Epistemic Frames and Islands of Expertise: Learning from Infusion Experiences

David Williamson Shaffer
Department of Educational Psychology, University of Wisconsin-Madison
Educational Sciences Room 1065, Madison, WI 53706
Tel: 608/265-4602, Fax: 608/262-0843
Email: dws@education.wisc.edu

Abstract: Building on the theory of islands of expertise developed by Crowley and Jacobs (2002), in this paper I develop the concept of epistemic frames as a mechanism through which infusion environments can help students use experiences in one context to help them deal with new situations. I describe epistemic frames as the ways of knowing, of deciding what is worth knowing, and of adding to the collective body of knowledge and understanding of a community of practice (Lave & Wenger, 1991). I use data from two design experiments to extend the concept of islands of expertise, showing how the ability of students to incorporate epistemic frames into their identities suggests a mechanism through which infusion experiences and other rich learning contexts may support activity in novel situations.

Design Experiments as Infusion Experiences

We conduct design experiments in the learning sciences to help understand the complex processes of learning in context, with the goal of reforming education through the development of better tools, activities, curricula and models for learning (Brown, 1992; Design-Based Research Collective, 2003). Along the way to this larger goal a much smaller group of students and/or teachers participate in a more isolated learning experience: the design experiment itself. Design experiments thus function for participants as infusion experiences in their school curriculum or in the broader curricula of their social, emotional, and intellectual development—powerful but often relatively isolated experiences with new topics and new ways of thinking and learning.

One striking aspect of design experiments—though one that is typically discussed anecdotally—is the effect that effective infusion experiences can have for participants beyond the scope of the intervention itself. I remember vividly one young woman, whom I'll call Natalie, who was a participant in Escher's World, a design experiment in which middle school students came to a summer program and learned about geometry by working as graphic artists to prepare a museum exhibit of digital designs (Shaffer, 2002). I was talking with Natalie late in the fall, several months after the conclusion of the experiment as part of the follow-up interviews for the project. Natalie's work on a variety of assessment instruments showed that changes in her understanding of the "content" of the workshop—transformational geometry and graphic design—had persisted over time. More striking, though, was how much more confident Natalie seemed in the fall than she had over the summer. I asked her about a new pager she was wearing proudly, and she replied that her parents had bought it for her because she was "getting all A's in all my subjects."

I knew from pre-interviews that Natalie had not been an A student the previous year, so I asked what had changed in her schoolwork. She said the difference was that now "I raise my hand at every single question… Last year, I [was] like, 'No, please don't call on me!' Now my teacher doesn't want to call on me any more." She went on to describe in some detail how her attitude had changed in each of her classes because of her participation in the experiment.

Natalie's story, while more dramatic than some, is not an uncommon result of participation in design experiments and other infusion activities. There are any number of reasons to be wary about reading too much into comments such as Natalie's. But they do suggest that effective infusion activities can impact students beyond the limited content and context of the experience itself. Infusion experiences such as Escher's World seem to accomplish, in a very general but very important sense, the elusive educational goal of producing worthwhile effects

that carry over from one context to another—in Natalie's case, from a summer program on mathematics and digital art to her performance in school more generally.

In this paper I propose a framework for thinking about how infusion experiences accomplish this important goal. Building on the theory of *islands of expertise* developed by Crowley and Jacobs (2002), I suggest the concept of *epistemic frames* as a mechanism through which infusion environments can help students use experiences in one context to help them deal with new situations. In the sections that follow, I first use excerpts from my conversation with Natalie to describe and extend Crowley and Jacobs's idea of islands of expertise. I then discuss the theoretical underpinnings of the concept of epistemic frames, which builds on the work of Lave and Wenger (1991), Broudy (1977), Perkins (1992), Schwartz and Sherin (2002), and on my own work on *pedagogical praxis* (Shaffer, in press-a). I then use data from the Pandora Project (Shaffer, in press-b)—another design experiment/infusion experience—to examine the existence of epistemic frames. Although at this stage evidence regarding epistemic frames is preliminary rather than conclusive, I end the paper by discussing some of the potential implications of the concept for the development of learning environments, and for our understanding of learning more generally.

Islands of Expertise

Crowley and Jacobs (2002, p. 333) define an island of expertise as "any topic in which children happen to become interested and in which they develop relatively deep and rich knowledge." These areas of connected interest and understanding, they suggest, create "abstract and general themes" that become the basis of further learning, both within and around the original topic area, and potentially in domains further afield (p. 334). They provide several examples of such islands, including a boy who develops relatively deep content knowledge and a "sophisticated conversational space" (p. 335) about trains and related topics after he is given a *Thomas the Tank Engine* book: the boy likes the book and ask to read it over and over; his parents buy him a Thomas the Tank Engine toy, and rent Thomas the Tank Engine videos for the boy to watch; the boy dresses as Thomas for Halloween; the family takes a trip to a local train museum where the boy gets a t-shirt with a picture of "Big Boy," a gigantic steam locomotive; they check out more advanced library books on trains; the boy and his mother talk about steam from a kettle as being "just like a train."

Crowley and Jacobs focus on how the islands of expertise in museums and other informal settings are constructed using *explanatoids*: short fragments of explanatory talk, typically between parent and child. Islands of expertise, they argue, develop as the culmination of a long series of collaborative interactions that are opportunistic and relatively unremarkable when viewed individually, but which collectively create a powerful linkage between understanding and interest. Crowley and Jacobs do not explicitly discuss the role of identity in this process, but it is implicit in their account—for example when the boy dresses up as Thomas or wears a t-shirt with a picture of a locomotive.

I have discussed elsewhere some of the mechanisms through which Natalie and the other participants in Escher's World developed understanding about mathematics and design (Shaffer, 1997, 2002, in press-a). In the more structured setting of a design experiment and summer program, linkages between interest and understanding were similarly created through a series of collaborative interactions with peers and experts. However, the interactions were fewer in number and organized more explicitly—and thus were characterized by fewer interactions that were more deliberate and less opportunistic than in Crowley and Jacob's examples.

Here I am more interested in using Natalie's example as a window into some of the ways in which this island of expertise in mathematics and design, once developed, became a vehicle for learning in other areas, and for Natalie's further development of interest and expertise in math and art. As Natalie and I spoke, she provided a number of examples of how her work in the Escher's World summer program had become part of her school experience more generally:

> Natalie: I look at my [art] teacher's artwork . . . and she says, "What's your opinion, Natalie?" And I go, "You should put in more [indistinguishable] symmetry in this, and the balance out." She was pretty amazed. Now she's working more artworks…. Some of my classmates, they don't [say much more than:] "Wow, it's a picture. It's colorful." But I tell my friends, "When you look at it carefully, it seems interesting." I tell them all these words I learned, like the [mirror lines] and patterns.

Interviewer: How do they respond?

N: "Whoa, Natalie, where did you learn all this…?" Now I'm teaching them art. They really want to learn stuff about art. I think that because of this program I'm getting all A's in all my subjects.

I: How come?

N: I don't know. I seriously don't. Maybe things I remembered, or the way I'm talking to teachers about all this. I don't know. It's a weird feeling…. In music class, we brought up art, because they say that music is art. And from this program, they think art is math. So I brought up the symmetry, and the music is symmetry and balancing. They told me after school, "Now I have a different way of looking at music…." We're doing a lot of artwork in Spanish…. And my classmates, they're not really good at art, but I'm the teacher's helper, because I speak Spanish too. And I tell everybody, "But look at this. Just imagine like this, and how it balances out, and the colors…." [In] Science. The math. I'm learning percents and degrees, angles. We're supposed to be learning in math. That's helped me understand better. Because I was usually shaky in that part, and now I'm pretty stable at that.

I: [Do you feel differently] about presenting your work in public, showing it to other people, talking about it?

N: That's easy. Dad has a video camera. I used to be not photogenic, and now it's like, "Hi, don't forget me." And students, they'll take pictures of me. I'm like, "Don't forget me in the picture." And presenting, I had critics. So that's a big thing…. Now I'm loud-spoken in public speaking, and pronouncing every single word, with no stumbles. Last year I was like, "Uhhh." [Makes a shivering sound.]

Natalie's examples suggest at least four mutually-reinforcing effects that the island of expertise in math and art had on her subsequent school experiences:

1. Specific elements of domain knowledge in mathematics and art developed in Escher's World helped Natalie work in these subjects. In math class, she felt more confident "learning percents and degrees [and] angles." Similarly, she is teaching her friends about art, showing them how "when you look at [art] carefully, it seems interesting."

2. This domain knowledge was closely associated with a particular way of seeing the world. A persistent theme in Natalie's description of her experiences in school following the workshop is on the close reading of works of art: on how attention to details of form and composition give her insight and help construct her as an expert in the eyes of peers and teachers. She described with pride the response of her friends ("Whoa, Natalie, where did you learn all this?"), and that her art teacher "was pretty amazed" at how much she knows about design principles.

3. This way of seeing helped construct Natalie as an expert to her peers, her teachers, and to herself, which gave her points of entry into new domains. She described having "a different way of looking at music" by using ideas about symmetry. In Spanish class, her recognized expertise and interest in art gave her a role as "teacher's helper" as the class discussed artwork as part of the curriculum.

4. Finally, interest and expertise supported the transfer of more general practices from the workshop to the school setting. An important element of design is public discussion of work in progress. Natalie's experiences in the workshop—supported by her understanding of mathematics and art and by her new identity as an expert in these areas—helped her become an active participant in all her classes.

I do not have data about how deep or long-lasting these effects were—although the pattern had apparently been going on for several months and, according to Natalie, had been effective in raising her grades considerably. What is more important here is recognizing that the island of expertise Natalie developed appears to have been a

combination of content knowledge and interest in a topic, as Crowley and Jacobs described, but also the explicit development of an identity of expertise and the association of that expertise with particular practices. Moreover, this nexus of content, interest, identity, and particular practices were developed together around a particular way of knowing—or perhaps more aptly in Natalie's case, a particular way of seeing: of knowing where to start looking at new situations. As she approached her schoolwork in a variety of subjects the island of expertise she developed around mathematics and design helped give her something that she wanted to say, helped give her a way to talk about it, and in the process helped give her an identity as someone who had something worth saying. Natalie's island of expertise was thus organized, I argue, around a coherent epistemic frame.

Epistemic Frames

Lave and Wenger (1991) describe a community of practice as a group of individuals who share a repertoire of knowledge about and ways of addressing similar (often shared) problems and purposes. In the process of participating in the practices of such communities, individuals develop ways of thinking and reframe their identities and interests in relation to the community. That is, students who work as designers of mathematical art incorporate new ways of thinking and working into their sense of self, coming to think of themselves, at least in part, as designers—and, in particular, as designers interested in and literate about mathematics.

Pedagogical praxis (Shaffer, in press-a) extends the idea of communities of practice by suggesting that different communities of practice (for example, different professions) have different epistemic frames: different ways of knowing, of deciding what is worth knowing, and of adding to the collective body of knowledge and understanding of the community. Broudy (1977) argues that the oft-discussed concepts of knowing *that* and knowing *how*—of declarative and procedural knowledge—are incomplete without the capacity of "knowing *with*," which he describes as providing "a context within which a particular situation is perceived, interpreted, and judged" (p. 12). Epistemic frames are the ways of knowing *with* associated with particular communities of practice. These frames have a basis in content knowledge, interest, identity, and associated practices, but epistemic frames are more than merely collections of facts, interests, affiliations, and activities. Extending Broudy's terminology, epistemic frames are a form of knowing *with* that comprise, for a particular community, knowing *where* to begin looking and asking questions, knowing *what* constitutes appropriate evidence to consider or information to assess, knowing *how* to go about gathering that evidence, and knowing *when* to draw a conclusion and/or move on to a different issue. Following Brown and Campione (1996), I have argued elsewhere (Shaffer, 2003, in press-a) that such ways of knowing form a coherent core around which effective practices are organized.

This concept of epistemic frames is related to but distinct from the sense in which other theorists have used the concept of epistemology. An epistemic frame is a broader concept, for example, than Perkins' (1992) *epistemic understanding* or Schwartz and Sherin's (2002) and Collins and Ferguson's (1993) *epistemic structures*. Perkins defines epistemic understanding as "knowledge and know-how concerning justification and explanation in the subject matter" (p. 85). As such, it is co-extant with—but distinguished from—knowledge of facts, routine procedures, problem-solving strategies, and inquiry skills. Schwartz and Sherin, building on work by Collins and Ferguson, describe epistemic structures as a combination of *epistemic forms* (abstract forms of knowledge or schemata appropriate to a discipline) and *epistemic games* (rules for manipulation of these forms). In contrast, epistemic frames include methods for justification and explanation and forms of representation, but orchestrated with strategies for identifying questions, gathering information, and evaluating results. Epistemic understanding and epistemic structures form the core of disciplines or subjects such as mathematics or history. Epistemic frames are the organizing principle for practices. Geometers, economists, statisticians, and engineers (all of whom use mathematics) have distinct epistemic frames that incorporate different epistemic understandings and structures from the domain of mathematics.

Developing expertise thus implies developing expertise of some particular kind, from some particular perspective, relative to the ways of knowing of some community of practice. An island of expertise is local to a particular topic—perhaps a domain of inquiry, but at first more likely some piece of a domain that a student finds particularly compelling. But building such an island necessitates developing an epistemic frame, which has the potential to be applied to other contexts. In the next sections of the paper, I present data from a design experiment in which students developed islands of expertise in the science and ethics of xenotransplantation (the transplantation of organs from one species to another) by engaging in the practices of professional mediators. The data from that study

suggests that as a result they came to think about issues of ethics and technology more generally using the epistemic frame of mediation.

Islands of Expertise and the Generality of Epistemic Frames in the Pandora Project

In the Pandora Project, high school students learned human immunobiology and biomedical ethics through computer-supported negotiation modeled on exercises developed by the Harvard Program on Negotiation for training professional mediators (Susskind & Corburn, 2000). An important core of the epistemology of negotiation is that stakeholders in a dispute have legitimate conflicting interests, and the goal of negotiation is to reconcile those interests in an equitable manner given the constraints of the situation. The focus is on the parties involved in a problem, understanding their needs, and analyzing how proposed solutions impact their legitimate interests. In the project, students acted as lead negotiators for parties in a dispute concerning a fictitious company seeking governmental approval to begin experiments with the controversial biomedical procedure (xenotransplantation) to introduce organs from pigs into human patients as treatment for late-stage organ disease.

Methods

A study was conducted with fourteen 17- and 18-year-olds at an independent school in suburban Massachusetts. Students participated in a two-week school-based curriculum. After a 3-class-period (150 minute) introduction, students spent 2 class periods (100 minutes) researching their positions in teams in preparation for a 3-class-period (150 minute) structured negotiation simulation.

The training of professional mediators and negotiators involves simulated negotiations in which learners take on the roles of the stakeholders in fictitious disputes. In the simulated negotiation for xenotransplantation, stakeholders were X-Gen (the biotechnology company who had developed the procedure), the National Government, the World Health Organization, the Animal Rights Coalition (a non-governmental organization), and the Patient Rights' Organization (a second NGO). The developers of a simulated negotiation identify the key issues in the dispute, and for each issue specify a set of possible outcomes. In the case of xenotransplantation, the issues were: Length of quarantine and post-operative monitoring for patients, Terms under which a moratorium would be declared on the use of the procedure, Decisions about the ethical treatment of animals used in the procedure, Compensation to developing nations for increased public health risks, and Funding for medical alternatives to the procedure. A confidential point score is assigned to each option for each stakeholder, representing the value of that outcome for the stakeholder. These *utility points* for each outcome vary from stakeholder to stakeholder. For example, the biotechnology company might receive 100 points if there is no quarantine and the patient may drop out of monitoring obligations at any time (which was Issue 1, Option a in the xenotransplantation simulation), because that will increase access to the procedure. The Animal Rights Coalition, which wants to make the procedure as expensive and difficult as possible, might get -50 points for the same outcome. Thus each stakeholder gets their highest score in utility points for a different set of outcomes to the issues in dispute. The negotiation takes place as the stakeholders trade options across the issues in dispute, trying to find a set of options that will satisfy the needs of all of the participants at the table.

Following a general introduction to the issues of xenotransplantation and the framework of the simulated negotiation, students were assigned roles in groups of three. They spent two class periods conducting research on their stakeholders' positions regarding xenotransplantation, and background information about genetics, epidemiology, and cell biology needed to assess potential problems raised by xenotransplantation. Based on this research, each stakeholder group prioritized the issues in the dispute as well as the options for each issue in the dispute from the point of view of its stakeholder's interests. Utility points for each role were computed using an algorithm that incorporated these prioritized lists. Students were then divided into groups of five, with each student representing a stakeholder in one of three separate negotiations.

Data Collection and Analysis

Data was collected in pre-and post-interviews conducted with eleven of the students who participated in the negotiation. (For logistical reasons, only 11 of the 14 students were able to complete both pre and post interviews.) Interviews asked students to discuss their views on biotechnology in general and xenotransplantation in particular and to complete concept maps about xenotransplantation. Students also responded to four scenarios presenting moral dilemmas raised by xenotransplantation in other contexts: problems of cost/benefit analysis, differential risk/reward

tradeoffs between developed and developing nations, individual and societal rights, and animal welfare. Two forms of each scenario were developed. Forms were randomized between pre and post interview for each student, and scenarios were given to students in a random order. Interviews were transcribed and broken into excerpts, defined as complete answers to interview questions with any additional follow-up questions directly related to the initial inquiry. Concept maps were coded by number of nodes and arrows used.

Results

I have described the results of the Pandora Project in more detail elsewhere (Shaffer, in press-a, in press-b). Here I argue more briefly that in the process of conducting a simulated negotiation: (a) students developed an island of expertise including understanding of and interest in xenotransplantation (and more generally in the ethical implications of technology), and (b) this island of expertise led to the development of an epistemic frame of mediation and dispute resolution, which students used to analyze moral dilemmas in other contexts.

Understanding of and Interest in Xenotransplantation

In the process of the simulated negotiation, students developed a better understanding of both the process of xenotransplantation and its social, economic, and personal consequences. Concept maps drawn by students showed significant change between pre- and post-interviews. Maps both had more nodes and more links in post-interviews. (Mean nodes pre=9.6, post=10.6; $p<.05$. Mean links pre=12.8, post=18.5; $p<.01$. See also Figure 5.)

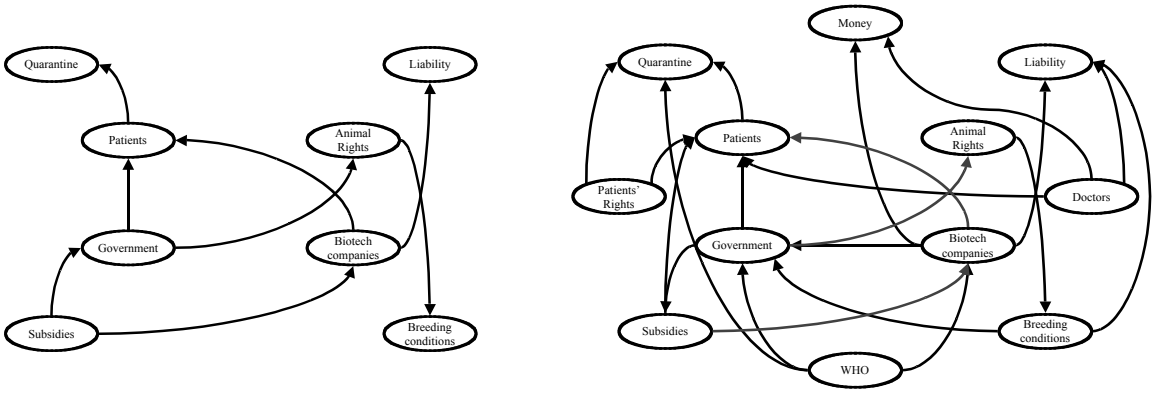

Figure 5: One student's concept maps from pre-interview (left) and post-interview (right) show a significant change in complexity of thinking about xenotransplantation.

Overall, 91% of the students (10/11) reported that they had changed their opinion about xenotransplantation over the course of the unit. The same proportion reported that they understood xenotransplantation better, and 55% (6/11) said that they now understood a range of perspectives on the questions raised by xenotransplantation. Moreover, 82% of the students (9/11) said they were interested in learning more about xenotransplantation and/or issues of ethics and technology more generally. As one student put it: "I think I definitely want to follow up on everything that we've done. Because it's really interesting. And it's really so powerful and so permanent in the science world that I think it would be a shame to just drop it."

Evidence that this interest and understanding was related to identity development was weaker, but interviews with students suggested that the structured negotiation (particularly the system of utility points) pushed students to take on the role of one of the stakeholders in the simulated dispute. As one student explained: "The points… forced me to think like a government official…. I had to, you know, adopt a stance that was government-like, and I had to defend it and find reasons for it. To try and defend myself, I had to take on Connor Andrews [the fictitious government negotiator] and think, like: 'What will we do? What would he say?'"

Development of the Epistemic Frame of Mediation and Dispute Resolution

As described above, students responded in pre- and post-interviews to four scenarios presenting moral dilemmas raised by xenotransplantation in other contexts. For example, they were asked to respond to two versions of the following scenario:

FieldFarms, an international grain supply company, has developed a new form of wheat that is far

less expensive that traditional forms of wheat. However, the grain is sterile, meaning that farmers cannot store seeds from one harvest to use the next year; they have to continually buy seeds from the company. The United Nations Food and Famine Commission is concerned that farmers in developing countries will be tempted by the lower price for the grain, but then become dependant on these grain supplies, and be required to pay whatever price FieldFarms demands for its grain. What conditions, if any, should be imposed on the use of this new form of wheat?

Before the negotiation about xenotransplantation, one student responded:

[I]f Field Farms made it, they have the right to sell it however they want to…. [T]he farmers should be made aware that they might have to pay higher prices, but I think they have to take that risk… of knowing that they might in the future have to pay higher prices for it because they could always buy it from somewhere else if Field Farms raised their prices too much. So, I don't think that they should require Field Farms to have any certain price because I think supply and demand will take care of that in a way in these foreign markets.

Two weeks later, after the negotiation, the same student responded to a similar scenario:

Field Farms has a right to sell it at what price they want to, but because it's a monopoly on the thing, I think in the developed world… whatever the market demands, that's what they'll sell it for…. But I think in the developing world… much like AIDS drugs, I think… they should lower the prices a little bit. You know, make sure it's fair. Because obviously developing countries are a lot more dependant on agriculture than we are, and I think it's sort of holding them hostage if every year you can just jack up the price on the grain.

Answers to moral dilemmas such as these showed that participation in the simulated negotiation helped these students think about ethical dilemmas using the epistemic frame of professional negotiation and dispute resolution. In particular, students began to analyze disputes in terms of legitimate conflicting interests of stakeholders, focusing on understanding the needs of the parties affected by a problem. Before the simulated negotiation curriculum, extensive and analytical responses involved looking for more information (R^2=0.46, $p<0.05$) and/or proposing a means to get more information about the problem (R^2=0.85, $p<0.01$). After the negotiation experience, extensive and analytical answers were still associated with the need for additional information (R^2=0.51, $p<0.05$), but such responses also showed (as in the example above) both analogical reasoning (R^2=0.82, $p<0.01$) based on students' islands of expertise in xenotransplantation (the case of AIDS was explicitly discussed as part of the curriculum), and consideration of a range of viewpoints from groups of people affected by the proposed technology (R^2=0.61, $p<0.01$).

Discussion

Crowley and Jacobs (2002) suggest that islands of expertise based on understanding of and interest in a specific topic create "abstract and general themes" that students are able to use in other contexts. Here I add that islands of expertise include development of identity and adoption of practices associated with the ways of knowing of a particular community. That is, I argue that islands of expertise are organized around coherent epistemic frames, and that these frames—these ways of looking at the world associated with different communities of practice—are the "abstract and general themes" that students use to leverage experience in an island of expertise in new situations.

To return for a moment to Crowley and Jacob's examples, the boy who developed an island of expertise about trains did so, they argue, through a particular set of practices—namely, the exchange of explanatoids. Just as participation in graphic design activities helped Natalie develop key elements of the epistemic frame of a graphic designer in looking at works of art, and participation in a simulated negotiation helped students in the Pandora Project develop key elements of the epistemic frame of mediation and dispute resolution, so visits to museums and libraries to learn about trains seem to have helped the boy develop what we might describe as an epistemic frame of a lay-scientist and collector, train enthusiast, or hobbyist. Epistemic frames are the proverbial "hats" or "glasses" we don as we take on a variety of identities or perspectives in dealing with different situations. Once students learn to think like designers, or mediators, or train enthusiasts, they can (and do) use the ways of knowing embedded in these practices in other contexts.

Epistemic frames thus include, but are a broader concept than, epistemic understanding, epistemic forms, and epistemic games. Although the data presented here is not rich enough to support a strong claim, it suggests that an epistemic frame may be more akin to Foucault's (1972) well-known concept of *episteme*. The episteme of an era, for Foucault, is the relationship between discoursive practices (patterns of discourse or forms of interaction) and structures of knowledge (which for Foucault are always intertwined with the organization of power). Episteme exists at the level of the culture, across domains of knowledge and forms of practice. Epistemic frames may represent a similarly tight linkage between practices and ways of knowing, but at the level of the local cultures developed by individual communities of practice.

The data in this relatively short paper are clearly illustrative rather than conclusive. Nonetheless, they do suggest that islands of expertise and epistemic frames may be useful ways to think about the potentially broad effects of isolated learning experiences such as design experiments and other infusion activities. Moreover, the ability of students to incorporate epistemic frames into their identities (or portfolio of potential identities) suggests a mechanism through which sufficiently rich experiences may support activity in novel situations.

References

Broudy, H. (1977). Types of knowledge and purposes of education. In R. C. Anderson, R. J. Spiro & W. E. Montague (Eds.), Schooling and the acquisition of knowledge (pp. 1-17). Hillsdale, NJ: Lawrence Erlbaum.

Brown, A. L. (1992). Design experiments: Theoretical and methodological challenges in creating complex interventions in classroom settings. The Journal of the Learning Sciences, 2(2), 141-178.

Brown, A. L., & Campione, J. C. (1996). Psychological theory and the design of innovative learning environments: On procedures, principles and systems. In L. Schauble & R. Glaser (Eds.), Innovations in learning: New environments for education (pp. 289-325). Mahwah, NJ: Erlbaum Associates.

Collins, A., & Ferguson, W. (1993). Epistemic Forms and Games. Educational Psychologist, 28(1), 25-42.

Crowley, K., & Jacobs, M. (2002). Islands of expertise and the development of family scientific literacy. In G. Leinhardt, K. Crowley & K. Knutson (Eds.), Learning conversations in museums. Mahwah, NJ: Lawrence Erlbaum.

Design-Based Research Collective. (2003). Design-based research: An emerging paradigm for educational inquiry. Educational Researcher, 32(1), 5-8.

Foucault, M. (1972). The archeology of knowledge (A. M. Sheridan Smith, Trans.). New York: Harper Colophon.

Lave, J., & Wenger, E. (1991). Situated learning: Legitimate peripheral participation. Cambridge, England: Cambridge University Press.

Perkins, D. (1992). Smart Schools. New York: Free Press.

Schwartz, J., & Sherin, B. (2002). Describing science content: Bridging the gap between content and process. In P. Bell, R. Stevens & T. Satwicz (Eds.), Keeping learning complex: Proceedings of the fifth international conference of the learning sciences (pp. 421-428). Mahwah, NJ: Lawrence Erlbaum.

Shaffer, D. W. (1997). Learning mathematics through design: The anatomy of Escher's World. Journal of Mathematical Behavior, 16(2), 95-112.

Shaffer, D. W. (2002). Design, collaboration, and computation: The design studio as a model for computer-supported collaboration in mathematics. In T. Koschmann, R. Hall & N. Miyake (Eds.), Computer support for collaborative learning 2 (pp. 197-222). Mahwah, NJ: Lawrence Erlbaum Associates.

Shaffer, D. W. (2003). Portrait of the Oxford design studio: An ethnography of design pedagogy (WCER Working Paper No. 2003-11). Madison: University of Wisconsin-Madison.

Shaffer, D. W. (in press-a). Pedagogical praxis: The professions as models for post-industrial education. Teachers College Record.

Shaffer, D. W. (in press-b). When computer-supported collaboration means computer-supported competition: Professional mediation as a model for collaborative learning. Journal of Interactive Learning Research.

Susskind, L. E., & Corburn, J. (2000). Using simulations to teach negotiation: Pedagogical theory and practice. In M. Wheeler (Ed.), Teaching negotiation: Ideas and innovations (pp. 285-310). Cambridge, MA: PON Books.

Acknowledgments

Funding for the studies described here was provided by the Foundation for Ethics and Technology, and the LEGO Corporation. Work on this paper was supported by the Wisconsin Alumni Research Foundation and the Spencer Foundation. I would also like to thank the students and faculty who contributed to Escher's World and the Pandora Project, as well as the members of the Epistemologies of Practice research group and my friend and colleague Rich Halverson.