Of Grids and Jars: A Comparative Analysis of Representational Infrastructure and Learning Opportunities in Middle School and Professional Science

Rogers Hall, Rich Lehrer, Deb Lucas, & Leona Schauble (alphabetical order)
162 Wyatt Center, Vanderbilt University, Nashville, TN 37203
Tel: (615) 343 7063, Fax: (615) 322 8014
Email: rogers.hall@vanderbilt.edu, deborah.d.lucas@vanderbilt.edu, rich.lehrer@vanderbilt.edu, leona.schauble@vanderbilt.edu

Abstract: We focus on representational infrastructures that allow people to render, manipulate, and explore aspects of complex natural systems (e.g., the foraging behavior of a colony of termites on the forest floor or the ecology of a closed pond). By contrasting routine and innovative uses of representational infrastructure, we seek to understand how opportunities for learning are distributed in project work that is enabled by infrastructure, while that infrastructure is, itself, under development. We report on a comparative analysis of how learning and infrastructure are related in a field entomology research group and in a 6th grade integrated science and mathematics classroom.

In classrooms or in workplaces, getting things done—including learning and teaching—depends upon layers of infrastructure that are typically hidden from view unless they break down or are intentionally disrupted (Bowker & Star, 1999; Engestrom, Brown, Christopher & Gregory, 1991/1997; Hall, Stevens & Torralba, 2002; Hutchins, 1995). In this paper, we focus on representational infrastructures that allow people to render, manipulate, and explore aspects of complex natural systems (e.g., the foraging behavior of a colony of termites on the forest floor or the ecology of a closed pond). By contrasting routine and innovative uses of representational infrastructure, we seek to understand how opportunities for learning are distributed in project work that is enabled by infrastructure, while that infrastructure is, itself, under development. We report on a comparative analysis of how learning and infrastructure are related in two different settings. In a field entomology research group, we analyze how a group of practicing scientists (entomologists, chemists, and a statistician) stretch a "grid" of sampling stations over wild land and residential sites to follow the foraging behavior of termites. In a 6th grade integrated science and mathematics classroom, we analyze how a teacher and entomology graduate student work with student teams to establish a collection of "pond jars" that are designed to model selected features of a local pond environment. The "grid" and collection of "pond jars" each provide a representational infrastructure for modeling natural phenomena. However, these infrastructures have a very different history of development, people in these sites are differently knowledgeable about how they work and can be repurposed, and they provide different opportunities for learning under conditions of routine and innovative use. The following questions have organized our comparative analysis:

(1) What is the relationship between representational infrastructure and the learning trajectories of people who make, use, and maintain this infrastructure?

(2) Given a certain level of sophistication in some existing infrastructure, what is the spread or distribution of understanding regarding this structure and what it enables? That is, how is being knowledgeable (defined as being able to do things, ask questions that fit the infrastructure available for answering them) distributed across participants in particular kinds of organizations (classrooms, research groups) under conditions of routine use?

(3) How does infrastructure change or get repurposed, during periods of innovation?

(4) What opportunities for learning arise during periods of innovation, and how are these related to the distribution of being knowledgeable? In particular, how do periods of innovation change the distribution of being knowledgeable?

Data for each setting (field entomology and middle school science) were selected from ethnographic observations, video recordings of work on group projects, documents and artifacts produced during project work, and interviews conducted with participants in each site (scientists, teachers, or middle school students). These field materials were collected over several years in each site, and for the purposes of close comparative analysis, we have assembled strips of activity that are "typical" of ongoing objectives and activity in each study site. Our judgments about typicality are informed by other, independent analyses of these materials (e.g., Hall, Stevens & Torralba, 2002; Lehrer & Schauble, 2002), and will be described further below. In the sections that follow, we first present each setting and the strips of interaction we have selected as typical examples of routine and innovative use. We then turn to a comparative analysis conducted within (routine versus innovative use) and across sites (field entomology versus middle school science). Finally, we discuss the educational implications of our comparative findings, both for the design of complex learning environments and for theories of learning and teaching that seek points of articulation between collective and individual levels of development.

Working the "Grid" at the BugHouse

The BugHouse (pseudonym) consists of a group of scientists (entomologists, chemists, and a statistician), working in a federal research lab to study the "chemical ecology of forest insects" (quoted terms are from study participants). One part of their research follows the foraging behavior and wood consumption of termites in what they call a "wild land" study site. This site lies inside an arboretum, established 40 years ago in the foothills of the Sierra Nevada mountains to cultivate an array of typical evergreen tree species. In the soil beneath these trees, the researchers have laid out rectangular plots of sampling stations, where each station is made of plastic pipe and loaded with a bundle of carefully measured and labeled wooden slats. Following a sampling protocol that specifies when and how stations are checked and wood bundles processed, field workers visit the wild land site each month to check for termite activity in stations. They remove wood bundles, replace these with alternate bundles, make estimates of termite activity and abundance (a station that has been "hit" can have thousands of individuals on the wood bundle), and then bring wood and termites back to the lab for further analysis. In the lab, wooden slats are cleaned of any dirt, dried in an oven, weighed precisely, and rebundled to be taken back to the same station on the researchers' next visit to the wild land. This iterated chain of research activities make up a representational infrastructure that BugHouse members call the "grid." They operate the grid over time to find termites in the wild, follow their foraging range, estimate the size of their colonies, and measure the amount of wood that each colony consumes.

In routine use, the grid is a stable network of technologies and human practices that inscribe (Latour, 1990) the world of termites into BugHouse publications. As an example of routine us, we have chosen a conversation recorded in a project meeting where researchers are preparing data to be used in an analysis of wood consumption. In order to estimate wood eaten by termites, they need to estimate wood lost as humans handle (clean, dry, and weigh) wood slats. They are trying to identify "controls" in a multi-page table of codes that estimate termite activity in stations (rows) over monthly samples (columns). A "control," in the table, should appear as a series of adjacent cells (a time interval) along a row (a station), in which codes show no termite activity. Wood lost during this time interval must be due to human activity, since (by fieldworkers' estimates) there were no termites present. To give a sense of how this activity proceeds, we first present a candidate control proposed by a senior researcher, Mark. "Wg7" refers to the plot, column, and row location of a station on the wild land grid (i.e., a physical location in the Sierra Nevada foothills). In the context of this conversation, however, it also refers to a row in the table they are jointly exploring. In the transcript, activity descriptions appear in italics enclosed by double parens. Onset of overlapping talk is shown with open brackets, matched across speaking turns. Upper case indicates emphatic talk, and stretches of enunciation are shown with repeated colons.

(Routine, Fragment 1)

Mark: Well Wg7 af, after December 21st, [1994... ((*whistles*)) Long string, but then it, you know they show up again. ((*R pen tracing across the row*)) So somewhere in there, that stuff, you know, I think it would be [legitimate to

Kris: [Wait. Are you sure... that, I think, no::: I think [the (oh) Wd...

((*brief exchange over codes*))

Kris: =No, but you're looking at Wg7, and I think that there's data (that) forgot to be entered in [here.

Seniors propose, and juniors disqualify, controls five times in the course of this brief conversation. Either the seniors fail to read the table correctly (e.g., choosing a column/month when no data were collected at all) or they choose candidates that, for reasons buried in the work of bringing data from the wild land to the lab, are unusable. In the above exchange, Kris (a junior member of the team) reveals there are data missing for Wg7, even as she deflects responsibility for this trouble from anyone in particular ("there's data (that) forgot to be entered"). Since junior members of the team operate the grid on a monthly basis and prepare these tables, they understand what the values (and patterns of values) in the table actually represent (or do not represent). Not surprisingly, the first viable control is found by Gaye, another junior researcher (and manager of the field protocol).

(Routine, Fragment 2)

Gaye: ((*gaze on data table*)) LOOK at [Wk64. (2 sec) Look at that one.]

Mark: [Oh. (2 sec) THAT should be noted, ((*L point traces to left margin*)) oh I see]

Victor: W[k64. Yeh, there is a better.

Gaye: [Wk[64.] There's a big gap between... October of 94 through... January of 96.

Mark: Um hm.

Based on ethnographic observation and analysis of similar exchanges in project meetings, this is a typical distribution of knowledge and responsibility in the BugHouse research team. When the representational infrastructure runs smoothly, juniors speak for the field in meetings with senior researchers (Victor and Mark), who because of their other commitments, have limited knowledge of what actually happens there. The senior researchers are, of course, responsible for the conduct of this research. As the conversation, excerpted above, continues, they arrive at an agreeable definition for a control and schedule a meeting to resolve individual data points, once data entry has been completed. As a practical accomplishment, what is known and what people have a chance to learn is divided hierarchically at the BugHouse. Projects (and jobs) end when money runs out at the BugHouse. But there is hope in innovation. To ask and answer new (and fundable) questions about termites, the existing grid can be used or a new grid can be stretched over the wild land (or some other) site. Repurposing the grid (both the physical object and the idea) to ask and answer new questions is the innovation under way in the following excerpt of conversation, taken from the same project meeting. Mark (the BugHouse leader) proposes a new research question concerning whether termites forage and feed at different times, a finding that would be very valuable to their applied research sponsors in the pest control industry.

(Innovate, Fragment 1)

Kris: So how would you do, how would you go about… researching that?

Mark: Well I think that, what I would like to do would be to, to um, set up a grid… with a thousand points or two thousand points on it. And then randomly select (3 sec) when to put stakes in the ground. So that you don't put 'em all in at once. And then evaluate, monthly, when these things are attacking the stakes. It's gonna be confounded by the amount of time that they're in. So if you could have a ((*R point pushes into region on "each time"*)) fresh cohort go in each time… (inaudible) I don't know if that's the best way to do it. ((*R reaches into region, then pulls up and right on "out"*)) Then, pull 'em out, find out how many are there.

Kris: Would('nt) they be, I mean you'd rather, every time you pull 'em out, though, you're gonna destroy the termites that're (in there) [(inaudible)

Mark: [Well, if they're there, I don't care. You know (they've) found it.

We make the following observations: (1) Kris' question about "researching," as a type of activity, contrasts with Mark's earlier (prior to this fragment) activity of "poppin' off my mouth." Within the scope of several turns at talk, we catch the BugHouse team transitioning between what Kuhn (1962) called contexts of discovery (i.e., Mark having a novel idea) and justification (i.e., the team designing research that may make the idea durable, later, as a claim). (2) A new kind of grid is proposed, made of different entities and relations than the existing grid. "Points" now act as a 2D frame, and "stakes" (not "stations") are placed at random. (3) Kris expresses concern about what *would* be a problem with the *existing* grid, "you're gonna destroy the termites," but Mark cuts her and the relevancy of her objection off ("I don't care"). The purpose of the grid (as an idea) has shifted, so the grid as a chain of activity and inscription will also change. The juniors need to catch up.

(Innovate, Fragment 2, immediately follows on first)

Gaye: So it's just that one moment in time? Y'know you can't really, it wouldn't be OVER time.

Mark: I'd wanna see if there's (timing) or not. Hitting stakes at noon, versus…

Victor: Whattya think we leave 'em out a month? Or two weeks, three weeks?

Three phenomena are important to us in this second fragment of talk: (1) Gaye's "one moment" collapses termite time (the thing modeled) onto fieldworker time (the act of modeling) as an obstacle (i.e., "you can't really" follow termites "OVER time"). (2) Mark and Victor's subsequent turns, in contrast, separate out these two kinds of time. In their way of talking, fieldworker time ("a month? Or two weeks, three weeks?") is organized to model termite time ("Hitting stakes at noon"). (3) In the existing wild land grid, monthly field worker visits correspond directly to seasonal variation in termite activity, so the unit of fieldworker time (months) is contained within the reported unit of termite time (seasons). However, the proposed grid will shuffle fieldworker time randomly in order to model termite time. So again, the juniors need to catch up, and they work at this (i.e., learning and teaching is underway) in parallel with the ongoing work of repurposing the grid.

(Innovate, Fragment 3)

Gaye: (But) when you say two thousand points, you're saying… stakes.

Mark: [No. points.]

Victor: [No, points.]

Mark: And then you randomly, so if you, let's say we use twenty four hundred… points. And then if we did it on a monthly basis, every month we would randomly select[…]two hundred of those points.

Gaye: [hhh] Oh:::! I see.

Victor: See that?

Gaye: [I see.

In this third fragment, there is still further learning and teaching: (1) The equivalence proposed by Gaye (i.e., that Mark means the same thing by "points" and "stakes") comes 25 turns after he first mentions these terms (Innovate, Fragment 1), so there is a clearly different pace and level of understanding by juniors and seniors. (2) Mark's elaboration makes it clear the innovation will repurpose space, as well as time, since "points" are idealized/actual locations of high relevance to human activity (the work of modeling), while "stakes" are objects of desire for termites. (3) The technique of making "random" choices comes up repeatedly in the talk of seniors, and it provides (with sufficient trials) a way to use fieldworker time to render termite time, without confounding the two (i.e., without compromising the world of termites). (4) The combined correction by Mark and Victor ("No, points."), followed by Victor and Gaye's coordination of what they "see," shows that participants mark this exchange as a relevant teaching moment. The contrast between routine and innovative uses of the grid reveals different ways of being knowledgeable and different opportunities for learning at the BugHouse. Scientific or mathematical thinking involves being able simultaneously to look *at* and *through* the interface between representing and represented worlds (Gravemeijer, 1994; Greeno & Hall, 1997; Hall, 2000). Under routine conditions, seniors get stuck looking at the representational system, and juniors provide a way to look through it onto the wild land (the world being represented). But when the grid (both as an actual structure and an idea) is repurposed in ways that enable innovation (new, fundable questions), the situation is at least partly reversed. We find the juniors stuck looking at the representational system (e.g., Kris' concern about "destroying" termites and Gaye's questions about time and space), while the seniors flexibly re-arrange the system to look out/through the grid onto new aspects of the world of termites (feeding/foraging and diurnal variation). The situation is only partly reversed because we find ample evidence that, even in the midst of innovation, juniors are still able to contribute information about the existing wild land grid that is not already known by the seniors. In terms of opportunities for learning and getting the work of the BugHouse done, there is a complementary relation across generations of participants. As Kris put it in an interview recorded while she was cleaning wood bundles (i.e., in the bowels of the routine), "here we're just doin' the, you know the dirty work," but this gives her (and Gaye) access to "the science… putting every thing together" in BugHouse team meetings.

Working the "Pond Jar" in the Classroom

The "Classroom" is an intact sixth grade class in a public school in the Midwest that, at the time of the study, included 19 students, their teacher, and a university entomology student. This group spent the entire year studying aquatic systems. Students made several visits to two urban retention ponds near the school, observing, sampling, documenting, and mapping the terrestrial and aquatic life in and near the ponds. Students posed and investigated questions about the health of the two ponds, and these questions eventually culminated in the general question, “What makes a system healthy and sustainable?” As the season changed and the ponds froze, students began to explore this question further by designing and investigating their own model aquatic systems, implemented in one-gallon jars. Designing a jar system involved choices of substrate (i.e. sand, gravel, soil), aquatic plants (e.g., elodea, wolfia) and animals (e.g., ghost shrimp, gourami), along with unanticipated participants, such as snails (carried by plants), bacteria and algae. Pairs of students planned, set up, and monitored the jars in various ways, all in service of first generating a sustainable system and eventually, understanding what makes an aquatic system “healthy.” For purposes of the classroom site, then, the infrastructure under construction and transformation is the collection of “pond jars,” yet these jars are located within a larger system of activity involving investigations of the ponds (to which students returned during the spring thaw).

To support student inquiry, the teacher and the entomology student designed an activity structure modeled after the entomologist’s practice—a research meeting. Research meetings featured reports of ongoing progress by teams of students, who presented and revised their research plans and findings in light of questions and comments from their classmates. Different teams reported each week, determined by lottery. Our data include 13 of these meetings, documented via videotapes, student artifacts (e.g., journals, critique sheets), field notes, and individual semi-structured interviews. Over the three months of the students’ investigation with jar-systems, we observed characteristic shifts in students’ activity and interpretation revealed through the lens of their research meetings. We have interpreted these shifts as efforts by students to get a “machinic grip” (Pickering, 1995) on the aquatic system. Student inquiry and the material agency of the jar were intertwined, and inquiry was disciplined by their interactive stabilization. We illuminate this process of stabilization by tracing fragments of interaction during research meetings. We focus on two teams of students, chosen because they represent extremes of the contours of what Pickering calls the “mangle of practice,” meaning that material and human agency are “reciprocally engaged in a play of resistance and accommodation” (Pickering, 1995, p. 23). For one team (Emily, Chris, and Daniel), the play of resistance and accommodation never stabilized, unprincipled innovation abounded, and the jars successfully resisted being harnessed to disciplined inquiry (although questions proliferated!). In the following fragment, the team starts with a researchable question, but apparently cannot resist the temptation to keep importing new considerations into the design. Ilya, a classmate who is watching their presentation, attempts to point out how their experimental improvisations will destroy their opportunities to address their original question. Daniel responds, but Ilya firmly points out that the proposed repair to the jar design will not suffice for the question posed.

(Innovate, Fragment 1)

Daniel:	OK, our question is, how much do fish and frogs affect DO? ((*gazes at Emily*))
Emily:	And, like um, if they do, do some kinds of fish affect it more than others? And do frogs affect it more than fish?
	((*Students describe an experiment using three jars, but they don’t agree about what will be done with these jars*))
Daniel:	In one of them, we’re going to put… well, just the first week, we’re going to put substrate in them…
DL:	In all three (jars)?
Daniel:	No, just two.
DL:	In two. All right. Just the substrate=
Daniel:	=Yeah=
DL:	=Same one? Different one?
Daniel:	Same. Then the next, we’re uh, like two weeks, ((*looks at Emily*))=
Emily:	=Yeah
Daniel:	We decided we’re gonna, do, put in the… plants after we check the DO for the substrates. So, then we check the DO for the plants and the substrate. And we, then after two weeks, we put in the fish, one fish in one of them and a frog in the other.
Emily:	See, we haven’t exactly decided which method we’re gonna use.
Ilya:	Well, uh, you do know if you’re doing something with the DO and your fish start dying, you won’t be able to help them with the bubbler, because that will ruin your whole experiment.

((*Entomology student initiates conversation about accuracy and meaning of DO measurements, then revoices Ilya's caution.*))

Emily: Well, um if our fish start to have problems, we could just move them back to this tank=

Daniel: =Yeah=

Emily: =and this tank is just like our storage container for the fish=

Daniel: =Yeah=

Emily: =and bubble that.

Daniel: Or else before we put the animals and the substrate in, we could first bubble it… to a pretty high DO.

Ilya: But isn't your question how fish and frogs affect the DO?… But=

Daniel: =Yeah, but=

Ilya: =just wait… If your fish or frogs start dying in the jar, and you take them out and put them in the middle jar, then you can't do your question any more, because they're not in the jars affecting the DO. They're in some other jar.

Emily: Well, yes.

For a second team, innovations led to impasses, which were successfully accommodated by re-designing the jars, so that inquiry eventually became disciplined. This pair, Alex and Ilya, initially designed a rather complex jar with a soil substrate, multiple kinds of plants, and two kinds of fishes. With this system, they proposed to change the pH in the jar over time and to observe the effects on plant growth. However, when they presented this proposal, other students immediately challenged the plan. They asked how Alex and Ilya would manipulate pH and what they expected to see. As the conversation continued, Alex and Ilya eventually concluded that their jar was too complicated to pursue this investigation. After all, if the plant growth varied, it might be due to changing pH, but it also might be due to the substrate or to the animals. And what if the different kinds of plants grew at different rates? Confronted with these problems, the pair next decided to monitor the jars of other pairs who were systematically recording pH. In other words, their strategy shifted to focus on comparative study. Yet this plan, too, faltered when it encountered two insurmountable difficulties. First, the other jars also encompassed uncontrolled variation (of substrate, plants, and animals), making it impossible to be confident about cause and effect. Moreover, students noticed that some of the jars were "crashing," with all of the plants and animals suddenly dying (often with quite smelly and messy results). Alex and Ilya wondered how it might be possible to control variation in a system in which the variables themselves were undergoing continuous interaction and change. As a result of these experiences, the pair next decided to generate a deliberate simplification. They would creat three jars, all featuring a sand substrate and elodea as the only kind of plant (no animals). Elodea were considered "good plants. They grow tons of buds in a very short period of time." In consultation with the university entomology student, they learned how to manipulate pH, and successfully conducted an elegant experiment.

In the following segment, they report their conclusion that plants grow fastest in the low pH solution. However, they note that the jar is a system, so things aren't that simple—rapid plant growth eventually causes the jar to "crash." At the end of this segment, Alex struggles with the implications of his simplified system for its status as a model. He wonders whether, in the interests of achieving a stable experimental infrastructure, perhaps they have squeezed the pond right out of the jars. Do the jars still serve as a model of the pond?

(Routine, Fragment 1)

Ilya: We now have a hypothesis why our (original) jar crashed=

Alex: =We do?

Ilya: Yeah we do. Um, well, I think it's because, like he said, I think it's because of the nutrients. Well, we found out from our experiments that the low pH jar has a very high dissolved oxygen, so…

Alex: It's kind of like supply and demand. It has too much supply and very little demand. So what it's doing with the rest of the supply, it's turning it into detritus=

Ilya: =Or algae.

Joseph asks Alex what he thinks these jars might be a model of. This leads to a question of whether their manipulations violate the idea of a "real" pond, in which outside manipulations do not occur. In what ways does a "run" of this apparatus serve as a fair model of a real pond?

(Routine, Fragment 2)

Ilya:	I think what we're trying to model is a a retention pond, because they're (the jars) supposed to be little models of the retention pond, so we can see if the pH of the retention pond, an actual pond, will affect the plants.
	((*exchange with another student, the class expert on algae*))
Joseph:	We've all seen in the retention ponds that there's a lot of pollution in there=
Ilya:	=Yeah
Joesph:	Are you going to try to simulate the type of pollution?
Alex:	I didn't know we were really modeling. I thought these were just kind of experiments, because if you did put pollution in, it would make them crash. We tried to make as few, what do you call it, you know, that scientific word that says how much stuff there is? Can't put my finger on it.
Joseph:	Measurements?
Alex:	No, no, like you got in a volcano, height, magma… Variables, that's what it is, variables! Because we tried to make them all simple so there wouldn't be any other factors, like snails or, you know, pollution. But this one has naturally done that (generated detritus) without us putting anything in it and we're not going to clean it, because that's what would actually happen in real life. So.

The excerpts above exemplify design variations that, for some groups, resulted in a stable representational infrastructure—a functioning pond jar apparatus and routines for taking measurements. On occasion, students' view of the pond jars shifted in ways that constituted an innovative use of the entire collection as an infrastructure. In particular, at one point Ryan began to shift his attention from his own carefully designed pair of jars to re-envision the entire roomful of jars as a system from which one could ask new questions. In the following segment, Ryan responds to a presentation in progress by proposing a new way of looking through the entire collection of jars onto the problem of an unwelcome participant, "a lot of snails."

(Innovate, Fragment 2)

Ryan:	One thing I noticed is that you and me and Ilya and Alex and Jero is the snails, I think, have been hanging out where there's higher pH levels. Hey, Danny, your group doesn't have a lot of snails, does it?
Daniel:	We have, like, six snails.
Ryan:	What's your pH?
Daniel:	Ours is 7.7.
Ryan:	Yeah, so you've got a much lower pH than me and Ilya and Samantha, too.
Taylor:	And me.
Ryan:	Jero, what's your pH?
Jero:	My pH ((*looks at notebook*)), last time I checked was 8.94.
Ryan:	And you've got, like, a medium amount of snails, probably?
Jero:	I've got like twelve, maybe.
Ryan:	((*Nodding*)). Yeah, so I think they (snails) like high pH.

Comparison and Discussion

The collection of "pond jars," while initially focused on local questions (some structured as experiments), becomes a shared infrastructure when students come to recognize that different local questions/experiments can be organized into comparative material for new questions (i.e., questions recruit variability available in the collection over time). In these cases, students are in control of the new questions, and it is they who repurpose the infrastructure to do new things. However, for some students, local innovations in design never produce a stable pond jar apparatus, and routine practices of measurement that would support asking and answering an apparatus-relevant question never arise. In this sense, developing a representational infrastructure that is stable enough to be routinized is a major accomplishment, and this is crucial for learning to conduct disciplined inquiry.

The situation is different at the BugHouse, since the grid (as an idea and an actual apparatus) is already in place and stable as our study begins. Juniors, who are responsible for implementing the field study protocol, speak for the field in meetings with more senior researchers, who do not have detailed knowledge of activity in the field. The grid functions as a routine protocol in a foraging study that comes to an end as we are studying the group. When new questions are raised, with the attendant needs to raise new funds, the seniors take over. While there is clear evidence that juniors can pursue new "findings" within the foraging study grid (i.e., under conditions of routine use), they are not expected to (and may not be able to) repurpose the grid to pursue a new study. One conjecture is that the demands of conducting the foraging study are such that a strictly hierarchical division of labor is in place at the BugHouse, where juniors represent routine aspects of practice to seniors, but when a new question arises, the seniors are expected to be in the lead. This is, after all, how they manage to keep their labs (and personnel) together as going concerns. Seen in this way, the organizational context suppresses innovation and learning on the part of juniors, much as in Lave and Wenger's (1991) analysis of butchers in high-volume supermarkets or in Beach's (1999) analysis of fast food workers. But in school, where the infrastructure is built by the students themselves and there are less extreme production pressures, the division of labor is less hierarchical and there is room for innovation (in this case it is expected and encouraged) from the juniors. And here, the routine is an important accomplishment, not something to be off loaded to less knowledgeable participants. The BugHouse, unlike the classroom, has not been organized to provide all participants with access to the full complement of what is known (by the seniors or the wider field) about studying forest insects. Members know different things, and this kind of specialization is why they have been recruited to the team (e.g., the chemist and statistician have very different ways of engaging the grid). Still, junior members with an interest in field entomology can gain access to research planning and innovation as part of their contribution to the larger team. As work at the BugHouse shifts from routine to innovative use of the infrastructure, their work (under their own initiative and with support from seniors) comes to include learning about how the grid can be repurposed.

Learning about the relation between representing and represented worlds in modeling activity, we argue, amounts to learning that an apparatus can be built for a particular purpose, that questions about complex processes in the represented world can be implemented in this apparatus (i.e., a stable representational infrastructure), and that the apparatus can be reconfigured or repurposed to ask and answer new questions. The adequacy of the apparatus as a model of something is open to argument, as we have shown in both the BugHouse and the science classroom.

References

Beach, K. (1999). Consequential transitions: A sociocultural expedition beyond transfer in education. *Review of Research in Education, 24*, 103-141.

Bowker, G. and Star, S. L. (1999). *Sorting things out: Classification and its consequences*. Cambridge, MA: The MIT Press.

Engestrom, Y., Brown, K., Christopher, L. & Gregory, J. (1991/1997). Coordination, cooperation, and communication in the courts: Expansive transitions in legal work. In M. Cole, Y. Engestrom & O. Vasquez (Eds.), *Mind, culture and activity: Seminal papers from the Laboratory of Comparative Human Cognition* (pp. 369-385). Cambridge, England: Cambridge University Press.

Gravemeijer, K. E. P. (1994). *Developing realist mathematics education*. Utrecht, The Netherlands: CD-Beta Press.

Greeno, J. G. & Hall, R. P. (1997, January). Practicing representation: learning with and about representational forms. *Phi Delta Kappan*, 361-367.

Hall, R. (2000, August). Work at the interface between representing and represented worlds in middle school mathematics design projects. In L.R. Gleitman and A.K. Joshi (Eds.), *Proceedings of Twenty-Second Annual Conference of the Cognitive Science Society* (pp. 675-680). Mahwah, NJ: Lawrence Erlbaum Associates.

Hall, R., Stevens, R., & Torralba, A. (2002). Disrupting representational infrastructure in conversations across disciplines. *Mind, Culture, and Activity, 9*(3), 179-210.

Hutchins, E. (1995). *Cognition in the wild*. Cambridge, MA: The MIT Press.

Kuhn (1962). *The structure of scientific revolutions*. Chicago, IL: University of Chicago Press.

Latour, B. (1999). *Pandora's hope: Essays on the reality of science studies*. Cambridge, MA: Harvard University Press.

Lave, J. & Wenger, E. (1991). *Situated learning*. Cambridge, MA: Cambridge University Press.

Lehrer, R., & Schauble, L. (2002). *Investigating real data in the classroom*. New York, NY: Teachers College Press.

Pickering, A. (1995). *The mangle of practice: Time, agency and science*. Chicago, IL: University of Chicago Press.