THE JOURNAL OF THE LEARNING SCIENCES, *10*(1&2), 63–112

Constructing Networks of Action-Relevant Episodes: An In Situ Research Methodology

Sasha A. Barab
Instructional Systems Technology & Cognitive Science
Indiana University

Kenneth E. Hay
Learning and Performance Support Laboratory, University of Georgia

Lisa C. Yamagata-Lynch
Instructional Systems Technology & Educational Psychology
Indiana University

In this article, we advance a methodology for capturing and tracing the emergence, evolution, and diffusion of a practice, conceptual understanding, resource, or student-constructed artifact. The Constructing Networks of Action-Relevant Episodes (CN–ARE) methodology allows researchers to identify relevant data from a complex, evolving environment, and then to organize it into a web of action that can illuminate the historical development (evolving trajectory) of the phenomenon of interest (e.g., conception of an eclipse, applications of a mathematical formula, an evolving student-constructed Website). To accomplish this end, experiences are (a) sectioned into action-relevant episodes (AREs), (b) parsed down to codes in a database, and (c) then represented as nodes in a network so that the historical development of the particular phenomenon of interest can be traced. The CN–ARE methodology is especially useful for researchers interested in carrying out design experiments in which research findings with respect to one iteration of a course are cycled into the design of future course instantiations. In addition to setting the context and providing a theoretical rationale for the CN–ARE methodology, this discussion includes an in-depth description of the methodology along with its application to data sets. Following these examples, we close with a discussion of the scope and limitations of this methodology, touching on issues of trustworthiness, credibility, and usefulness.

Correspondence and requests for reprints should be sent to Sasha A. Barab, School of Education, Room 2232, 201 North Rose Avenue, Bloomington, IN 47405. E-mail: Sbarab@Indiana.Edu

Drawing primarily on the learner-as-processor metaphor, there is a long tradition of methodological practices for assessing the learning process (e.g., Sax, 1989; Wittrock & Baker, 1991). Due to the fact that the assumptions to this approach start with the student's mind as unit of analysis, "attempts are made to control rather than measure the information within the testing environment and questions are rarely asked regarding the interaction between the agent and environment at the time of assessment" (Young, Kulikowich, & Barab, 1997, p. 135). Given the individual or, more specifically, the mind of the individual as unit of analysis these traditional methods appear to deal more or less adequately with capturing the phenomena of paradigmatic interest (Brown, 1992; Schoenfeld, 1992). However, as one moves to a distributed perspective it is the complex and dynamic intersection of individual, environment, and activity over time that constitutes the unit of analysis. The focus is on learning and knowing in practice, not on some hypothesized reification of practice.

Over the last several years we have been developing rich, project-based learning environments and, reciprocally, researching learning as it takes place in these classroom contexts (Barab, Hay, Barnett, & Keating, 2000). We have developed interview techniques to probe deep understanding (Keating, Barnett, & Barab, 1999), thought experiments to assess the fragility of knowledge (Barab, Hay, Barrett, & Squire, in press), and even built rich case studies of learning groups (Barab, Hay, & Squire, 2000). However, a central methodological concern in our research has been how to capture the trajectory of learning as it unfolds over the semester-long courses. In other words, rather than describing students' ready-made knowledge at the end of the course we have been interested in tracking knowing in the making as the course unfolds. In fact, from our situated perspective, the notion of knowledge existing as a thing that can be assessed apart from the learning context becomes suspect.

From a situative perspective, assessments and methodological approaches that focus solely on the individual learner are necessarily limited, and will fail to provide the rich contextual descriptions of knowing about that are so fundamental to situative conceptions of cognition. However, in spite of the intuitive and theoretical appeal of situated cognition (Brown, Collins, & Duguid, 1989; Greeno, 1997; Hutchins, 1993; Lave, 1993; Lave & Wenger, 1991; Roth & Bowen, 1995; Suchman, 1987), there have been few attempts to develop methodologies for making sense of how learner understandings are constructed and are grounded across contextual particulars that occur over extended time frames (see Roth, 1998, for an exception). In fact, research in general tends to look at the products, not the processes of learning (Wittrock & Baker, 1991; Young et al., 1997). The difficulties with capturing the process of learning are only exacerbated when one adopts a situated perspective on what it means to know and learn. This is because from the situativity perspective, knowledge, more aptly phrased "knowing about," is no longer conceived of as a static structure residing in the individual's head. Instead, knowing about refers to a dynamic activity (trajectory of participation) that is distributed across knower and that which is known and is spread out across extended time frames and multiple resources (Barab et al., 1999).

It is the participation trajectory over time that constitutes the unit of analysis when one adopts a situativity perspective of knowing and learning (Greeno, 1998). The difficulty in finding methods for capturing this unit of analysis lies in the fact that it is distributed spatially and temporally across multiple components (Barab, Fajen, Kulikowich, & Young, 1996; Greeno, 1997; Greeno & MSMTAPG, 1998; Young, 1993; Young et al, 1997). In spite of the challenges in capturing such a dynamic and distributed unit of analysis, it is imperative that educators continue to explore innovative methodological approaches that capture learning as it emerges within rich environments so as to inform instructional practice and design. It is in introducing a methodology for capturing and representing this "distributedness," what we view as cognition, that this article is targeted. More specifically, in this article we represent this trajectory as a network of activity—a network that allows for the inclusion (capturing) of material, individual, and social components over time.

To capture the process of learning in situ, we have developed an innovative method for tracking the emergence, evolution, and diffusion of practices, conceptual understanding, resources, and student-constructed artifacts that occur across extended time frames (Barab, Hay, Barnett, & Squire, in press). We have found this method particularly useful in carrying out design research (Brown, 1992), in which we are designing entire courses, examining the impact of various interventions on the learning process, and feeding this information back into the next iteration of the course (Barab, Hay, Barnett, & Keating, in press). Our methodology allows us to capture occurrences distributed across time and space that influence and constitute a learner's understanding, providing information on how environmental particulars contribute to evolving understandings. Furthermore, a learner's understanding of an object, issue, concept, process, or practice can be attributed to, and is distributed across, the network that these occurrences form. It is in this sense that we view cognition as distributed, embodied, and situated, and it is with the goal of capturing knowing in the making that we advance our Constructing Networks of Action-Relevant Episodes (CN–ARE) methodology.

We have written this article with the intention of accomplishing three goals. Given that all methodologies are predicated on a set of theoretical assumptions, our first goal is to provide a description of the commitments and assumptions that underlie the design of our methodological approach. Our second goal is to describe this methodological approach. The approach begins with the parsing of rich learning experiences (classrooms) into what Jordan and Henderson (1995) described as "ethnographic chunks" (we refer to these as AREs) and categories that represent the "minimal meaningful ontology" for capturing cognition in situ (i.e., the minimal amount of information that needs to be described so that the researcher can derive a useful interpretation). It is important to note that the boundaries of what constitutes a chunk are determined by the needs of the study and not some ontological truth. Once these chunks are coded and categorized in a relational database, the next step involves graphically representing the data in a manner, as a network, that allows the researcher to gain an appreciation of the trajectory of knowing in the making. From here, the researcher can then follow the data through the network to build an understanding of how particular interactions contributed to the trajectory of knowing-in-the-making. Following a description of our methodological approach, the third goal of this manuscript is to show the application of the approach to a particular data set, including touching on issues of trustworthiness, credibility, and usefulness.

THEORETICAL BACKGROUND

Cognition as Situated

Briefly, in our thinking, cognition and knowledge are best described using ecological terms that characterize the dynamic relations among the changing world and changing individuals. Knowledge is not some ontological substance that lies in peoples' heads (or in the pages of textbooks) waiting to be actualized through cognitive processes. Instead, and consistent with our relational or situated perspective, knowing is an action-relevant term that delineates a person's potential to act in a certain fashion. Barab and Duffy (2000), borrowing from Lave and Wenger (1991), described individuals as being knowledgeably skillful and use the phrase "knowing about" to describe what is frequently called "knowledge." Briefly, knowing about

1. refers to an activity—not a thing.
2. is always contextualized—not abstract.
3. is reciprocally constructed as part of the individual–environment interaction—not objectively defined or subjectively created.
4. refers to functional relations—not objective "truths."

Conceived in this fashion, cognition or knowing about are not static entities owned by individuals or environments, but instead are distributed acts that exist in the flow of activity and involve persons interacting in a functional (progressive) manner over time with other persons and available social, physical, and intellectual resources. Although it is a pervasive practice to attribute knowledge as the prerequisite or the outcome of learning, in our conception, knowing about and learning are simply different ways of describing the dynamics of evolving participation. Becoming knowledgeably skillful, from this perspective, is characterized by an individual's increasing potential to build and transform relations with the (material, psychological, and social) world.

Learning is thus fundamentally connected with and constitutive of the environmental particulars (including other people) through which it is actualized (Cobb & Yackel, 1996; Lave, 1997). Conceived in this fashion, the boundaries among individual cognition and the material and social world become difficult to identify. Lave (1988) stated,

> There is a reason to suspect that what we call cognition is in fact a complex social phenomenon. The point is not so much that arrangements of knowledge in the head correspond in a complicated way to the social world outside the head, but that they are socially organized in such a fashion as to be indivisible. "Cognition" observed in everyday practice is distributed—stretched over, not divided among—mind, body, activity and culturally organized settings which include other actors. (p. 1)

In addition to stretching cognition across multiple individuals, context, activity, and the cultural and material artifacts of the world, cognition also is spread across multiple time frames (see Kulikowich & Young, 2001, this issue; Roth, 2001, this issue). A learner's ultimate understanding of any object, issue, conceptual understanding, process, or practice, as well as her ability to act competently with respect to using these, can be attributed to, and is distributed across, the physical, temporal, and spatial occurrences through which her competencies have emerged. It is in this sense that cognition and knowing about are situated, and it is the individual's evolving participation over time as well as the changing environment in which he evolves that must be captured when one adopts a situated perspective of what it means to know and learn.

To clarify the argument, if the goal is to account for the historical development of knowing, then the methodology must capture and coordinate the multiple interactions, distributed across time and space, in a fashion that constitutes the trajectory of knowing in the making. It is the complex and dynamic intersection of individual, context, and activity over time that constitutes the unit of analysis (Engeström, 1993; Greeno, 1998; Lave, 1988). It was much simpler to accept cognitive science's isolated problem solver as the unit of analysis, wherein observations in laboratory settings serve to "analyze … structures of the informational contexts of activity, but [with] little to say about the mutual interactions that people have with each other and with the material and technological resources of their environments" (Greeno, 1998, p. 6). However, from a situative perspective, assessments and methodological approaches that focus solely on the individual learner are necessarily limited, and will fail to provide the rich contextual descriptions of knowing about that are so fundamental to situative or distributed conceptions of cognition. In this article, we represent this trajectory as a network of activity—a network that allows for the inclusion (capturing) of material, conceptual, and social components. Now that we have clarified our theoretical perspective and the methodological problem, in the next section we describe the grounding for our methodological approach.

A Methodological Grounding

In advancing a new methodological approach, it is important to acknowledge intellectual history while at the same time illustrating where and why the approach being advanced departs. Although having a broad intellectual heritage and a theoretical grounding in situativity theory as previously described, the approach discussed has close ties with and must acknowledge the intellectual contribution of (a) interaction analysis, (b) network approaches, (c) Activity Theory, and (d) the notion of *tracers*. We briefly describe those aspects of this work that have informed this methodological approach. It is the synthesis of these aspects that has informed the building of our methodological approach for capturing the evolving trajectory of the phenomenon of interest.

Beginning with *interaction analysis*, our approach has much overlap with the work of Jordan and Henderson (1995). In their work, they bring together groups of researchers to analyze videos. The goal in their work is to develop coding schemes, whatever they may be, for segmenting and building interpretations of the episodes depicted in the video. We have found their work to be informative and consistent with our approach. In fact, our approach could be considered one instantiation of the broader research agenda that they outline for interaction analysis. However, in our approach we have committed to a particular coding scheme and our focus is on the relations among episodes, not simply the episodes themselves. In this sense, our methodology can be considered one particular instance of interaction analysis in which we have committed to a particular set of assumptions that inform our description of what constitutes an episode and how we make sense of the network of interactions that these episodes form. Throughout the rest of this article, we clarify these commitments from both theoretical and empirical vantage points.

Network theories have been used by anthropologists to understand the historical development of computer technologies and paper-based manuscripts (Callon, 1987; Latour, 1987); by sociologists to understand social relations, screening programs, and the historical development of medical technologies (Doreian & Stockman, 1997; Doreian & Woodward, 1994; Prout, 1996; Singelton & Michael, 1993); by computer scientists to understand systems design (Gartner & Wagner, 1996); by cognitive scientists to understand the “structure of knowledge” (Gonzalvo, Canas, & Bajo, 1994; Schvaneveldt, 1990); by various authors to ground ontological commitments (Lee & Brown, 1994; Radder, 1992); and by educational psychologists to understand learning in open-ended learning contexts (Barab, Hay, Barnett, & Squire, in press; Roth, 1996) and understand human–computer interactions as captured in log files (Barab et al., 1996). In many of these applications, network analysis was applied not just as a sociological exercise but as an analytical tool. For example, in understanding systems design, Gartner and Wagner (1996) built actor networks of two case studies for companies in Germany and Austria, focusing on the various ways actors and intermediaries contribute to the work and to systems design, how legitimate agenda are created, and the relations between systems design and these other agenda. By mapping out these evolving networks, including actors, artifacts, procedures, and intermediary links they were able to understand the mediations and mediating influence of artifacts, cultures, and political agendas with respect to systems design. Discussed more fully later, Barab, Hay, Barnett, and Squire (in press) were able to build networks of activity that represented the historical development of two learner practices during a week-long summer camp.

The methodology discussed in this article integrates a network approach for capturing the distributed and situated nature of knowing in the making. Networks are constituted by collections of nodes (the particular items of analysis) and links (connections among the nodes), which when combined result in a network web that illustrates the relations among the nodes (Barab et al., 1996; Degenne & Forse, 1999; Schvaneveldt, 1990). One of the first challenges in adopting a network approach is the conceptualization of what constitutes a node—both in terms of its constitutive features and in terms of the boundaries that separate one node from another.

In our methodology, the determination of what constitutes a node is informed by *Activity Theory* (Barab, Barnett, Squire, Yamagata-Lynch, & Keating, in press; Engeström, 1987, 1993, 1999; Leont'ev, 1974, 1989), referring to a line of theorizing and research that was initiated by Leont'ev, Vygotsky, and Luria at the beginning of this century. When referring to "activity," activity theorists are not simply concerned with doing as disembodied action but are referring to doing to transform some object, with a focus on the contextualized activity of the system (Barab, in press; Engeström, 1987, 1993; Kuutti, 1996; Nardi, 1996). An activity system is made up of a participant (individuals or groups that act and whose agency is selected as the point of view for the analysis) and an object (that which is acted on), as well as the components that mediate the relations of participant and object. The meditating components are tools (conceptual and physical), community, rules, and divisions of labor (Engeström, 1987, 1988, 1993; Kuttii, 1996). It is this collective system that constitutes the "minimal meaningful context" from which to understand human praxis more generally, and intentionally designed learning environments in particular. An activity system can be an entire course, a particular class, or even an isolated event—the latter being the unit of analysis adopted in this article. The important point to be gleaned from Activity Theory and that informs our analysis is that when describing the constitutive elements of activity, at any level, one must consider behavior in context.

For Activity Theory, the context is not simply a container nor a situationally created experiential space, but is an entire activity system, integrating the participant, the object, the tools (and even communities and their rules and divisions of labor) into a unified whole (Barab, Barnett, et al., in press; Engeström, 1993). Similarly, activity is not one aspect of learning and learning is not one type of activity; activity is learning and learning is activity. Given its emphasis on the reciprocal nature of knowing and doing, and of content and context, Activity Theory has much to offer in tackling the theoretical and methodological questions that are central to theories that suggest cognition as practice-bound or -situated; for example, situated cognition. We have found Engeström's characterization of the elements that constitute an activity system to be informative in terms of conceptualizing the constituent features and the boundaries of a node in our network. In our description of networks, each node represents an ARE—discussed more fully in the next section. Consistent with Activity Theory (Engeström, 1987, 1993; Leont'ev, 1974; Vygotsky, 1978), each one of these AREs include participants who act on particular objects (individual and groups), as well as other mediating components such as tools, resources, and other participants—all in relation to the participant's goals and intentions. As a result, a minimal description of a node conceived as an ARE must include participants and objects, as well as those components that mediate their relations.

An important limitation and strength of this manuscript is its micro unit of analysis, focusing primarily on "episodes" as the minimal building blocks in constructing a particular trajectory. Although supporting a detailed explanation of a particular trajectory, such a constrained unit of analysis also runs the risk of not adequately accommodating molar units of analysis that would be more noticeable if we took a step back in characterizing the boundaries of a node. Additionally, at this micro-level of analysis we do not meaningfully capture and code community at the individual node level. Although we do gain insight into the macrocommunity structure when explaining the full network of nodes and links, there are clearly social and cultural elements that are overlooked when one builds descriptions of the whole simply through connecting its constituent parts.

Although nodes provide basic building blocks of our methodology, it is important to note that each component of a node (a participant's understanding, a tool, an object being acted on), in addition to being a part of the current activity being examined, is also constituted by previous instances of activity through which it was developed. For example, although a computer or a student-created inscription may be a tool in one network, on a previous occasion it may have been the object of activity (Barab, in press; Barab, Barnett, et al., in press; Latour, 1987). In other words, although nodes and their components exist in one network, nodes and their components are also constituted by networks; that is, nodes are both constitutive of and constituted by networks, reciprocally determining and being determined by the episodes in which they are a part. Representing experience in terms of nodes and links provides a means of capturing and visualizing multiple time scales and environmental particulars in one analysis. Such an approach is particularly appropriate for researchers who recognize that cognition is distributed across the task, the individual, and the (physical and social) setting. Furthermore, it can be used to complement the sociological tradition of ethnomethodology, aimed toward providing "grounded" accounts of social action through understanding the context in which practice takes place—in spatial, cultural, and social terms (Garfinkel, 1967). For example, once the research team has been grounded in a context through extended naturalistic observation, building a network can be helpful in tracing a particular phenomenon of interest.

Our desire to capture the historical development and diffusion of practices, conceptual understanding, resources, and artifacts has much overlap with how others have applied Actor–Network Theory. Actor–Network Theory is a sociological approach developed by Callon and Latour (Callon, 1987; Callon & Latour, 1981; Latour, 1987) to trace the emergence, evolution, and diffusion of scientific knowledge and artifacts across a society. The network approach "allows researchers to position actors within a larger context and reflect on their specific 'mediating' roles and to formulate appropriate practices of intermediation" (Gartner & Wagner, 1996, p. 187). For actor–network approaches, and network theories more generally, organizations, communities, and even technical artifacts such as published articles are described as and can influence interlocking networks. Although we may follow the trajectory of a nonhuman artifact or even examine the relations of a nonhuman artifact and a particular understanding, in our conception only humans are coded as actors. Our focus is primarily on tracing the events through which an individual or a number of individuals come to engage in a specific practice, understand a particular concept, evolve their use of a resource, or construct a particular artifact. The important methodological challenge is to portray the practice or understanding as a contextualized trajectory of individual–environment interactions and not as abstract concepts residing in the individual's head. This requires that researchers are able to describe not only the actor's actions but also the environmental conditions that was the focus and that constrained these actions.

Roth (1996) used network theory to examine how learning unfolds within student-centered classrooms. Roth investigated the way resources (i.e., any piece of information, objects, tools, student-constructed artifacts or machines) and practices (i.e., embodied tool-related laboratory skills and understanding and application of concepts) influence a classroom community. He used network theory to portray the diffusion of resources and practices within the context of science classes, so as to provide empirical evidence for understanding the distributed and situated nature of learning and knowing in school settings. Central to his research was the notion of tracers. Newman, Griffin, and Cole (1989) used the term *tracer* to denote a preexisting methodological strategy to find the "same activity" across different contexts. In our use, and consistent with the work of Roth (1996; Roth & Roychoudhury, 1993), *tracers* can refer to practices, conceptual understanding, and student productions (e.g., projects developed) that can be observed and followed over time. In Roth's (1996) research, tracers were selected and then their history was followed through the network.

For example, in one study, students participating in a 13-week long unit on civil engineering were expected to develop a bridge that had to have a minimum span of

30 cm using toothpicks (Roth, 1996). Analysis of videotaped classroom interactions and field notes allowed him to trace the diffusion of students' adoption and understanding of resources (facts, objects), tool-related practices, and conceptual understanding. Results suggested that the process of learning a tool-related practice (in this case, the use of glue guns to connect toothpicks) actually transformed the community as the children began to embody the practice. Roth was able to document the trajectory from peripheral participant to core participant, a process that occurred in relation to the implementation of particular resources and practices. Also of interest was that specific artifacts (e.g., placing a flag on one's bridge) tended to spread relatively easily and had little effect on the overall composition of the community, whereas tool-related practices diffused more slowly and had the greatest impact on the overall composition of the community. In contrast to both of these was the diffusion of concept-related practices (e.g., using methods of triangulation to support their bridges), which was extremely slow and only occurred with constant prompting of the teacher. On the other hand, students were able to express the fact ("triangulation supports structures") rather quickly.

THE CONSTRUCTING NETWORKS OF ACTION-RELEVANT EPIDODES METHODOLOGY

Developing A Methodology

In advancing a methodology that is empirically grounded, we situate our methodological discussions using a simplistic hypothetical example and then describe actual data collected as part of our previous research to further illuminate the process and usefulness of our methodology. We describe the data collection context, and provide three brief transcriptions taken from this research for the reader to examine and to apply the method being introduced. Although we do not view it as possible to provide a body of data large enough to truly situate the reader, we do provide examples and analysis that are rich enough to illuminate for the reader the process and potential of this methodology for capturing cognition in situ.

Data Collection

The goal of data collection is to capture learning in a way that allows researchers to fully appreciate its complexity and make it accessible to future analysis. Given our conviction that knowing about is situated as part of the interactions among collaborating individuals engaged with the material world, a requirement of our data collection efforts is that they go beyond the examination of isolated minds. Instead, data collection must also be situated in social interactions that are distributed across time and space—not simply in an individual's accounting of those interactions. As such, naturalistic observation becomes a central part of our methodology. Lincoln and Guba (1985) suggested that human observers can provide rich insights into the history of the participants, group dynamics, unspoken tensions, and interactions between actors, resources, and the environment. However, given the rapidly unfolding classroom dynamics, videotaping events provides a necessary historic record of the event that, when used to supplement real-time, real-place observation, can provide a rich source of data. "In particular, it provides the crucial ability to replay a sequence of interaction repeatedly for multiple viewers—and on multiple occasions" (Jordan & Henderson, 1995, p. 39).

Eventually, these observations are chunked into episodes, assigned labels, and organized as part of a relational database (described more fully later). The ability to assign codes is, in part, dependent on the human observer's familiarity with the context. As such, our data collection procedures involve researchers engaged in direct observation in the classroom. At this point, we are still learning about how much classroom observation is necessary to build meaningful interpretations from the database. In addition to direct classroom observation, we also use multiple video cameras that are directed at individual learning groups in a particular classroom so that the researcher can code and reanalyze "fast-flying" interactions (see Jordan & Henderson, 1995, for an in-depth description of shooting videotape for analysis).

To supplement and triangulate interpretations, our team also collects field notes, student-constructed artifacts, and carries out interviews with students and teachers. In particular, the data-collection efforts have been informed by other naturalistic accounts of classroom data-collection practices (Roth, 1996) and are targeted toward interactions that (a) document practices (e.g., tool use, problem solving, student inquiry) and use of resources (e.g., concepts implemented, tools used); (b) capture the discussions among students and between students and teachers; (c) document the progress of student projects; (d) trace the same students, artifacts, actions, and procedures over time; and (e) support and refute emerging hypotheses about how practices, resources, task constraints, task manifestations, and student understandings evolved over time. In constructing and triangulating interpretations, we use the multiple data sources; however, the primary data collection procedures are direct observation and video recordings. More specifically, while observing student interactions researchers are chunking and parsing the data in terms of the categories and codes that are central to our methodology.

Defining Ethnographic Chunks: The AREs

Operationally, the identification or "chunking" the raw data into meaningful units or nodes is the first step in the creation of the network. Although Activity Theory has informed our thinking with respect to the elements (categories) that make up a node, the theory offers less description on the size of the unit of analysis. In the analytical tools of Event-State and Causal Networks (Miles & Huberman, 1984), the nodes are defined as time-dependent events that "happen" (a meeting, a conversation, or a mouse click) or they are defined as a state of mind (student frustration or pressure by parents). In our approach, nodes are equivalent to what qualitative researchers have described as "units," "chunks of meaning," or "ethnographic chunks" (Jordan & Henderson, 1995; Lincoln & Guba, 1985). Given our emphasis on activity and participation, we refer to these units as AREs. AREs are identified as activity occurrences that are judged to be a significant happening in the learning context, and are delimited by a change in theme, activity, subject, or resources. This is consistent with the criteria discussed by Jordan and Henderson (1995) for selecting ethnographic chunks when carrying out interaction analysis. They stated that "analytically, transitions from one segment of an event to another are often indicated by shifts in activity, heralded by changes in personnel, movement of participants in space, or the introduction and manipulation of new objects" (p. 60). What qualifies as a significant happening or a segment is somewhat subjective and specific to the needs and interests of each particular research context.

Lincoln and Guba (1985) described two criteria for selecting units of analysis: They must be heuristic and they must be the smallest piece of information about something that can stand by itself. As stated previously, although we have found it useful to define our chunks at a certain scale the boundaries of what constitutes a chunk should be determined by the phenomenon under investigation and the needs of the researcher and not some ontological truth. Beginning with the first criterion, heuristically, AREs, minimally, contain information about the material, conceptual, or social object of focus, who the initiators are, who the participants are, what practices the initiators are engaged in, and what resources are being used. Specifically, the critical *categories* of an episode are the issue at hand, the initiators, the participants, the resources, and the practices (see Table 1). Each of these larger categories may also have *subcategories* (e.g., under practices, we have additionally delineated among those that were instructor-related, student-related, tool-related, and modeling-related practices). Each of the five broad categories and any subcategories then contain specific codes that form our restrictive vocabulary (e.g., under instructional practices, we included coaching, Socratic questioning, lecturing, just-in-time lecturing, among others). These codes are based on interpretations of the actions. However, this does not mean that the CN–ARE approach is condemned to subjectivity or to "getting inside the head" of the participants. These inferences are based on what the externally observable behavior indicates with respect to intent. The challenge, as stated by one reviewer, is how to be a "behaviorist" in the sense that observable behavior is what is used to back up claims, without becoming a mechanistic behaviorist who denies intent, motives, and so forth—in effect, developing a naturalistic psychology of the act (Mead, 1934).

TABLE 1
Summary Labels for the Various Features That Constitute a Node

Category	*Description*
Issue at hand	A summary label that is chosen to identify the content of the node. It is the "direct" object of discussion or manipulation (the only way a practice can be considered an issue at hand is if it becomes the explicit object of discussion or manipulation). It can refer to an artifact, tool-related practice, or a conceptual tool or process.
Initiator	An individual or group (when engaged in a practice as a single unit) that is producing an action. Although we listed only observable initiators, it is important to note that actors do not emerge in a vacuum; rather, they exist within a context that is reciprocally constituted by the cultural surround and transformed by their initiator actions. In this fashion, the cultural surround could arguably be considered an initiator involved in defining the specifics of the issue at hand. However, it becomes impossible and overly presumptuous to define the numerous aspects of cultural influence that interact with the issue at hand. Therefore, we have not included these nonobservable (yet potentially important factors) in our coding scheme and must acknowledge this as a limitation. We have also not included nonhuman objects, such as computers; instead, the contribution of these objects to the historical development of a particular tracer is captured as part of the network as a resource.
Participant	An individual who is involved in a node but not initiating the action.
Resource	"Any piece of information, object, tool, or machine" that an initiator uses to carry out a practice (Roth, 1996, p. 191). In addition to technological tools, our definition of tool includes those of a conceptual nature (i.e., heat–color relations) and those of a social nature (e.g., community norms). An artifact is transformed to a resource when it is used by an actor as part of a practice. As such, it is important to note that it only becomes a resource within a particular node if it is being used by an initiator to support a practice.
Practice	An activity that is carried out by an initiator who is using a resource. Practices can be tool related (i.e., embodied tool-related laboratory skills), scientific (i.e., calculating), instructional related (i.e., coaching), learning related (i.e., using an inquiry strategy), or conceptual (theorizing about quantum mechanics) and always involve the use of a resource.

Lincoln and Guba's (1985) second criterion for a unit of analysis is to select the "smallest piece of information," a grain that we have already stated is somewhat dependent on the subjective needs and interests of the particular researcher. For example, one researcher may be interested in capturing fine-grained actions (e.g., mouse clicks or turn taking in a conversation), whereas another researcher may be interested in more molar units (e.g., moving an object across a screen or a planning discussion). In our research, whenever we observed a change in the focus of an episode (e.g., from eclipses to animation), the practice (from modeling to Socratic questioning), or the participants (from one student to another) we coded a new episode. It is important to note, and a point we return to in the section regarding limitations, that this is not a straightforward process and involves intimate knowledge of the context and the participants being investigated. Even with highly trained coders who have worked together for a year in the same research context and who had continuous feedback of the participants being investigated we still find this to be the most challenging aspect of the coding system. However, on numerous occasions we were able to get high scores on interrater agreement (r =.85) and positive participant confirmation with respect to selected AREs.

Defining the Core Categories

Consistent with Activity Theory, the *issue at hand* is the "object" of discussion or manipulation. It can refer to a resource, a practice, or a conceptual tool or process. For example, an ARE in which there is a discussion between two students about the size of the moon is a straightforward example of an issue at Hand. The issue at hand is the object of discussion, the moon. When a student is animating a model of the moon, the issue at hand is the object of manipulation, the moon. It is important that the action not be confused with the direct object, even though the direct object can be an action. In the previous example, animating was the action, not the direct object of discussion or manipulation. However, when discussing a bug in an animation of the moon, there are two issues at hand: the object, moon, and the action, animating. This is because the action of the ARE is the "discussion" and the direct object of that discussion is both "animation" and the "moon."[1] The issue at hand serves a primary identification and labeling function in the overall coding scheme.

An *initiator* is an individual (the participant) or group (when engaged in a practice as a single unit) that is producing an action. With respect to our research interests, initiators are important to focus on because we study learner-centered environments in which the teacher is no longer the primary initiator, how and when learners initiate their own learning is a crucial issue. Although we listed only observable initiators, it is important to note that activities do not emerge in a vacuum; rather, they exist within a context that is reciprocally constituted by the cultural surround. In this fashion, the cultural surround could arguably be considered an initiator involved in defining the specifics of the issue at hand or even which practices emerge. However, it becomes impossible and overly presumptuous to define the numerous aspects of cultural influence that could possibly be considered Initiators. Therefore, we have not included these nonobservable, yet potentially important, cultural influences in our coding scheme and must acknowledge

[1]These distinctions will become more apparent later, when we apply the CN–ARE methodology to examples from our own research.

this as a limitation. However, in our research some of these influences are developed through interviews and member checks and are included in the "description" area of our coding scheme. In fact, the description area more generally becomes in practice a catch-all for logging field notes and researcher interpretations of many shapes (images or words) and sizes (one sentence to multiple pages). Additionally, we have not included nonhuman initiators; however, the contribution of nonhuman objects (tools and resources) becomes fused and is a part of those networks in which they played an important part. The coding of these nonhuman objects is not as initiator but as issue-at-hand or as resource. The third category, *participants*, comprises other individuals who are involved in an ARE but not initiating the action—acknowledging division of labor.

Next we refer to the tools (conceptual and material) that allow participants to build and evolve objects. We have found it useful for coding purposes to distinguish between those tools that learners use (resources) from those tools that support the act of using these resources—more often referred to as "practices." With that said, the fourth category we identified as a critical element is the tool or *resource*. A resource is "any piece of information, object, tool, or machine" that an initiator uses to carry out a practice (Roth, 1996, p. 191). These include student-developed artifacts. In addition to technological tools, our definition of tool includes those of a conceptual nature (i.e., relative scale as a way of perceiving a model). We contrast a resource that is in use to an object that is simply available or is the focus of the activity more generally. An object is transformed to a resource when an initiator as part of a practice uses it.

The final critical element of any ARE is the *practice*. The practice is an action carried out by an initiator or participant. There can be many different categories of practice within a network of AREs (N–AREs). Some of these categories of practice are associated with specific types of initiators (i.e., student or instructor practices), some are associated with different content areas (i.e., mathematics, science, or English practices), and some are associated with particular resources (i.e., the World Wide Web, word processing, or ruler practices). In fact, there are often several different practices simultaneously conducted within one ARE. For example, in the work of Roth (1996) previously discussed, two students collaboratively building a toothpick bridge with a glue gun may be involved in three practices. They are engaging in the learning practice of discussion, the tool-related practice of using the glue gun, and the mathematics and engineering practice of triangulation all within one ARE. However, each practice involves a specific resource: prior experiences that the students are drawing into their discussion in the case of the learning practice, the glue gun and the toothpicks in the case of the tool-related practice, and the toothpicks in the case of the mathematics and engineering practice. To summarize, each ARE has, minimally, an issue at hand, the initiator, the participant, the resource, and the practice. We now turn to the operational consideration of creating N–AREs.

Defining Codes and Subcategories

The next step in our methodology involves developing *codes* for the *core categories* and for any relevant subcategories (instructional-related, tool-related, modeling-related practices). In our research, the evolving subcategories and the evolving sets of specific codes are developed through weekly meetings in which members share field notes and analyze course interactions to develop grounded lists of subcategories and codes (Glaser & Strauss, 1967). In other words, these codes are not applied top–down, but emerge from the data. In this fashion, the development of the coding types is an evolving and iterative process that takes extended group discussions through which the evolving codes and subcategories are continually tested against empirical data. Based on these discussions, a computerized coding form is then developed with a relational database that allows researchers to input the basic information (time, date, coder, tape, etc.), a written description, a rating of the conceptual richness, and the codes with respect to the issue at hand, initiators, participants, resources, and practices for each ARE (see Figure 1 for an example of a coding form of our Virtual Solar System [VSS] course).

Ethnographic Descriptions

Initially, it was our intention to limit the qualitative descriptions with the emphasis of the CN–ARE methodology being on creating and selecting codes. In practice, however, it has also proven necessary to add a field to our database for *ethnographic descriptions* that allow researchers to gain a rich contextual picture when later examining the nodes. In addition to textual descriptions, our database allows for pictures, audio recordings, or even displaying the segment of video associated with the node (not shown in Figure 1). In practice, we have found that these ethnographic descriptions have been used extensively as researchers entered descriptive field notes and emerging interpretations as they relate to the particular ARE being coded. In interpreting the meaning of a particular node, we have found this information to be very useful.

Building Tracer Networks of Activity

The second main feature of a network is the *links* that connect the nodes. We conceptualize the links as anything that ties one node (an ARE) to any other node. Thus, conceptually, all our codes can serve as links between nodes. Time links nodes historically, practices link nodes of similar practices together, resources link nodes of specific resources used together, and initiator and participant codes link people. These linkages through all the nodes of a given database can be envisioned as akin to a densely woven, highly complex “knot” of nodes and links. This knot would not be particularly useful without the ability to tease out issues and “stretch” the knot in

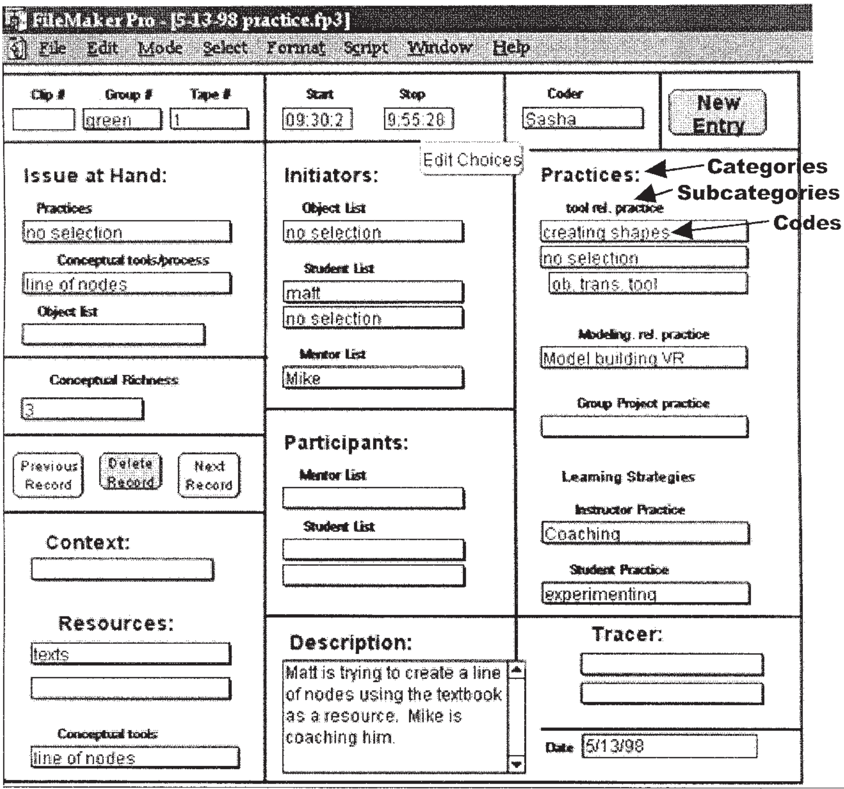

FIGURE 1 Web-based coding form used to capture the salient information of a node.

theoretically interesting ways. The question becomes, What links are productive to graphically represent within a network to address the underlying questions? In event-state and causal networks (Miles & Huberman, 1984), particular types of links (causal links) are selected for representation to demonstrate the policy events that have led up to particular district level outcomes. In our work, to bring order to this knot, we have developed a method to visualize this database in a fashion that enables us to explore the issues around the emergence, evolution, and diffusion of practices, concepts, resources, and artifacts occurring over extended time frames. At the most simplistic level, links are simply lines in the network that denote relations among episodes (i.e., that signify the historical development of a tracer).

Central to this research is the notion of tracers, which we use to denote those facts, practices, student productions, or understandings that can be observed and followed over time (Newman et al., 1989; Roth & Roychoudhury, 1993). In our approach, tracers are identified through grounded theory development (Glaser &

Straus, 1967) and refer to connected paths of events (network) that constitute the historical development of the particular phenomenon that the researcher is interested in understanding. By selecting a particular practice, concept, resource, or student production for intense analytical attention, the researcher is opening up the "black box" that results from post activity analysis of learning and, instead, is exploring the trajectory of events that constitute (situate) knowing about. In the words of the sociologist Latour (1987), the researcher is making a transition from examining "ready-made knowledge," to examining "knowing in the making," the latter being an ongoing process.

Visualizing Nodes and Links

In visualizing the data (knowing in the making), we have found it useful to present observed links among nodes with lines and to present nodes of the same phenomenon using colors or patterns. Operationally, the visualization and representation of links starts with the visualization of the nodes on a time line. This process begins by developing graphs in which the *y*-axis represents ordinal, not necessarily ratio, time and the *x*-axis represents the node initiator. We present a hypothetical example to illuminate the process of building networks. In this discussion, we use an example of one group of four students for simplicity. However, the CN-ARE methodology can be used with larger groups (see Barab, Hay, Barnett, & Squire, in press). At this stage in the visualization process of our example, the AREs are represented by bars that indicate actual time duration for each node organized by initiator (see Figure 2). The time intervals on the *y*-axis are defined by the unit of analysis of interest to the researcher. In this case, they represent 1-min blocks.

These node bars are then abstracted into numbered circles, and positioned in the appropriate initiator column (see Figure 3). We found that for our analysis the exact time duration of the node was not important in terms of the graphic representation of the network, so we have created generalized number circles all of similar size to represent nodes. Others may find that maintaining the node time duration to be of some analytical benefit and therefore could use different sized nodes. As a general rule, we line up nodes with similar start times. In this case, we chose to display the node at Time 3 on Figure 2, but a reasonable argument could be made for displaying it at Time 4 instead. However, for our purposes,[2] the placement of the

[2]At its most basic level, the network of activity provides an inscription, a graphical representation, for the researcher that can scaffold the interpretation as well as the presentation of the data. However, depending on the rigor in which one moves from the database to the network of activity, it can actually be an interpretation of the data, not simply a scaffold for the interpretation of the data. This is especially useful when used to document the historical development of a tracer over a short period with a limited number of nodes. This is because we can make one-to-one mapping of the data, gathering the entire network of activity for the intervention and, thus, maintaining interval or even ratio attributes of the data. In our

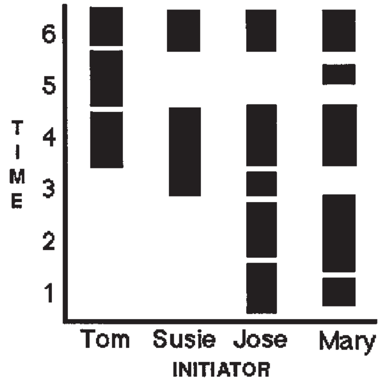

FIGURE 2 Time duration of AREs for each initiator. Each time interval on the *y*-axis represents 1 min, and bars represent time duration of each ARE.

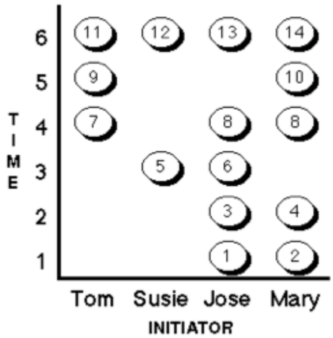

FIGURE 3 Nodes for each initiator. For this diagram the bars have been abstracted into circles that represent relative position in time.

node at Times 3 or 4 would not change the overall picture in a meaningful way; this placement would have little effect on how we trace and interpret the historical development of a particular practice, concept, resource, or student-produced artifact. Also of note was that Node 8 was dual initiated and, therefore, there are two nodes at Time 4 marked as Node 8.

---

case, however, we are coding entire courses as part of our design experiments, resulting in databases with more than 2,000 nodes per section. As such, we have found it impractical to document the entire network, instead, using the database to locate the particular nodes of a selected tracer and then graphing related nodes in an ordinal fashion, occasionally adding icons to the graph to symbolize extended time frames of particular nodes.

Participants and links are then added to the network. Beginning with participants, in Figure 4 noncircled numbers have been added to the network to indicate additional individuals who were not initiators to a particular node. At this point, an examination of the inscription (see Figure 4) provides insight into when individuals participated, who they collaborated with, and in what role. For example, we can see that Tom acts as a participant for Nodes 1 and 3 where José is the initiator. We also see that, at Time 4, Mary and Tom are dually initiating Node 8. Examination of this figure reveals which individuals took the most active role in initiating the interactions and what collaboration occurred in the nodes. As previously stated, the goal of building a network is to generate an inscription that can scaffold the researcher's interpretation and presentation of the historical development and diffusion of the tracer of interest. With this goal in mind, we now take a closer look, illuminating what can be learned from a full examination of Figure 4.

Continuing with an explanation of Figure 4, this visualization illustrates a network of a tracer with links representing the connection of two nodes that share common facts, practices, student productions, or understandings, and are related historically through a common actor. In this network, all the shaded nodes in Figure 4 are related to a particular tracer—referred to as "the practice." In this hypothetical vignette, Mary is working by herself on the practice in Nodes 2 and 4, and the other students are working during this time in a group initiated by José on activities not coded as related to the practice. In Node 6, José calls Mary over to show her and Tom how to do the practice. José and Mary continue by dually initiating a discussion of the practice in Node 8. We

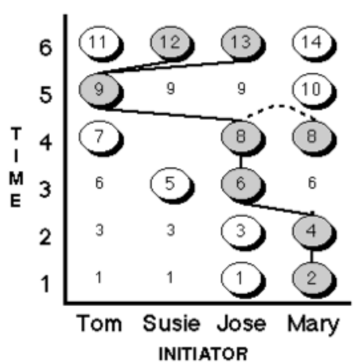

FIGURE 4 Nodes for each Initiator with numbered circles representing node initiators and noncircled numbers representing node participants. Shaded nodes represent those nodes in which a particular practice is being carried out, referred to as "the practice." In addition, lines represent links between two nodes, with the dashed line representing nodes that were dually initiated.

used dual initiation to capture those interactions in which the researcher is unable to assign initiator status to either member. Then, in Node 9, Tom goes back to his computer and finishes up a prior activity before he asks José to help him, Susie tags along. Susie then returns to her computer to work on the practice (Node 12) as does José (Node 13). Last, Mary returns to her computer to work on other parts of the project (Node 14), as does Tom (Node 11).

Once a tracing through the N–ARE has occurred, then the researcher needs to go back and examine the ethnographic descriptions to build an interpretation of the network. This involves an examination of each node and moving along the tracer network, building a rich interpretation of the historical development of the tracer being examined. Given the subjective interpretation of these networks and the fact that much of our analysis relies on inferred intentions, we have found it useful to have the research team use the videotapes, as audit trails, to build consensus on interpretations. When possible, member checks with the original students were also performed to further ground interpretations.

In the aforementioned discussion, we described the process of constructing N–AREs. The process from observation to analysis involves the following steps:

1. Collection of the data through direct observation and through videotaping.
2. Chunking the data into discernible units of analysis that we have described as AREs.
3. Recording information related to the specifics that constitute each ARE (see Figure 1).
4. Developing a visual representation of the data by recording the time duration of each ARE for each initiator, and then abstracting these times into numbered circles that are sequentially arranged in an ordinal, not ratio, fashion (see Figures 2 and 3).
5. Selecting the particular issue at hand, practice, or resource to serve as the tracer.
6. Tracing the historical development of the particular tracer over time by shading in all the related nodes, adding observed links, and examining the path (see Figure 4).
7. Reexamining node descriptions as well as videotapes to build interpretation of the network. If possible, performing member checks to validate interpretations.

In this list, we primarily focused on the first four steps and did so somewhat in the abstract. We next apply the seven steps to data taken from our own research with the intention of supporting the reader in building a contextualized appreciation for, and understanding of, the CN–ARE methodology.

INSTANTIATING THE CATEGORIES (OUR RESEARCH)

To illuminate the use of the CN–ARE methodology within a classroom, we now describe one of our particular research contexts and how we have used the CN–ARE approach to trace the historical development of various phenomenon. In particular, we demonstrate how we have used the CN–ARE methodology to capture the emergence, evolution, and diffusion of conceptual understanding, practices, resources, and student-created artifacts in our VSS project. It is important to note that this is an illustrative example of applying the CN–ARE methodology to a particular context and the reader should not view this one instantiation as representative of the myriad of potential uses for this tool.

Research Context

In this research, we have been exploring learning and instruction within collaborative, technology-rich, project-based learning environments. The VSS project is an experimental undergraduate Astronomy course taught at two universities. In the VSS project, we completely transformed this traditional lecture-based course into a project-based course (see Barab, Hay, Barnett, & Keating, 2000; Barab, Hay, Squire, et al., 2000; Hay, Johnson, Barab, & Barnett, in press). Where previously listening to lectures constituted the primary learning activity, in the VSS course, listening to lectures was replaced by students' building 3 three-dimensional models of different aspects of the solar system: (a) the Earth, moon, and sun; (b) the entire solar system; and (c) a learner-defined object of the solar system (a comet, the asteroid belt, etc.). Students worked in teams of two to four members, using high-end graphics computers with a direct manipulation, three-dimensional, model creation software application that allowed the projects to be exported directly to the World Wide Web (see Barab, Hay, Barnett, & Keating, in press, for a full course discussion).

We used video cameras to capture each of four student groups as they constructed their three-dimensional worlds within a computer laboratory. Although each student had their own desktop computer, the course projects required extensive collaboration and students spent significant amounts of time working on each others' computers. In addition to targeted video cameras, a researcher was assigned to each group during class time, allowing for most of the coding (selecting interactions and filling out the nodes) to occur "on the fly," as researchers used laptops to select the codes from the database. Videotapes were later inspected to ensure reliability of nodes and, in some cases, students were also interviewed to confirm interpretations. To increase consistency across group coding and to provide all researchers exposure to each group, we rotated groups on different days and performed audit checks by having researchers examine each others' coding of nodes.

Coding Examples

The first step in adapting the CN–ARE methodology to a particular research context is to choose the subcategories and the respective codes. We have found it most efficient to enter these subcategories into a database program in which the items can be accessed as pop-up menus (see Figure 1 for the coding form developed for our VSS context). In addition, it is essential that these items be editable and that items can be added as new subcategories are identified for issues at hand, practices, initiators, participants, and resources. Included in our form are fields for the group, date, start and stop times, the name of the person coding the form (coder), the issue at hand (practices, concepts, and objects—constructed artifacts or used resources), conceptual richness, initiators (students, mentors), participants (students, mentors), practices (tool-related practices, modeling related, mathematical, group project, instructor, student), ethnographic descriptions, context, resources (including concepts used as tools such as logarithms or even student-created artifacts), conceptual tools, and tracers. The five major category labels and the ethnographic descriptions elements were previously discussed (see Table 1); however, in making the CN–ARE methodology a useful analytical tool, we have found it necessary to include additional fields to our form. We briefly explain these additional categories.

The *group* field is useful for searching and sorting the records when using the CN–ARE method in a context with more than one group working on similar projects and, potentially, being combined in the same database. The *date* and *start* and *stop* times allow researchers to sort records and follow the historical development of various items. *Conceptual richness* is a rating on a 10-point scale ranging from 0 (*nodes not related to course content*) to 9 (*nodes involving interconnections of ideas or systems-level understandings of the particular domain of interest*). For example, the concept of a line of nodes is central to the domain of astronomy. It refers to the imaginary line formed by where the plane of the moon's orbit intersects the plane of the Earth's orbit. An eclipse is possible only when the moon, Earth, and sun are all on the line of nodes. An ARE would be rated a 5 when a node contains the line of nodes in a definitional form, as just described. It would be rated a 7 if the line of nodes were modeled in the node and the model was used to discuss eclipses, and a 9 when it was used to develop an understanding of the Earth, moon, and sun system (i.e., the eclipse season).

Conceptual tools refers to concepts when they are being used as tools to support the carrying out of a practice (e.g., using logarithms to determine scale sizes). We are making the same distinction as we made with other types of tools; that is, we need to code them differently when they are being used versus when they are being talked about. If students were talking about what logarithms are, then the logarithms would be the issue at hand. However, if they were using logarithms as a resource to determine planet distances in a mathematical way, then they are using logarithms as a resource. Context was added as a code because as we coded the interactions we occasionally observed relevant contextual factors (e.g., grades, homework, family issues) that did not fit any of our existing categories but that we know were an important part of the interaction being observed. Last, we added a tracer field in which we associated particular interactions with a specific tracer even when it was not originally coded as part of the node being examined, because at that point in the process the tracer had not yet been identified as one of our codes. This field was primarily used after we had already coded all the nodes and we were going through the database an *n*th time to build a particular tracer network.

Developing Codes

The codes related to our categories and subcategories emerged through the process of grounded theory development, in which our data and emergent interpretations interacted in a dialectic fashion, reciprocally informing and being informed by the other (Glaser & Struass, 1967). Although some categories were created on the fly, usually new categories were added during our biweekly research meetings in which we reexamined videotapes to determine the necessity of creating an additional category. Complementing the emergent interpretations, we performed content analysis and examined the literature to enhance our "theoretical sensitivity" (Schatzman & Strauss, 1973), engaging in a dialogue between previous theory and current data. Additionally, resources were simply lists of resources that were available to learners in the environment. However, over time, new resources (physical and conceptual) became available, and additional types were added to the resource field. Context and tracer codes evolved in a similar fashion. All practices from all categories, in addition to being available in the practices category, were also made available under issue at hand, as were resources. Lastly, all students and instructors were added to initiator and participant categories, and group, date, and coder categories were also added to the database.

Coding Scenarios as AREs

In this section, we present scenarios from our research program to demonstrate how the CN–ARE methodology has been used to develop interpretations of cognition in situ. We have included three scenarios all related to eclipses, which provide insight into the context through which students' understanding of eclipses evolved through the course. These scenarios are presented as three different examples, each of which includes multiple interactions coded as multiple AREs. The first scenario involves the coding of a practice and how it changes from an issue at hand to a tool-related practice over time. The second scenario illustrates how the line of nodes changed from a concept, to an object, and finally to a conceptual tool over time. The third scenario, taken from Barab, Barnett, Yamagata-Lynch, et al. (in press), illustrates how a conceptual tool for astronomers became a visualization tool for a student and how before embodying this visualization tool in her model Erica read about the concept, only later becoming black-boxed as a tool to support the visualization process. The third scenario also shows the intergroup collaboration that emerged between members from both groups.

In these examples, we illustrate how we have parsed a scenario into separate AREs (nodes),[3] and how we coded AREs. In each scenario, we begin with a set-up that will contextualize the reader to the goals of and the activities prior to the scenario. Then we present a brief dialogue excerpt broken up into turns. The far right column indicates how we chunked the data into nodes representing a particular ARE. Lastly, each node is coded using multiple category labels. Students include Todd, Taro, and Roger in Group A, Keith and Erica in Group B, and the instructor is Igor. Following the dialogue, we list the particular codes our research team selected for this dialogue. Later in the article we present a network generated from these three segments of dialogue that incorporates the coded nodes. Note that node numbers associated with the dialogue do not start with 1 and do skip numbers (e.g., jumping from Node 3 to Node 6). This is because during the original coding of this data there were other coded nodes at the same time period that were not related to eclipses and that were not included in the three presented scenarios for space reasons.

Scenario 1 (viewpoints). The following set of interactions illustrates how setting viewpoints moved from an issue at hand to a tool-related practice over time. Viewpoints refer to perspectives or "camera positions" that can be placed in a virtual reality (VR) model, allowing viewers of the model to immediately shift to various locations. The interaction begins after Todd has built an Earth, moon, and sun system and animated all the pieces. The actual categories, subcategories, and codes assigned each node in the dialogue are displayed in Table 2. To reiterate, AREs were delimited by a change in theme, activity, or initiator. In other words, whenever we observed a change in the issue at hand (e.g., from eclipses to animation), the practice (from modeling to Socratic questioning), or the initiator or participant (from one student to another), we coded a new node.

[3]It is important to clarify that each node in the network represents an ARE and, in a very real sense, can be considered an actor on the historical development of the practice, conceptual understanding, or resource. However, each initiator within a node could also be considered an actor, revealing the nested nature of N–AREs. At some point, issues of grain and focus become a distinguishing factor in determining the unit of analysis with one researcher's node potentially serving as another researcher's N–ARE.

Participant	*Description*	*Node*
Todd	[*Todd is setting a viewpoint so that end-viewers can go to a perspective on the VR world that he determines.*]	3
Todd	Okay, in a lunar eclipse does the Earth block the light of the Sun?	6
Taro	Yeah, let's see [*then Taro moves next to him and says "show me" as he looks at the computer*]	
Todd	So, in a lunar eclipse, wouldn't it make sense to have the camera going from the Earth to the Sun [*pointing to the screen*] … If we put the camera on the Sun and make it face towards the Earth so we can see what the Earth is doing when it gets in the way of the light of the Moon.	
Taro	[*Taro shows Todd what the eclipse looks like by modeling with his hands*]	
Todd	Oh, so a lunar eclipse is when the Earth blocks the light of the Sun?	
Taro	Yes.	

The dialogue continues:

Participant	*Description*	*Node*
Todd	[*Todd is viewing the virtual model's viewpoints. He is jumping from one to another. He is visibly frustrated*]	9
Todd	I thought I set a viewpoint here yesterday, but it is not working [*Todd's inflection hinted at it being a question*]	11
Igor (instructor)	Okay, so what did you do to set the viewpoint?	
Todd	Somehow I put one viewpoint camera right in the center of the Earth, but I erased it and now all of the cameras are screwed up.	
Roger	We put two cameras up there [*referring to the top of the Earth*], but I don't understand what happened to them.	
Igor	Let's look for the viewpoints you have now, and delete them and start again.	
Todd	[*Todd, with Igor coaching and Roger watching, finds the two cameras and deletes them*]	14
Igor	[*Igor does a just-in-time lecture on setting viewpoints so that Todd and Roger can use the cameras to demonstrate various aspects of their model. For space reasons we have compressed much of this lecture into italicized notes that decenters some of the teaching in this analysis.*]	15

The scenario continues:

Participant	*Description*	*Node*
Todd	[*Todd sets a viewpoint that illustrates a lunar eclipse*]	18

TABLE 2
Classification of Nodes, Categories, Subcategories, and Types for Scenario 1

Node	*Issue at Hand*	*Initiator*	*Participant*	*Practices*	*Resource*	*Conceptual Richness*
3	Object: Earth, moon, sun model	Student: Todd		Tool-related: Viewpoint setting Modeling: Model building VR		6
6	Concept: Lunar eclipse Practice: model building VR	Student: Todd	Student: Taro	Student Practice: Group discussion	Student props (hands) Computer model	6
9	Object: Viewpoints Concept: Lunar eclipse	Student: Todd		Modeling: Model evaluation	Computer model	6
11[a]	Practice: Setting viewpoints	Student: Todd	Student: Roger Mentor: Igor	Instructor practice: Questioning Student practice: Question teacher	Computer model	2
14	Practice: Setting viewpoints	Student: Todd	Student: Roger Mentor: Igor	Modeling Practices: Debugging Instructor Practice: Coaching	Computer model	2
15	Practice: Setting viewpoints	Mentor: Igor	Student: Roger and Todd	Instructor practice: Just-in-time lecture		2
18	Object: Earth, moon, sun model	Student: Todd		Tool-related practice: Setting viewpoints	Computer model	4

Note. VR = virtual reality.

[a]Although this is a conversation where Roger also poses a new dimension to the conversation we have found it most efficient to code whole conversations as one node. The exception is when one of the participants poses a question or makes a statement that clearly changes the topic and direction of the conversation.

Scenario 2 (line of nodes). The following set of interactions illustrates how another group was also confused about eclipses, and how to best represent them in their model. The instructor, Igor, then introduces the line of nodes, a conceptual tool used by astronomers to describe the imaginary line in space formed by the intersection of the ecliptic and the celestial equator in which the sun, Earth, and moon must lie if an eclipse is to occur. For Erica, Igor introduced the line of nodes as a visualization tool to help illuminate when eclipses occur in her model. In order for her to use it as a visualization tool, she had to first learn the concept as an issue-at-hand, after which this learning became black-boxed and it again became a visualization tool. As before, the actual categories, subcategories, and codes assigned each node in the dialogue are displayed following the dialogue (see Table 3).

Participant	*Description*	*Node*
Erica	I am wondering if I should extend it all, the edge to the moon's orbit to demonstrate eclipses, like a lunar eclipse.	31
Keith	That is something to think about because you could.	
Erica	But that is just showing the orbit.	
Keith	If you have the Moon rotating [using his hands to enact the motion] the Sun rotates, then the Moon rotates … wouldn't the Moon rotating around the Earth wouldn't they eventually hit this plane [points to the ecliptic plane] to show an eclipse?	33
Erica	When there is an eclipse there is the [orbital] plane of the Moon and the [orbital] plane of the Sun have to be the same or near. So for a lunar eclipse the same conditions have to be met. This plane would only demonstrate a lunar eclipse so I should probably have to extend it out.	

Keith shifts back to his computer to work on textures and the instructor walks up to Erica. The dialogue continues.

Participant	*Description*	*Node*
Erica	Ok, here is a view from above the Earth. Here is this plane, the reddish stuff plane is the plane of the Sun and the Earth [ecliptic], and this is the plane of Moon. It looks like it is all intersecting, it is not, because it is angled. You can see a difference.	34
Igor	Part of the problem is you are looking from above. This is a better view for looking at it [changes their viewpoint].	
Erica	[*Erica works on her model while Igor watches.*]	36
Igor	Another thing to keep in mind is this is static here, you have done a good job of showing the ecliptic and the Moon's orbit. Have you put in the line of nodes yet? That is something to explore.	38
Erica	Ha, Ha, Ha. The line of Nodes, eh?	
Igor	The book gives a pretty good discussion on it.	

TABLE 3
Classification of Nodes, Categories, Subcategories, and Types for Scenario 2

Node	*Issue at Hand*	*Initiator*	*Participant*	*Practices*	*Resource*	*Conceptual Richness*
31	Object: Earth, moon, sun model Practice: Model planning	Student: Erica	Student: Keith	Student related: Questioning student	Resource: Other student	9
33	Concept: Eclipse Practice: Developing Insights	Student: Keith	Student: Erica	Student related: Work collaborative	Resource: Other student Computer Model	9
34	Practice: Model debugging Concept: Eclipse	Student: Erica	Mentor: Igor	Student practice: Questioning teacher	Resource: Mentor	9
36	Practice: Model building	Student: Erica	Mentor: Igor	Model practice: Building		5
38	Concept: Line of nodes	Mentor: Igor	Student: Erica	Instructor practice: Coaching		7
41	Concept: Line of nodes	Student: Erica		Student practice: Reading	Resource: Textbook	8
42	Object: Line of nodes	Student: Erica	Student: Keith Mentor: Igor	Student practice: Telling	Resource: Computer model	9

Participant	*Description*	*Node*
Erica	Ok, the line of nodes [*goes off to research the line of nodes*].	41
Erica	So once you get this line of nodes [looking at the book]. Oh I see. That is the line where … [moving around in her model] That would be along here where these two intersect. … The line of nodes would be … no … [moving through her model]. Anyway, you see how the Moon' orbit is angled here, so the line of nodes is supposed to be here.	42
Keith & Igor	[*Keith and Igor simply watch and listen to Erica*]	

Scenario 3 (intergroup collaboration). After a class in which setting viewpoints became the issue at hand, Todd then returned to use this skill in representing when and how eclipses occur. Similar to the development of the line of nodes, viewpoints were black-boxed and now used as a tool to complete a different issue at hand. During this scenario, Todd is still confused about the process of when an eclipse occurs and, especially, how to represent it in his model. The instructor then suggests that Erica was having similar difficulties and that she has developed an approach to represent the eclipses in her model (see Figure 5). As in the previous scenarios, the actual research codes are displayed in a table (see Table 4) at the end.

Participant	*Description*	*Node*
Todd	[*Is working hard on his model but appears to be at an impasse. He calls over the instructor*].	45
Todd	The ecliptic is here [*pointing to the screen*] where the two lines come together?	49
Igor	Yes, but it is more complex in three dimensions. Erica is using the line of nodes to show it, you might want to talk with her.	50

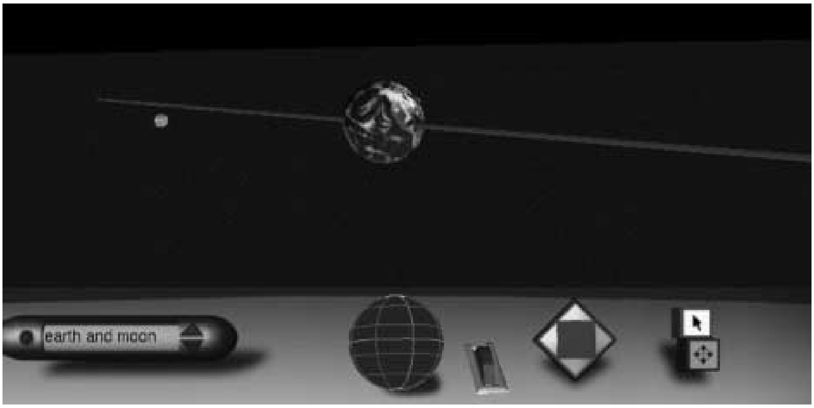

FIGURE 5 A screen shot of Erica's line of nodes. Note that the moon is not on or near the line of nodes; therefore an eclipse is not possible.

Participant	*Description*	*Node*
Todd	There is a rumor that you're working on the line of nodes in your model. I'm not sure what it is.	55
Erica	It's where the plane of the ecliptic between the sun and earth, and the plane of the earth and moon intersects … It is not a real line … Whenever the moon crosses this line [*pointing to the screen*] there is an eclipse … [*Todd nods*]	
Erica	[*pointing to the screen, Erica continues*] The way I made mine, I made a long cylinder and made it a very long line.	58
Todd	Wow, that thing is a cylinder!	
Erica	Yeah, (*pointing to a line on the screen*) … . I grouped the earth and the line of nodes so the line of nodes would stay with the earth when it revolves.	

Later, after Erica completes her model and is presenting to the class, she points to the line of nodes in her model to explain the difference between a solar eclipse and a lunar eclipse.

Participant	*Description*	*Node*
Erica	You can only have total eclipses when the moon is on the line of nodes. [pointing to the screenshot in Figure 5]. If the moon is on the side of the earth facing the sun, that would be a new moon, you can get a solar eclipse because the sun would be blocked by the moon's shadow. And when the moon is on the side of the earth, that would be a full moon, you can get lunar ellipses because the moon passes through the earth's shadow.	65

Interpreting Data

We have found it useful to carry out two types of data interpretations on the database of nodes generated through the CN–ARE methodology (Barab, Hay, Barnett, & Squire, in press): (a) as a database search tool to support frequency counts and grounded theory development (Glaser & Strauss, 1967), and (b) the N–ARE graphs discussed previously and further detailed later. The first use involves using the database of nodes to examine the frequency of occurrence of one particular nodal element or to identify patterns or particular episodes that illuminate key characteristics of the phenomenon being studied. This process is useful when characterizing course dynamics (Barab, Barnett, et al., in press), or in identifying instances related to a particular issue (Barab, Hay, Barnett, & Squire, 1998, in press). The other more exciting data interpretation method, and the one highlighted, is to actually trace the emergence, evolution, and diffusion of concepts or practices over time through the entire network of activity (see Figure 4). It is with this goal in mind that we developed the CN–ARE methodology, and it is this function that allows researchers to

TABLE 4
Classification of Nodes, Categories, Subcategories, and Types for Scenario 3

Node	*Issue at Hand*	*Initiator*	*Participant*	*Practices*	*Resource*	*Conceptual Richness*
45	Object: Earth, moon, sun model	Student: Todd		Modeling: Model building VR		6
49	Object: Earth, moon, sun model	Student: Todd	Mentor: Igor	Student related: Questioning teacher	Resource: Model	7
50	Practice: Visualizing[a]	Mentor: Igor	Student: Todd	Instructor related: Eliciting collaboration	Resource: Other student	7
55	Concept: Line of nodes	Student: Todd	Student: Erica	Student practice: Questioning student	Resource: Model other student	8
58	Concept: Eclipse Practice: Grouping	Student: Erica	Student: Todd	Student Practice: Retelling	Resource: Prior experience	4
62	Concept: Line of nodes	Student: Erica		Tool-related practices: Coloring		2
64	Object: Line of nodes	Student: Todd	Student: Roger and Taro	Student practice: Telling	Resource: Computer model Prior experience	8
65	Concept: Total eclipse (lunar and solar) Object: Project 2	Student: Erica	Student: All students Mentor: Igor	Student practice: Telling	Resource: Computer model Line of nodes	8

Note. VR = virtual reality.
[a]This illuminates the distinction between an issue at hand and a practice. Although visualizing is the issue at hand, the practice of the initiator, Igor, is to elicit collaboration, so that Todd can use visualize eclipses through his model.

capture cognition in situ. However, given that both functions have proven useful for our research, we briefly overview the first use as well.

A database search tool. The database of coded interactions can simply be treated as a relational database, and thereby searched for various purposes. For example, Barab, Hay, Barnett, and Squire (1998) used the database to record the number and duration of times the mentor was coded as initiator throughout the semester long VSS course. In their research, mixed initiative interactions (nodes where both learner and mentor appeared to initiate the same activity) were coded with both learners and mentors as the initiators; thus, student-initiated nodes and mentor-initiated nodes are not mutually exclusive. They then counted the number and length of time of nodes that were mentor-initiated or that were student-initiated. Results suggested that there were less mentor-initiated nodes for Group 1 than for Group 2 and, on a related note, there were more student-led nodes for Group 2 than for Group 1. They used a similar strategy to gain insight into the differences of planning in both groups, with findings suggesting that one group had more nodes and spent more time related to project planning than did the other group. Given the subjective process in which nodes are carved out and coded from the entire corpus of data, it would be inappropriate to draw meaningful interpretations using frequency and time counts alone. Therefore, in addition to using the database, Barab, Hay, Barnett, and Squire (1998) reexamined the videotapes to triangulate the emergent hypothesis that one group was more student centered than the other group. In a similar process, they incorporated additional data to characterize the apparent differences in group planning, gaining insights into how and why they differed. In another study, Barab, Barnett, et al. (in press) used the database to locate particular interactions that related to their research and that occurred during the semester-long course. In this instance, the coded database of interactions provides a source for locating particular indexed interactions that are of relevance to the researcher—providing an indexing system.

Connecting nodes to build networks. A more innovative application of the coded information is for the generation of N–AREs. In our design experiments, we have found it impractical to document the entire network because our unit of analysis is over an entire semester and results in more than 2,000 coded AREs. However, we have found it useful to use the database to locate tracer-related nodes and then to graph them in an ordinal fashion. This network provides an inscription, a graphical representation, that can then be used by the researcher to scaffold her interpretation as well as her presentation of the data. For example, in the work of Barab, Hay, Barnett, and Squire (in press), they were able to build two networks so as to trace the emergence, evolution, and diffusion of two learner practices (animation and geometric transformation) during the summer camp being investigated. Their findings suggested that becoming knowledgeably skillful with respect to a particular practice was a multigenerational process, evolving in terms of contextual demands and available resources. These tracings further revealed the reciprocal nature of learning and doing, with building conceptual understandings being a part of doing concrete practices and doing practices being a part of student learning.

Focusing in on the practice of animation, they were able to document how the practice of animation, and the nested parent–child relations practice, diffused over the camp, frequently changing hands among students and involving independent application as well as more collaborative discussions. In addition, in-depth analysis of the dialogue within particular nodes showed how the practice transformed over time (i.e., the contextual influence). Initially, students were more concerned with aesthetic appeal and realism; however, by Days 4 and 5, realism was secondary to the need for completion. Time efficiency eventually became the more salient constraint on defining the practice, with one student stating, “At this point I’m less concerned with how it looks. I just want to get him from one side of the stage to the other.” Furthermore, learner specialization for a particular type of animation began to emerge. By Day 5, the group had made one learner responsible for all walking behavior of the characters whereas another student modeled head turns, and still another focused on arm movement and animating the fingers of “the monkey’s paw.”

Returning to the three example scenarios previously described, we now develop a N–ARE and then use it as an inscription to scaffold our interpretation of the data (see Figure 6). Due to space limitations, Figure 6 only represents a section of the evolution and diffusion of the tracer, *eclipses*. Specifically, it represents that portion of the historical development of eclipses that we have already provided transcriptions for in the above three scenarios. Again, we used numbered circles in a particular column to denote nodes and their initiators, numbers to indicate participants with a particular nodes, and we have added in a dotted line connection for two nodes with the same number to signify those nodes in which it appeared to us as if there were two initiators. Note, in addition to the nodes generated from the coded dialogue about eclipses, we also have included a sample of nodes representing the activities of other group members that occurred at the same time as the above presented dialogue. However, when no member of a group was doing tracer-coded activity, we simply left that area blank. In Figure 6, we also see that on the left side of the instructor (Igor) are the members of Group A (Roger, Taro, and Todd) and on the right side are the members of Group B (Erica and Keith).

In examining the development of the tracer for Nodes 3 through 18, we see that for Group B the eclipse-related activities begin with Todd. This can be further understood when one appreciates that in a group planning meeting it was decided that Taro would focus on issues of scale, Roger would focus on planetary cross sections, and Todd would focus on the Earth, moon, and sun system dynamics as they relate to eclipses. Obviously, the activities in a group project are not totally compartmentalized and there were times when Roger and Taro were participants in eclipse activities. For example, we can see how at Node 6 Taro is a participant and

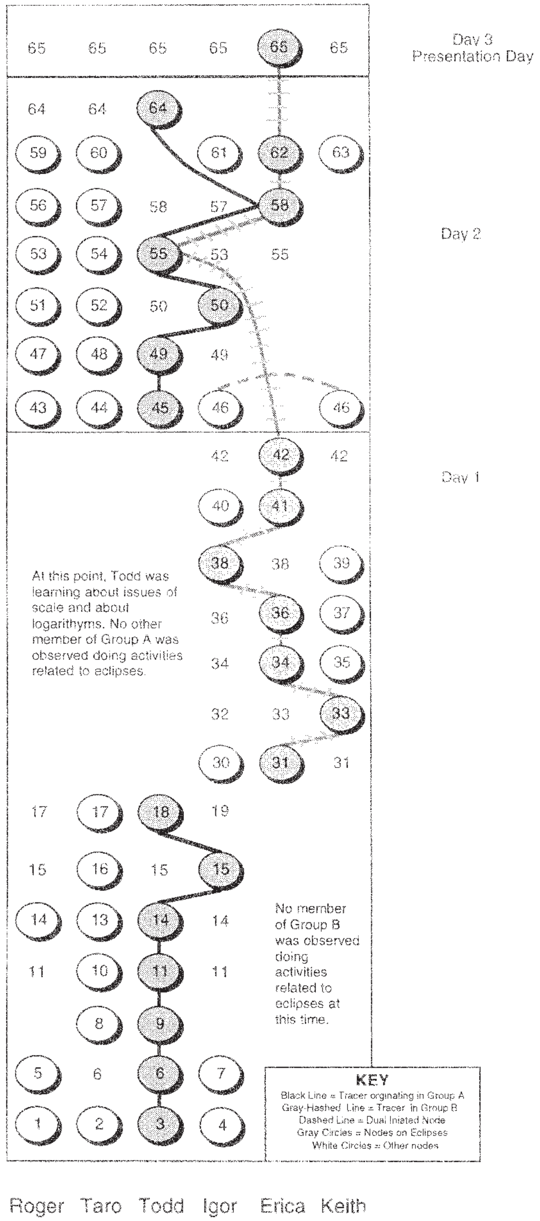

FIGURE 6 Tracer network for eclipses, showing eclipse-related nodes and links for Groups A and B. Again, nodes are presented for each initiator with numbered circles representing node initiators and noncircled numbers representing node participants. Shaded nodes represent eclipse-related nodes. In addition, lines represent links between two nodes, with the dashed line representing nodes that were dually initiated.

at Node 11 Roger is a participant, and at Node 15 both Roger and Todd are participants in the activity the instructor initiated. As we have already stated, when one examines the content of the nodes more closely we can see how setting viewpoints moved from an issue at hand to a tool-related practice. This last interpretation requires reexamining the actual data, emphasizing that frequently the N–ARE is simply an inscription that can support, and is not sufficient for, data interpretation.

Examining Scenario 2, Nodes 31 through 42, it is apparent that Erica is the main initiator with Keith only initiating at Node 33. At Node 33, no one in Group A was focused on eclipses, although if we had chosen logarithms as a tracer Group A would have more shaded nodes during this point because the central activity for this group at this time was related to logarithms. Again, to more fully appreciate the content of these interactions we need to return to the coded nodes and possibly even the original dialogue. Simply from an examination of the database, however, it is apparent that the line of nodes became an important (conceptual and visualization) tool for Group B. At a conceptual level, based on our interview with Erica at the end of the class, visualizing the line of nodes was important in developing her appreciation for why eclipses do not occur every month. As a visualization tool, in Figure 5 we see how the diagonal line representing the line of nodes illuminates when an eclipse occurs, and in their VR model it illuminates the importance of a third dimension for understanding when eclipses occur, and how the 5° tilt of the moon's orbit off the ecliptic plane limits the frequency of eclipses.

Examining the third scenario, Erica, continuing from Node 42, is still working on adding the line of nodes to her model. However, Todd is also working on the line of nodes at Nodes 45 through 49. Then, under the prompting of the mentor (Node 50), at Node 55 Todd initiates a discussion with Erica around what the concept line of nodes is and how she created the line in her model. Erica, then changing the discussion from line of nodes as a concept to a visualization tool, discusses its use and its creation as part of her model. At Node 62, Erica continues to work on the line and Todd, at Node 64, shares what he learned with Taro and Roger. Finally, at Node 65 we can see Erica presenting her model to the other class members. Both from an examination of the dialogue and more directly from examining the raw data we can see the diffusion of knowledge from Group B to Group A. It is also evident how the instructor supported students by facilitating nodal activities, being a participant more than an initiator. Even when he was initiating it was frequently with Socratic questioning and not dyadic lecturing. Also note that, in Node 46, our research team had difficulties deciding if the instructor was the Initiator or if Keith was the initiator, and it was decided that there was dual initiation and participation occurring so we coded both as initiators and drew a dotted line signifying the dual initiation.

There are two distinct tracers on eclipses that this analysis generates through this network of activity. The first tracer originates in Group A, starts with Todd, and is indicated by the black links in Figure 6. The second tracer originates in

Group B with Erica and is indicated by the gray-hashed links. These tracers illuminate the historical development of students' use of eclipse within these two groups. Furthermore, when these two tracers come together and in fact merge in Nodes 55 and 58, they show the clear path of diffusion of understanding when Erica introduces Todd to the line of nodes concept. Although black-and-white journal figures make this a challenge, we could imagine that when the groups begin to overlap in Nodes 55 and 58 that the line may become a mixed color link to indicate the blending of understanding. Furthermore, we may represent the change in Group A's understanding attributable to Erica through some mixture between the black and gray linkages to Node 64, whereas we observed little or no change in Erica's understanding attributable to the interaction as she continues on to Node 62. However, at this point in the evolution of this CN–ARE methodology we have not had an opportunity to flesh out these possibilities, and such inferences would clearly require more intense member checking.

In completing this story it is important to provide evidence that this experience was a part of students' understanding. It is also important to note that line of nodes was not a course requirement or a tool that the instructor initially imagined students' using in their projects. Using data from interviews carried out by Keating, Barnett, and Barab (1999), Todd, in a preinterview, demonstrates his confusion with the cause of lunar eclipses:

> Interviewer: When do we get a lunar eclipse?
>
> Todd: I think it has something to do with the day and night sequence. I guess that when the Earth is turning, we see different sides of the moon.

In his postinterview statement, Todd synthesized two conceptual and visualization tools developed during the VR modeling process, the 5° tilt of the Moon's orbital plane and the line of nodes, to explain the reason for lunar eclipses.

> Todd: The moon is going around the Earth and the moon is behind the Earth and the Earth is going around the sun. The ecliptic and the rotational path intercept at the line of nodes and, due to the 5° tilt, they cross at certain points. If it is a total eclipse than it is an umbral eclipse it is beet-red, if it is a penumbral eclipse, then it is partial eclipse. It depends on when the moon is on the line of nodes.

Although this response does suggest that Todd's ability to explain the reason for lunar eclipses did grow, it provides little insight into this process and what condition may have supported this growth. It does not tell the researcher that he learned about line of nodes and its role in eclipses through collaboration with another student, or through enacting the line of nodes in his own model. The power of the CN–ARE methodology is that it captures and represents cognition in situ, showing how cognition is contextually embedded and distributed across concrete experiences. This approach allows us to move beyond capturing ready-made knowledge to capturing the situated dynamics that constitute knowing in the-making (i.e., students actualizing conceptual tools in their model and as part of their collaborative dialogue).

TRUSTWORTHINESS, USEFULLNESS, AND LIMITATIONS

Is the Coding Scheme Trustworthy?

The original coding scheme was developed by Barab and Hay with necessary modifications occurring while working on actual data with six graduate students.[4] After we ironed out many of the details, jointly, on a number of videotapes, our research team coded numerous tapes separately. In establishing reliability, two researchers coded the same 60-min segment separately. Results indicated 88% agreement in terms of number of nodes selected, with one researcher selecting 22 interactions to be categorized as nodes and the other selecting 25. Examination of the videotapes and the selected nodes suggested that, of those 22 nodes, all but one corresponded to the same segment in the video. The next step in establishing reliability of the coding scheme involved examining the categories, subcategories, and codes selected for each node. On average, both coders selected eight categories (pull-down menus) per node (e.g., one issue at hand, two initiators, one participant, two practices, and two resources). In terms of the content selected within a category, there was 80% agreement.

Other evidence for reliability was found in the research of Barab, Hay, Barnett, and Squire (in press). In this instance, two researchers collaboratively coded 10 hr of videotape for two separate groups building VR worlds. Altogether, 480 nodes were generated, with 238 for one group and 242 for the other group. They stated, "Given the qualitative nature of determining the boundaries of a particular node, the relative consistency regarding the number determined for each group to some extent validates our approach at node identification" (p. 17). Although the number of nodes derived was similar across contexts, the content of these nodes was clearly different.

---

[4]We extend a special thanks to Kurt Squire and Michael Barnett for enduring the late hours as we developed this coding scheme. As they can attest, tracing this method's historical development would fill a book.

In spite of our ability to train a set of researchers who are then able to code segments with consistency, the trustworthiness of a coding scheme based on our subjective interpretations of such complex events is certainly not a straightforward process. We are having to coordinate student gestures, dialogue, computer screens, and a class history all into a momentary judgement that occurs within the continuous flow of data. Although later we can revisit videotaped interactions, it is not possible to capture all the information in one video screen or to resituate oneself into the momentary contextual dynamics based on a video. Even if we could, it is important to note that the situation for the researcher may be very different than the situation for the learner and, as such, any interpretive judgements are necessarily suspect. As with the other limitations discussed later, we view these not as reasons to abandon the methodology or to refrain from building interpretations, but as points to consider and as problems to work toward minimizing through interviews with participants and through using other forms of data to triangulate interpretations.

Is the Coding Scheme Useful?

In terms of use, our goal was to develop a methodological approach that would support researchers interested in capturing the emergence and historical development of learning in situ. More specifically, we sought a method for tracking the emergence, evolution, and diffusion of practices, conceptual understanding, resources, and student-constructed artifacts that occur across extended time frames and that are distributed across multiple environmental particulars (e.g., computer screens, collaborating individuals, textbooks). To this end, we have found the CN–ARE methodology to be useful. At one level, the use of the coding scheme to create a database of nodes is particularly useful for getting a broad look at an element, to search for particular episodes, for drawing contrasts between groups (e.g., whether two teachers differ in terms of number of times Socratic questioning was used), for simply examining the frequency in which a particular resource was used (e.g., using the World Wide Web as a resource) or a practice was carried out (e.g., how many times scaffolding was used), for determining the average conceptual richness of the coded nodes, or for discovering characteristic themes in the data. In particular, we have been able to compare groups and gain insights into pedagogical differences and group dynamics—differences that were consistent with interview and observational data.

The more powerful function of the CN–ARE methodology is that it can be used to represent the historical development of cognition in situ, showing how cognition is contextually embedded and distributed across concrete experiences. The CN–ARE approach has allowed us to trace the evolution of various practices and understandings and to see how environmental particulars (e.g., the development of three-dimensional worlds, discourse among individuals) contributed and were bound up within this evolution (Pea, 1993). In previous work, Barab, Hay, Barrett, & Squire (in press) used the methodology to document the historical development and diffusion of the practice of animation. They were able to show how the practice of animation evolved based on collaborative discussions, task constraints, and contextual demands, and were able to illuminate the reciprocal relations of practices and nested concepts.

In the aforementioned discussion (see Scenarios 1–3 and Figure 6), we showed how the N–AREs can be used to document the historical development and diffusion of students' eclipse-related activities and understanding. We then used this network, in conjunction with transcripts of student activity, to build a story of the situated dynamics that we have argued constitute knowing in the making. On a related note, this has been central to our design experiments surrounding our VSS course in which we introduce interventions and use the CN–ARE methodology to examine the role these interventions play in the learning process (Barab, Hay, Barnett, & Keating, 2000).

In What Situations Is the Coding Scheme Useful?

Throughout this document we have alluded to the usefulness of the CN–ARE methodology for capturing learning within open-ended environments. We have found the CN–ARE to be appropriate for tracking the emergence and historical development of knowing about within contexts in which individuals have access to various resources and learning that is occurring over extended time frames. This suggests that the method's usefulness is better leveraged to learning contexts in which there is ample opportunity for engagement with various resources and collaborating individuals. Furthermore, evolution of a particular practice or understanding requires environments that afford repeated opportunity to participate in the development and application of a practice, or opportunity to gain new insights into an understanding. However, this is more than a "crisscrossing of the same landscape"—to build on Spiro and Jheng's (1990) metaphor. For the evolution of knowledge to take place there needs to be novel contexts, in a sense, new landscapes that support the learner in continual renegotiation of practices and understandings. We have been using the CN–ARE methodology in collaborative, project-based environments where individual members and, potentially, individual groups are focused on shared tasks. Within these contexts, there exists a rich opportunity for knowledge diffusion.

The CN–ARE methodology may provide less insight into traditional didactic lecture environments in which the goal is to transfer specific content from the all-knowing teacher to the individual learner with little translation of the knowledge under question. This is because there is less opportunity to participate in the emergence, evolution, and diffusion of conceptual understanding, practices, and resources.

What Are the Limitations?

With respect to the limitations of the CN–ARE methodology, we have already alluded to the need for rich learning contexts in which there is ample opportunity for the historical development of knowing about, thus requiring that knowledge development takes place over extended time frames and across multiple environmental particulars. Therefore, in order to actually capture these occurrences, it is necessary that researchers have large amounts of video data regarding student–student, student–teacher, student–tools, and student–resource interactions. Both capturing and analyzing this data are extremely labor intensive, and, in many situations, simply an impractical task (see Jordan & Henderson, 1995). Therefore, this approach is appropriate for researchers but will most likely have little application, at this stage, to the classroom teacher—although interpretations derived from analysis can prove useful to teachers.

Other limitations include the time-consuming process of training coders, getting them properly situated in each new context, and the qualitative nature of determining the boundaries of a particular node. To speak more directly to the latter point, this has been the most challenging aspect of using the CN–ARE methodology. Although for isolated segments we are able to get high interrater reliability, it has been quite a challenge when it comes to the multivariate and idiosyncratic dynamics that characterize real-world activity. Over time, as our research team continues to work in the same contexts coding similar types of activities, we have been able to increase our agreement on the boundaries of what constitutes a "meaningful unit." On a related note, we have found that each new context carries a steep enculturation curve as we come to develop a shared language and perspective on how to segment the data into AREs, as well as the labels for those identified units. Furthermore, we have not adequately explored how these boundaries overlap with the actual participant's interpretation of recorded events. Clearly, to quote one of the article's reviewers, "The observable behavior of human actors does not wear its meaning on its sleeve." Therefore, the obtaining of information about the participants' interpretations, intentions, and feelings with respect to the observed activity is essential. In this research, we are incorporating what Jordan and Henderson (1995) called "video review sessions" (p. 49), referring to the practice of having individuals who have been recorded come to a viewing session with the research team.

Another limitation is grounded in the requirement that one must be able to capture a significant amount of the relevant interactions. Within the summer camp context researched by Barab, Hay, Barnett, and Squire (1998, in press), they found it tenable to hypothesize that many of the meaningful interactions related to the particular tracers of interest happened under the lens of the video cameras. Albeit, clearly outside experiences and the cultural milieu through which all activity takes place are important and frequently uncodable components. In the context of a university course that happened over 15 weeks there were significant learning occurrences that happened outside of the formal educational environment being studied. Therefore, it is unreasonable to believe that we have captured all of the meaningful interactions. In fact, there were many occasions in which students gathered outside class or on weekends out of view of our video cameras.

There have been numerous critiques targeted at network theory more generally. For example, in critique against the Actor Network Theory (ANT) approach, Engeström and Escalante (1996) stated: “In its search for convergence, irreversibilization, and closure, this kind of analysis overlooks the inner dynamics and contradictions of the activities of the various actors in the network” (p. 344). They further stated that “the concepts of trust and reciprocity, so central in new theorizing on network organizations, and the whole contradictory dialectic of cooperation and competition, are curiously missing in the vocabulary of actor-network theory” (p. 46). Our approach also fails to adequately incorporate the motivations of individuals or to truly account for the cultural context within which the network is situated—although one may possibly create a web that pulled out culturally relevant chunks in that same way that we have pulled out more constrained ethnographic chunks. Clearly psychological, cultural, and social factors are an important part of understanding situations when one adopts a situated perspective on what it means to know and learn. We are currently exploring ways of more explicitly including these relevant factors into our coding and analysis process.

To reaffirm, our methodology is useful for identifying those interactions related to a particular tracer of interest. It is then the responsibility of the researcher to contextualize these interactions in terms of the larger context in which they unfold. For example, Barab, Barnett, Yamagata-Lynch, Squire, and Keating (in press) used the CN–ARE methodology to identify the frequency of occurrences related to a particular tracer, and then used Activity Theory (Engeström, 1987) to contextualize these in terms of the larger context (activity system). We have found that coupling the network story with a more general ethnographic account provides a much richer description of the context in general. Actually, in all our applications of the CN–ARE methodology, we have been simultaneously building case studies and ethnographic accounts of the context, and we are not sure on the usefulness of simply building networks without an appreciation for this larger story.

CONCLUSION

All too often, assessments capture the products of learning as conceived from a representational perspective in which the individual’s mind becomes the unit of analysis. Due to the fact that the individual is the unit of analysis, questions are rarely asked regarding the interaction between the agent and environment and what constituted the particular experiences that led to the understanding being assessed. These assessments frequently fail to address the historical development and diffusion of knowledge as it occurs, especially when conceived from a situativity perspective. Our goal has been to develop a methodology to capture these interactions with the goal of tracing the historical emergence and development of knowledge, allowing us to capture and understand the dynamic and contextualized process of knowing in the making. Central to our situative epistemological commitment is the conviction that knowing about is a continuous event distributed across multiple time frames and environmental particulars—not a static structure existing in an individual's head. As such, it was essential to have a methodology for capturing and tracing cognition conceived as such.

In advancing our CN–ARE methodology, we began with a description of the theoretical assumptions, the issues to be addressed, and the rationale for the method. This was then followed by an in-depth description of the method, along with its application to particular data sets. We described its application in terms of identifying important interactions and patterns and in providing a database of coded interactions for later users of the database. More important, from our perspective, we described and provided an in-depth example of how we applied the method to trace the emergence, evolution, and diffusion of students' understanding and visualization of eclipses. Through following knowing in the making as it relates to eclipses we gained insights into how setting viewpoints moved from the focal point of student activity to a tool-related practice useful for illuminating the Earth, moon, and sun system dynamics. We also were able to view the history of the nested astronomy concept the line of nodes, and how this conceptual tool transitioned from a visualization tool to a conceptual one and then back to a visualization tool.

We then offered methodological discussion of the trustworthiness, usefulness, scope of application, and limitations of the method. More specifically, we talked about the usefulness of this tool to produce inscriptions for the researcher that can scaffold the interpretation as well as the presentation of the data. We also discussed the challenges with respect to defining episode boundaries and in carving out chunks of meaning within the continuous flow of data, a process that we have found to require an intimate appreciation for the context being examined. The challenges inherent to the requirement that one must be able to capture a significant amount of the relevant interactions was also discussed. Even withstanding these challenges we have found the CN–ARE methodology to provide a useful tool for building representations of knowing in the making as conceived from a situative perspective.

The CN–ARE methodology allows researchers to identify relevant data from a complex, evolving environment, and then to organize it into a web of meaning that can illuminate the emergence and historical development of various practices, concepts, resources, and artifacts occurring over extended time frames, as well as the potential of a particular environment for supporting these processes. When researchers focus on learning situated as part of a complex, evolving environment, the data that can be generated regarding learning can easily become overwhelming. The goal of our data collection is to capture learning in a way that we can fully appreciate its complexity and make it accessible to future analysis. We utilize several data collection methods to accomplish this: We (a) use humans as data-collection instruments, (b) videotape the event, and (c) developed a minimal ontology to efficiently describe and organize in a database the critical aspects of the cognitive process.

Regarding the first method, Lincoln and Guba (1985) articulated the advantages of using humans as instruments in that an immersed human can be sensitive to the subtleties of the here and now, as well as to the spatial, social, and historical trajectory through which the unfolding events are contextualized and given meaning. Consistent with Jordan and Henderson's (1995) discussion of the vital role of video in interaction analysis, we also found that our approach depends on the "technology of audiovisual recording for its primary records and on playback capability for analysis" (p. 39). There is only so much information that an observer can capture on the fly, and videotapes allow us to revisit and elaborate on the in situ coding. Additionally, it can provide a means of member checking with participants. Third, we have developed a restricted vocabulary to describe the captured events in an efficient manner. The vocabulary serves both as a mechanism to collect and to code the data for further analysis. These three data-collection methods create the primary data set for the CN–ARE methodology.

The central organizing metaphor for the final portrayal of data using the CN–ARE methodology is the network. As previously stated, the key elements of any network are nodes and links. In CN–ARE, nodes are analogous to what qualitative researchers describe as units or chunks of meaning (Lincoln & Guba, 1985). These discrete chunks of meaning must be identified within the continuous flow of data that comes from an authentic learning environment. In the CN–ARE methodology, we call these units AREs and have described the particular boundaries of our AREs as well as its constitutive elements. The last step in our approach involves using the database to build a network that allows the researcher to equate multiple time scales and multiple interactions in a manner that supports tracing the historical development of a practice, conceptual understanding, resource, or student-constructed artifact. Through this process, the final visualization loses much of the richness and important context that was a part of the original experience; however, this process makes possible the coordination of multiple time scales and environmental particulars, which is necessary when one views cognition as distributed (Salomon, 1993). To aid the researcher in using the database, we are currently working on a strategy to easily expand grain sizes so as to contextualize the node being examined. Using advanced digital technologies we are able to link the nodes in a network directly to the original clips from which they are generated. Therefore, a researcher who is examining a network can simply click on a node and see the associated video clip as well as extend this clip out to interactions occurring before and after the particular node being examined.

Our methodology builds on interaction analysis (Jordan & Henderson, 1995), Activity Theory (Engeström, 1987; 1993; Leont'ev, 1974, 1981), network theories (Doreian & Stockman, 1997; Doreian & Woodward, 1994; Latour, 1987), and the notion of tracers (Newman et al., 1989). However, our methodology also expands on or departs from these others in important ways. First, we have built on interaction analysis, explicitly defining the elements and boundaries of an interaction, and then creating links across particular interactions so that a researcher may trace the historical development of the phenomenon of interest. Second, regarding activity theory, we have broken down the elements of the episode and then made connections among episodes in much more fine-grain detail than we have seen used in other work.

Third, with respect to network theories, we have theoretically bound our conception of what constitutes a node in terms of an ARE. This provides methodological constraints and theoretical grounding to analytical decisions about parsing up experiences. Furthermore, and specifically in contrast to actor-network theory (ANT), our view of an ARE positions individuals (and not nonhuman objects) as the primary agents in determining the historical development of the practice, conceptual understanding, resource, or student-constructed artifact being traced. We are simply using ANT as a structural framework for the development of our analytical approach and not as a theoretical framework for conceiving the relationship between human and nonhuman actors.

Third, whereas ANT has been primarily applied to more global characterizations of activity systems in general, we have used it to define the individual instances or episodes of action. Following the characterization of the local episodes, our methodology involves stringing these instances of activity together to form a more global web of activity while also illuminating the nested relations through which the more global characterization has come about.

Fourth, whereas Newman et al. (1989) used the term *tracer* to denote a preexisting methodological strategy to find the "same activity" across different contexts without resorting to intensive interpretation, in our approach tracers are identified through grounded theory development (Glaser & Straus, 1967) and refer to connected paths of events (network) that constitute the historical development of the particular phenomenon that the researcher is interested in understanding. Following this examination, it would then be useful to identify similar tracers in different contexts and compare their networks.

IMPLICATIONS

Although researchers have typically relied on methods such as "think alouds," protocol analysis, and stimulated recall to understand cognition, the CN–ARE methodology proposed in this article provides a means of capturing cognitive activity on the fly as it unfolds in its full contextualized splendor. The ability to capture knowing in the making is becoming increasingly valuable as educators design and implement more participatory-based learning environments where students are central initiators in the learning process. This information is particularly useful in design experiments where the goal is to introduce innovations and understand the impact of these interventions on environments intentionally designed to support learning. In this article, we described and then provided evidence for the trustworthiness and usefulness of our CN–ARE methodology. Future research must continue to examine the applicability of this approach for multiple contexts. More important, we need to continue to explore what types of information this method, as opposed to other techniques, provides, and why this information is useful.

One potential expansion of this methodology is to add quantitative information to the information coded at the node level—in a sense, quantifying the qualitative analysis of the data. For example, Chi (1997) discussed methodological practices that draw on content and discourse analysis for quantifying qualitative analyses of verbal data. Such an approach would first involve chunking interactions from the flow of experience into the episodes that would constitute the database (as described in the CN–ARE approach above). From here, the researcher would then examine videotapes to more comprehensively examine the content of the interactions. A rubric or coding scheme would then be applied to each interaction, evaluating it in terms of the dimensions of interest (e.g., conceptual understanding, soundness of argument, quality of design). The coded interactions would then be mapped out as a network with the quantitative scores attached to each node. In this way, the researcher could visually show the evolving sophistication of the particular content or dimension being assessed—statistical analyses could also be used to provide further evidence of the level of change. Furthermore, the researcher could focus in on those periods in which there was a clear rise or fall in scores, building grounded theory about causes for the shift. We view the coordination of content analysis, discourse analysis, and the CN–ARE methodology discussed as offering much to researchers who want to better understand and explain the historical development of knowing about as well as the products that students build during the learning process.

We are at a time of paradigmatic shifts in ontology, epistemology, and pedagogy, and researchers need to continue to look for novel techniques that are able to capture cognition conceived as situated. As we continue to do empirical research the descriptions of context, knowing about, and their mutual relations will become more sophisticated. However, commensurate with recent epistemological shifts, it is a time for real and meaningful exploration, applying data analytic techniques that afford researchers rich descriptions of the process through which learners become knowledgeably skillful within the context of their participation. Once we have a better understanding of these processes, we can then examine the influence of various interventions for supporting students in this process. We hope that this article stimulates discussion and prompts researchers to explore innovative methods for capturing the emergence, evolution, and diffusion of knowing about (the distributed event and not the cognitive structure), allowing us to better understand cognition and to improve environments intentionally designed to support learning.

ACKNOWLEDGMENT

An earlier version of this article was presented at the annual meeting of the American Educational Research Association, Montreal, Canada, April 1999.

REFERENCES

Barab, S. A. (in press). Commentary: Human–field interaction as mediated by mobile computers. In T. Koschmann, R. Hall, & N. Miyake (Eds.), *Computer supported collaborative learning.* Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Barab, S. A., Barnett, G. M., Yamagata-Lynch, L., Squire, K., & Keating, T. (in press). Using activity theory to understand the contradictions characterizing a technology-rich introductory astronomy course. *Mind, Culture, and Activity.*

Barab, S. A., Cherkes-Julkowski, M., Swenson, R., Garrett. S., Shaw, R. E., & Young, M. E. (1999). Principles of self-organization: Ecologizing the learner-facilitator system. *The Journal of the Learning Sciences, 8,* 349–390.

Barab, S. A., & Duffy, T. (2000). From practice fields to communities of practice. In D. Jonassen, & S. M. Land. (Eds.), *Theoretical foundations of learning environments* (pp. 25–56). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Barab, S. A., Fajen, B. R., Kulikowich, J . M., & Young, M. F. (1996). Assessing hypermedia navigation through Pathfinder: Prospects and limitations. *Journal of Educational Computing Research, 15,* 175–195.

Barab, S. A., Hay, K. E., Barnett, M. G., & Keating, T. (2000). Virtual solar system project: Building understanding through model building. *The Journal of Research in Science Teaching, 37*(7), 719–756.

Barab, S. A., Hay, K. E., Barnett, M. G., & Squire, K. (1998, May). *Constructing knowledge and virtual worlds: Knowledge diffusion in future camp 97.* Presented at the annual meeting of the American Educational Research Association, San Diego, CA.

Barab, S. A., Hay, K. E., Barnett, M. G., & Squire, K. (in press). Constructing virtual worlds: Tracing the historical development of learner practices. *Cognition and Instruction.*

Barab, S. A., Hay, K. E., Squire, K., Barnett, M., Schmidt, R., Karrigan, K., Yamagata-Lynch, L., & Johnson, C. (2000). Virtual solar system project: Learning through a technology-rich, inquiry-based, participatory learning environment. *Journal of Science Education and Technology, 9*(1), 7–25.

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

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher, 18,* 32–42.

Callon, M. (1987). Society in the making: The study of technology as a tool for sociological analysis. In W. E. Bijker, T. P. Hughes, & Pinch (Eds.), *The social construction of technological systems* (pp. 83–103). Cambridge, MA: MIT Press.

Callon, M., & Latour, B. (1981). Unscrewing the big leviathan. In K. Knorr & A. Cicourel (Eds.), *Toward an integration of micro and macro sociologies* (pp. 51–80). London: Routeledge & Kegan Paul.

Chi, M. (1997). Quantifying qualitative analysis of verbal data: A practical guide. *The Journal of the Learning Sciences, 6,* 271–315.

Cobb, P., & Yackel, E. (1996). Constructivist, emergent, and sociocultural perspectives in the context of developmental research. *Educational Psychologist, 31,* 175–190.

Degenne, A., & Forse, M. (1999). *Introducing social networks.* Thousand Oaks, CA: Sage.

Doreian, P., & Stockman, F. (Eds.). (1997). *Evolution of social networks.* Amsterdam: Gordon & Breach.

Doreian, P., & Woodward, K. L. (1994). Defining and locating cores and boundaries of social networks. *Social Networks, 16,* 267–293.

Engeström, Y. (1987). *Learning by expanding.* Helsinki: Orienta-konsultit.

Engeström, Y. (1993). Developmental studies of work as a testbench of activity theory: The case of primary care medical practice. In S. Chaiklin & J. Lave (Eds.), *Understanding practice: Perspectives on activity and context* (pp. 64–103). New York: Cambridge University Press.

Engeström, Y. (1999). Activity theory and individual and social transformation. In Y. Engeström, R. Miettinen, & R. Punamaki, (Eds.), *Perspectives on activity theory* (pp. 19–38). Cambridge, MA: Cambridge University Press.

Engeström, Y., & Escalante, V. (1996). Mundane tool or object of affection? The rise and fall of the postal buddy. In B. Nardi (Ed.), *Context and consciousness: Activity theory and human–computer interaction* (pp. 325–374). Cambridge, MA: MIT Press.

Garfinkel, H. (1967). *Studies in ethnomethodology.* Englewood Cliffs, NJ: Prentice Hall.

Gartner, J., & Wagner, I. (1996). Mapping actors and agendas: Political frameworks of systems design and participation. *Human–Computer Interactions, 11,* 187–214.

Glaser, B. G., & Strauss, A. L. (1967). *The discovery of grounded theory.* Hawthorne, NY: Aldine.

Gonzalvo, P., Cañas, J. J., & Bajo, M. (1994). Structural representations of knowledge acquisition. *Journal of Educational Psychology, 86*(4), 601–616.

Greeno, J. G. (1997). Response: On claims that answer the wrong questions. *Educational Researcher, 26,* 5–17.

Greeno, J. G. (1998). The situativity of knowing, learning, and research. *American Psychologist, 53,* 5–26.

Greeno, J., & Middle School Mathematics Through Applications Project Group. (1998). The situativity of knowing, learning, and research. *American Psychologist, 53,* 5–26.

Hay, K. E., Johnson, H., Barab, S. A., & Barnett, M. G. (in press). The next best thing: Virtual reality in the astronomy classroom. *Mercury.*

Hutchins, E. (1993). Learning to navigate. In J. Lave & S. Chaiklin (Eds.), *Understanding practice: Perspectives on activity and context* (pp. 35–63). New York: Cambridge University Press.

Jordan, B., & Henderson, A. (1995). Interaction analysis: Foundations and practice. *The Journal of the Learning Sciences, 4,* 39–103.

Keating, T., Barnett, M., & Barab, S. A. (1999, May). Student learning through building virtual models. Presented at the Annual Meeting of the American Educational Research Association, Montreal, CA.

Kulikowich, J. M., & Young, M. F. (2001). Locating an ecological psychology methodology for situated action. *The Journal of the Learning Sciences, 10,* 165–202.

Kuttii, K. (1996). Activity theory as a potential framework for human-computer interaction research. In B. Nardi (Ed.), *Context and consciousness: Activity theory and human-computer interaction.* Cambridge, MA: The MIT Press.

Latour, B. (1993). *We have never been modern.* Cambridge, MA: Harvard University Press.

Latour, B., & Woolgar, S. (1979). *Laboratory life: The social construction of scientific facts.* Beverly Hills, CA: Sage.

Lave, J. (1988). *Cognition in practice: Mind, mathematics and culture in everyday life.* Cambridge, England: Cambridge University Press.

Lave, J. (1993). Situating learning in communities of practice. In L. B. Resnick, J. M. Levine, & S. D. Teasley (Eds.), *Perspectives on socially shared cognition* (pp. 17–36). Washington, DC: American Psychological Association.

Lave, J. (1997). The culture of acquisition and the practice of understanding. In D. Kirshner & J. A. Whitson (Eds.), *Situated cognition: Social, semiotic, and psychological perspectives* (pp. 17–36). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

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

Lee, N., & Brown, S. (1994). Otherness and the actor network: The undiscovered continent. *American Behavioral Scientists, 3,* 772–790.

Leont'ev, A. (1974). The problem of activity in psychology. *Soviet Psychology, 13*(2), 4–33.

Leont'ev, A. (1981). *Problems of the development of mind.* Moscow: Progress.

Leont'ev, A. (1989). The problem of activity in the history of Soviet psychology. *Soviet Psychology, 27*(1), 22–39.

Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic inquiry.* Beverly Hills, CA: Sage.

Mead, G. H. (1934). *Mind, self, and society.* Chicago: University of Chicago Press.

Miles, M. B., & Huberman, A. M. (1984). Drawing valid meaning from qualitative data: Toward a shared craft. *Educational Researcher, 13,* 20–30.

Nardi, B. (Ed.). (1996). *Context and consciousness: Activity theory and human-computer interaction.* Cambridge, MA: The MIT Press.

Newman, D., Griffin, P., & Cole, M. (1989). *The construction zone.* New York: Cambridge University Press.

Pea, R. (1993). Practices of distributed intelligence and designs for education. In G. Salomon (Ed.), *Distributed cognitions: Psychological and educational considerations* (pp. 47–87). Cambridge, England: Cambridge University Press.

Prout, A. (1996). Actor-network theory, technology and medical sociology: An illustrative analysis of the metered dose inhaler. *Sociology of Health & Illness, 18,* 198–219.

Radder, H. (1992). Normative reflexions on constructivist approaches to science and technology. *Social Studies of Science, 22,* 141–173.

Roschelle, J., & Clancey, W. J. (1992). Learning as social and neural. *Educational Psychologist, 27,* 435–453.

Roth, W.- M. (1996). Knowledge diffusion in a grade 4–5 classroom during a unit of civil engineering: An analysis of a classroom community in terms of its changing resources and practices. *Cognition and Instruction, 14,* 170–220.

Roth, W.- M. (1998). *Designing communities.* Dordrecht, The Netherlands: Kluwer.

Roth, W.- M. (2001). Situating cognition. *The Journal of the Learning Sciences, 10,* 27–61.

Roth, W.- M., & Bowen, G. M. (1995). Knowing and interacting: A study of culture, practices, and resources in a grade 8 open-inquiry science classroom guided by a cognitive apprenticeship metaphor. *Cognition and Instruction, 13,* 73–128.

Roth, W.- M., & Roychoudhury, A. (1993). The concept map as a tool for the collaborative construction of knowledge: A microanalysis of high school physics students. *Journal of Research in Science Teaching, 30,* 503–534.

Salomon, G. (Ed.). (1993). *Distributed cognitions: Psychological and educational considerations.* New York: Cambridge University Press.

Sax, G. (1989). *Principles of educational and psychological measurement and evaluation.* Belmont, CA: Wadsworth Publishing company.

Schatzman, L., & Strauss, A. (1973). *Field research: Strategies for a natural sociology.* Englewood Cliffs, NJ: Prentice Hall.

Schoenfeld, A. H. (1992). On paradigms and methods: What do you do when the ones you know don't do what you want them to? Issues in the analysis of data in the form of videotapes. *The Journal of The Learning Sciences, 2,* 179–214.

Schvaneveldt, R. W. (Ed.). (1990). *Pathfinder associative networks.* Norwood, NJ: Ablex.

Singleton, V., & Michael, M. (1983). Actor-Networks and ambivalence: General practitioners in the UK cervical screening programme. *Social Studies of Science, 23,* 227–264.

Spiro, R., & Jehng, J. (1990). Cognitive flexibility and hypertext: Theory and technology for the non-linear and multi-dimensional traversal of complex subject matter. In D. Nix & R. Spiro (Eds.), *Cognition, education, multimedia: Exploring ideas in high technology* (pp. 163–202). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Suchman, L. A. (1987). *Plans and situated actions: The problem of human–machine communication.* Cambridge, England: Cambridge University Press.

Vygotsky, L. (1978). *Mind in society: The development of higher psychological processes.* Cambridge, MA: Harvard University Press.

Wittrock, M. C., & Baker, E. L. (Eds.). (1991). *Testing and cognition.* Englewood Cliffs, NJ: Prentice Hall.

Young, M. (1993). Instructional design for situated learning. *Educational Technology Research and Development, 41,* 43–58.

Young, M. F., Kulikowich, J. M., & Barab, S. A. (1997). The unit of analysis for situated assessment. *Instructional Science, 25,* 133–150.