perhaps fundamental to all the rest that we know.

External representational systems such as language, algebra, and now capability with computer systems—perhaps programming—may play a special role within an enactive perspective. While some may see these only instrumentally (they allow us more effectively to write down what we know and compute with it), a material/enactive view sees these as fundamental, possibly even defining, extensions or parts of our knowledge building and manipulating capacity. Put succinctly, we cannot know the same things and we are blocked from important forms of knowing if we don't have and can't effectively manipulate external representational systems.

This position has great synergy with social perspectives on knowledge. All the classic examples of external representational systems, starting with language, are manifestly social creations. If they are hewn in communities and serve their primary functions in communication, how could they fail to reflect a social basis? The currently growing movement toward *situated cognition,* I believe, joins social and material/enactive epistemological points of view in this way (diSessa, 1993).

As suggested in the social epistemology section, some aspects of Boxer work are based on the presumption that social evolution (new literacies) are prerequisite to a deep new material intelligence and new materially mediated knowledge forms. My chapter in this volume talks about our claims to have discovered new means for students to think about, talk about, and experience physics. Other papers from our project talk in more detail about how Boxer might facilitate different patterns of communication and knowledge construction (diSessa, in press). We even consider the possibility that, since it is based on a different material/enactive substrate, programming physic*s* may simply not be the same physics that appears in textbooks or that current experts know (Sherin, 1993). More generally, one might expect that a material/enactive view would be resonant with designers of computer systems. Indeed, this fact is amply demonstrated in the contributions to this volume. What follows below is an abbreviated annotated index into segments of this volume that deal in various ways with the epistemologically fundamental issue of how the material, presentational and interactive properties of systems relate to the knowledge students may acquire in using them.

The Labordes argue that teaching geometry suffers from the fact that diagrams are seen by students as pictures in a conventional sense. Students see arrows and dots, but not the theoretical objects and relations of geometry (rays, points and parallelism). However, the dynamic interaction with moving diagrams that respect geometric relations may give students a powerful window on the real geometric entities. The claim is wonderfully enactive because it is dynamic hands-on interaction that is really the knowledge-developing path. So to describe the system as a "window" is misleading, since coming to see differently arises from being able to interact differently.

Al Cuoco takes an explicitly epistemological approach to understanding the mathematical concept of function in terms of the Piagetian notion of "encapsulation-interiorization spiral," which is proposed as a very general and important process in the evolution of knowledge. Cuoco then considers how various computational representations help students progress along this spiral.

In this regard, Alberti and Marini emphasize a classic representational view of computational systems for learning—that these should be rooted in deep and careful analysis of the structure of the knowledge taught, and a great deal of care is necessary to preserve this structure in the system's presentation to the student. Hancock discusses the epistemologically challenging notion of transparency. Edwards, in her final reflections on the representational properties of microworlds, discusses our implicit models of knowledge and its conveyance, and warns that these sometimes underemphasize social aspects of knowledge construction.

A cluster of other papers also deal directly or indirectly with the "fitness" of new computational representations for capturing and making learnable particular ideas or subjects. Matos and Neuwirth discuss successes and failures of spreadsheets. Neuwirth feels spreadsheets enhanced with overlay representations are stunningly clearer and can be more effective instructionally for certain kinds of subject matter than conventional mathematical materials. Matos shares those hopes, but notes the familiar phenomenon that students may be captured in some measure by the structure of the tools without these becoming the powerful and effective lenses on the world that they may be.

2.3 Epilog

I close by reporting and briefly elaborating part of the deliberations of a working group at the conference. These few lines cover a wealth of issues touched on in the above discussion, and they highlight both broad commitments and what we do not know. My annotations are italic.

- Where does the system begin? We need conceptions of:
  a) The objects of the domain. *One must take the epistemology of instructed disciplines seriously, but part of our strength is in the innovative perspectives we can bring to bear on subject matter.*
  b) Patterns of children's learning. *We are broadly committed to a genetic perspective, if not a particular genetic epistemology. It is as important that we learn from those we teach as well as the other way around.*
  c) What kinds of activities we envision. *We are designers of mediated activities as much as designers of artifacts. Our craft demands a social/enactive view of knowledge.*
- Can we identify an epistemological basis for visual or manipulative or linguistic interface designs? *We need foundations. Epistemology, possibly multiple epistemologies for different modalities, may provide such grounding.*
- There is still a large gap between epistemology, developmental psychology, and expert understanding *(domain epistemology)* on the one hand and systems design on the other. *Systems design is part art and part complex engineering practice, for all of its scientific bases. The gap may be narrowed by epistemological and other scientific progress, but it is likely to remain a permanent feature of the craft of designing educational technology.*

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