DOCUMENT RESUME

ED 432 597 TM 029 979

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TITLE	Constructing Networks of Activity: An In-Situ Research Methodology.
PUB DATE	1999-04-00
NOTE	53p.; Paper presented at the Annual Meeting of the American Educational Research Association (Montreal, Quebec, Canada, April 19-23, 1999).
PUB TYPE	Reports - Descriptive (141) -- Speeches/Meeting Papers (150)
EDRS PRICE	MF01/PC03 Plus Postage.
DESCRIPTORS	*Cognitive Processes; Educational Research; *Networks; *Research Methodology
IDENTIFIERS	*Situated Learning

ABSTRACT

This article adopts a situative perspective on what it means to know and to learn, describing knowing as a continuous event distributed across multiple time frames and environmental particulars (e.g., textbooks, collaborating individuals, previous experiences, and computer representations). A methodology is presented that captures cognition in situ, with the goal of tracing the emergence and development of practices, concepts, and resources, as well as the role of particular interventions in supporting this process. The sociological approach of actor-network theory provides the structural framework within which the Constructing Networks of Activity (CNA) methodology is grounded. In advancing CNA methodology, a set of criteria for researchers introducing novel methods that was developed by A. Schoenfeld (1992) is applied. In addition to setting the context and providing a rationale for the CNA methodology, the discussion includes an in-depth description of the methodology and its application to data sets and a discussion of the reliability, validity, scope of application, and limitations of the method. Three appendixes contain scenarios of the method in use. (Contains 2 tables, 7 figures, and 44 references.) (Author/SLD)

Constructing Networks of Activity: An In-Situ Research Methodology

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This paper was presented at the 1999 Annual Meeting of the American Educational Research Association. Please do not duplicate without the permission of the authors.

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Abstract

Drawing primarily on the learner-as-processor and acquisition metaphors, there is a long tradition of assessment and methodological practices for evaluating learning. Because the individual is the unit of analysis, questions are rarely asked regarding the interaction between the agent and environment broadly defined, leading to impoverished descriptions of the learning process. Further, an acquisition focus has led to an emphasis on ready-made knowledge as opposed to knowing-in-the-making. In contrast, in this article we adopt a situative perspective of what it means to know and learn, describing knowing as a continuous event distributed across multiple time frames and environmental particulars (e.g., textbooks, collaborating individuals, previous experiences, and computer representations). We advance a methodology for capturing cognition in situ, with the goal of tracing the historical emergence and development of practices, concepts, and resources, as well as the role of particular interventions in supporting this process. It is this latter information that is especially useful for researchers interested in carrying out design experiments where research findings with respect to one iteration of the course are cycled into the design of future course instantiations. The sociological approach of actor-network theory provides the structural framework within which our Constructing Networks of Activity (CNA) methodology is grounded. Our interest in actor-network theory is not at the sociological level, but we couple it with emerging theoretical perspectives of learning and cognition to create a new analytical tool for examining learning and the context within which it occurs. In advancing our CNA methodology, we adhere to a set of criteria for researchers introducing novel methods that was put forth by Schoenfeld (1992). In addition to setting the context and providing a rationale for the CNA methodology, our discussion includes an in-depth description of the methodology along with its application to data sets. Following these examples, a methodological discussion of the reliability, validity, scope of application, and limitations of the method is forwarded.

CONSTRUCTING NETWORKS OF ACTIVITY: AN IN-SITU RESEARCH METHODOLOGY

INTRODUCTION

In spite of the intuitive and theoretical appeal of situated cognition (Brown, Collins, & Duguid, 1989; Greeno, 1997; Lave & Wenger, 1991) and distributed cognition (Pea, 1993; Resnick, Levine, & Teasley, 1991; Salomon, 1993), there has been little empirical research that actually attempts to understand how learner understandings are constructed and are grounded in contextual particulars (see Barab, Hay, Barnett, & Squire, 1998; Roschelle & Clancey, 1992; Roth, 1996, 1998; Roth & Bowen, 1995 for some exceptions). In fact, research in general tends to look at the products, not the processes of learning (Wittrock & Baker, 1991; Young, Kulikowich, & Barab, 1997). Some of 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 (Brown, Collins, & Duguid, 1989; Lave & Wenger, 1991). This is because from this 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 that is distributed across knower and that which is known.

It is this intersection of individual, context, and activity over time that constitutes the unit of analysis when one adopts a situated perspective (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 these reciprocal components (Barab, Fajen, Kulikowich, & Young, 1996; 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.

To capture the process of learning in situ, we have been developing an innovative method for tracking the emergence, evolution, and diffusion of practices, concepts, and artifacts that occur across extended time frames (Barab, Hay, Barnett, & Squire, 1998). 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. Our methodology is designed to capture occurrences distributed across time and space that influence/constitute a learner's understanding, providing information on how environmental particulars contribute to evolving understandings. We believe that a learner's ultimate understanding of any 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 see 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 Activity methodology.

UNDERSTANDING AS PRACTICE

Since the cognitive revolution of the 60's, representation has been the central concept of cognitive theory and the representational theory of mind has been the most common view in cognitive science (Gardner, 1985; Fodor, 1980; Vera & Simon, 1993). The central tenet of this position is that "knowledge is constituted of symbolic mental representations, and cognitive activity consists of the manipulation of the symbols in these representations, that is, of computations" (Shannon, 1988; p. 70). In contrast, others have argued for a shift away from a representational theory of mind toward a theory of practice and participation in which cognition is considered situated and distributed across time and space (see Greeno, 1998; Kirshner & Whitson, 1997; Salomon, 1993). A move toward activity-based (participatory) theories and away from a representational epistemology is also consistent with the works of Dewey (1925/1981), and Quine (1969), who rejected conceptual representations as primary in explaining knowledge. Instead, they viewed learning as taking part or being able to participate, and this process involved whole persons (not isolated minds) and rich contexts (including other individuals) (Barab & Duffy, in press).

From this perspective, "knowledge," perhaps more aptly termed "knowing about," refers to a process distributed across the knower, the environment in which knowing occurs, and the activity in which the learner is participating—a dynamic unfolding cycle of perception-action (Barab, Cherkes-Julkowski, et al., in press). Knowing and context are inextricably linked (Greeno, 1998). Learning is thus (re)conceived as fundamentally connected with and constitutive of the environmental particulars in which it is nested (Cobb & Yackel, 1996; Lave, 1997). From this perspective, 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). How much simpler it was 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 situativity conceptions of cognition.

ACTOR-NETWORK THEORY

For the most part, situative theories have been developed and researched through anthropological studies, frequently with a focus on activity that takes place in contexts of daily living and working (Engeström, 1993; Knorr-Cetina, 1981, 1992; Lave, 1991; Hutchins, 1993; Latour & Woolgar, 1979; Lave & Wenger, 1991; Rogoff & Lave, 1984; Saxe, 1992; Scribner & Cole, 1973; Suchman, 1987). The central focus of these studies has been on understanding "context" as a social world constituted in relation with acting persons (see Lave, 1988 for a collection of chapters related to this issue). For our research, we chose an approach to conceptualizing and capturing these relations that builds on Actor-Network Theory (ANT). The ANT 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. "This 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, organizations, communities, and even technical artifacts such as published articles are constituted of (and interrelations are fused through) interlocking networks of actors. Actors, generally speaking, can be human and non-human, collectives or individuals, material or non-material, with each individual, group, company, technology, belief, raw material, or artifacts constituting an actor (Roth, 1996). They are referred to as actors because in some way they <u>act</u> on the historical development of the phenomenon (whether it is physical, social, or conceptual in nature) being studied. A particular actor-network consists of heterogeneous, but seamless, interactions among actors, with no a priori distinction among human and non-human actors; they constitute "symmetrical anthropologies" (Latour, 1993). In addition to being a part of networks, actors are also constituted by networks; that is, they are both constitutive of and constituted by networks of actors, reciprocally determining and being determined by the interactions in which they are a part.

> The network approach thus allows us to eschew the reductionism of more traditional approaches that focused a priori on the individual or the social, the social or technological, content or context, human or nonhuman actors; it integrates all these dichotomies)... Understandings that arise out of such analyses are heterogeneous because they focus on more than just the technical or the social, content or context, and human or non-human by stressing the coevolution of each of these pairs. (Roth, 1996, p. 183).

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 (Garfinkel, 1967; Kirshner & Whitson, 1997; Lave, 1988; Lave & Wenger, 1991; Roth, 1996). Further, it complements the anthropological tradition of ethnomethodology, which is aimed toward providing "grounded" accounts of social action through understanding the context in which practice takes place—in spatial, cultural, and social terms (Garfinkel, 1987).

The ANT has been applied by anthropologists to understand the historical development of computer technologies and paper-based manuscripts (Callon, 1986; Latour, 1987), by sociologists to understand screening programs and the historical development of medical technologies (Prout, 1996; Singelton & Michael, 1993), by computer scientists to understand systems design (Gartner & Wagner, 1996), by various authors to forward ontological commitments (Lee & Brown, 1994; Radder, 1992), and by educational psychologists to understand learning in open-ended learning contexts (Barab, Hay, Barnett, & Squire, 1998; Roth, 1996). In many of these applications, actor-network analysis was applied not just as a sociological exercise but as an analytical tool (Gartner & Wagner, 1996; Prout, 1996; Singelton & Michael, 1993).[1] For example, Gartner and Wagner (1996), in understanding systems design, actually built actor networks of two case studies of 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.

Wolf-Michael Roth (1996) used actor-network theory to examine how learning unfolds within student-centered classrooms. Roth (1996) investigated the way resources (i.e., any piece of information, objects, tools, or machines) and practices (i.e., embodied tool-related laboratory skills and understanding and application of concepts) influence a classroom community. He used actor 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 this research was the notion of tracers. Tracers can refer to facts, practices (tool and concept related), student productions (e.g., projects developed), or understandings that can be observed and followed over time (Newman, Griffin, & Cole, 1989; Roth & Roychoudhury, 1993). In Roth's (1996) research, tracers are selected and then their history is 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) and tool-and concept-related practices. 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, while 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 intellectual- or concept-related practices (for example, the notion of triangulation), which was extremely slow and only occurred with constant prompting of the teacher. On the other hand, students were able to express the fact (triangulating supports structures) rather quickly.

Consistent with ANT, no one actor, whether it be the computer, teacher, other resources, or student is given a priori priority over others in explaining the development of the tracer. "Any aspect of a collective or technology can be understood by following one or more actors of the network that constitutes the collective or technology" (Roth, 1996, p. 186). Further, many of the actors can have "simultaneous multiple membership" in histories associated with multiple tracers. Examination of these networks and the nested tracers can provide insights into the possible roles of teachers and how students construct meanings in participatory learning environments.

DEVELOPING A METHODOLOGY

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. Because the assumptions to this approach start with the student 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 et al., 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 situativity perspective it is the complex and dynamic intersection of individual, environment, and activity over time that constitutes the unit of analysis (Greeno, 1998; Lave, 1993; Engeström, 1993). That is, the focus is on learning and knowing in practice, not on some hypothesized reification of practice.

The adoption of situativity perspectives, which take seriously the dialectic relations among individual, environment, and practice, suggest a need for new methodological practices that are more able to capture these dynamic relations. This state of affairs was described by Schoenfeld (1992):

> Since becoming a student of cognition, I have been in the awkward position of having at my disposal a wide range of scientific methods and perspectives … alongside the recognition that they are frequently inadequate to deal with the issues I find central. Each established method provides some insights, but those insights (whether from ethnographic analyses or cognitive modeling, to pick two paradigmatic examples) have been, from my perspective, either too narrow or too partial to give a true sense of what thinking and learning are all about. (p. 180)

The design of new methods to capture one's phenomena of interest is a risky undertaking, and the "the pursuit of what one finds 'challenging and interesting' can lead to an ad hoc empiricism that is theoretically vacuous" (Schoenfeld, 1992, p. 181). Therefore, in presenting this methodology, we have attempted to address the following criteria, which is consistent with those criteria advanced by Schoenfeld (1992).

1. Establish the context, describing the issues to be addressed.
2. Describe the rationale for the method.
3. Describe the method in sufficient detail that readers who wish to can apply the method.
4. Provide a body of data that is large enough to allow readers to (a) analyze it on their own terms, to see if their sense of what happened in it agrees with the author's, and (b) employ the author's method and see if it produces the author's analyses.
5. Offer a methodological discussion that specifies the scope and limitations of the method, as well as the circumstances in which it can profitably be used, and that treats issues of credibility and trustworthiness.

In the previous sections, we focused our discussion around the first two criteria, with continued discussion of these throughout the paper. In the next section, we will describe our methodology for tracing the emergence, evolution, and diffusion of knowledge and artifacts across groups, providing examples of data and analyses. Although we do not view it as possible to provide a body of data large eough 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 knowing-in-the-making. We will then close with a discussion of the scope and limitations of this manuscript, including issues of reliability and validity.

CONSTRUCTING NETWORKS OF ACTIVITY METHODOLOGY

The Constructing Networks of Activity (CNA) methodology discussed in this paper operationalizes ANT into an analytical tool for capturing the distributed and situated nature of learning environments—our focus is on what Bereiter and Scardamalia, 1993, referred to as intentional learning environments. The CNA 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, and resources occurring over extended time frames, as well as the potential of a particular environment for supporting these processes. The network is the central organizing metaphor for both the theoretical ANT framework and the CNA methodology. The key elements of any network are nodes and links.

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 CNA, 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 CNA methodology, we call these units Activity Nodes. Lincoln and Guba (1985) described two criteria for units of analysis: they must be heuristic and they must be the smallest piece of information about something that can stand by itself.

Beginning with the first criterion, heuristically, Activity Nodes, 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 the Activity Node 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, for example, under practices we have additionally delineated between 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, for example, under instructional practices we included coaching, Socratic questioning, lecturing, just-in-time lecturing, among others.

[insert Table 1 about here]

Defining the Central Catagories

The Issue at Hand or theme is the "direct" object of discussion or manipulation. It can refer to a resource, a practice, or a conceptual tool/process. For example, an Activity Node 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 Activity Node is the "discussion" and the direct object of that discussion is both "animation" and the "Moon."[2] The Issue at Hand serves a primary identification and labeling function in the overall-coding scheme.

An Initiator is an individual, technology, object, 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 for two reasons. First, 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. Second, because students are working with interactive models, new activities are often initiated by the running models themselves. That is, after creating a model and running it, the model stimulates new activities and discussions for learners in which is otherwise difficult to engage. 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 surrounding 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 we believe, overly presumptuous, to define the numerous aspects of cultural influence that could possibly be considered Initiators. Therefore, we have not included these non-observable, yet potentially important, cultural influences in our coding scheme and must acknowledge this as a limitation. The third category, Participants, are all other individuals who are involved in an Activity Node but not initiating the action.

The fourth category we identified as a critical element of learning is the 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 "artifact" that is simply available. An artifact is transformed to a Resource when an Initiator as part of a practice uses it.

The final critical element of any Activity Node is the activity itself. The Practice is an activity carried out by an Initiator or Participant who is using a resource. There can be many different categories of Practice within a Network of Activity. Some of these categories of Practice will be associated with specific types of initiators (i.e., student or instructor practices), some will be associated with different content areas (i.e., mathematics, science, or English practices), and some associated with particular resources (i.e., WWW, word processing, or ruler practices). In fact, there are often several different Practices simultaneously conducted within one Activity Node. For example, in the work of Roth (1996) discussed above, two students collaboratively building a toothpick bridge with a glue-gun might 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/engineering practice of triangulation all within one Activity Node. 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/engineering practice. In review, each Activity Node has, minimally, an Issue at Hand, the Initiator, the Participant, the Resource, and the Practice. We will now turn to the operational consideration of creating a Network of Activity.

Coding Nodes

Operationally, the identification or "chunking" the raw data into units or Activity Nodes is the first step in the creation of the network. Activity Nodes are identified as an activity occurrence that are judged to be a "significant happening" in the learning context, and are delimited by a change in theme, practice, or incidence. What qualifies as a significant happening is somewhat subjective and specific to the needs and interests of each particular research context. This subjective judgement goes to Lincoln and Guba's (1995) second criterion for a unit of anlaysis, "smallest piece of information." For example, one researcher might be interested in capturing fine-grained practices (e.g., mouse clicks or turn-taking in a conversation) while another researcher may be interested in more molar units (e.g., moving an object across a screen or a planning discussion).

Once the Activity Nodes are identified, the next step in our methodology involves developing codes for the critical categories (e.g., Practices, Resources, Initiators) and for any relevant subcategories (instructional-related, tool-related, modeling-related practices). In our research, the subcategories are usually based on content analysis and pilot research. However, the sets of specific codes are then developed through weekly meetings in which members share field notes to develop grounded categories of 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 in 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 Activity Node (see Figure 1 for an example of a coding form of our Virtual Reality Astronomy course).

[Insert Figure 1 about here]

Developing Links

The second main feature of a network is the links that connect the nodes. We can conceptualize the links as anything that ties one Activity Node to any other Activity Node. Thus, conceptually, all our codes serve as links between Activity Nodes. That is, 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 nodes of people and technology. 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 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, and resources occurring over extended time frames. We have established two types of links: Primary Secondary. The Primary Links are focused on people as they move from one Activity Node to another. For example, if Patricia were a part of two Activity Nodes, she would be a Primary Link. If she had a collaborator (say Tim) who participated in the two Activity Nodes, then he too would be a Primary Link between the two Activity Nodes. However, if Tim were not a part of the second Activity Node but were a part of a third node, then he would link the first node to the third node. This is important conceptually because it is our contention that the study of the emergence, evolution, and diffusion of various practices, concepts, and resources occurring over extended time frames can only be traced through the activities of people.

Secondary Links conversely, are not represented through lines connecting nodes (as are Primary Links), but rather are represented with node indicators (color and patterns) on the Activity Nodes and can be traced through the Primary Links. These Secondary Links can be any of the codes within the coding scheme, but we have focused on the link across the following codes: concepts, practices, resources, and student-developed artifacts.

Visualizing Nodes and Links

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 time and the X-axis represents student Initiators. In this discussion, we use an example of one group of four students. However, the CNA methodology can be used with larger groups. The Activity Nodes 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 one-minute blocks.

[Insert Figure 2 about here]

These node bars are then abstracted into circles that represent relative position (see Figure 3). We acknowledge that these ovals do not have a one-to-one mapping in terms of actual node duration or in terms of when they occurred. However, for the purpose of this analysis, the graph does maintain the relative position of nodes with respect to the time when they occurred. For example, the two nodes in which José and Mary initiated at time 1 had different duration but occurred during the same time period relative to the nodes displayed for time 2. In some cases, the actual node overlaps the time periods (e.g., the node initiated by Susie occurs across times 3 and 4). 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, the placement of a node at time 3 or 4 would not change the overall picture in a meaningful way; that is, this placement would not effect how we trace and interpret the historical development of a particular practice, concept, resource, or student-produced artifact.

[Insert Figure 3 about here]

Lastly, links are added to represent the participants of a node (see Figure 4). This represents a person's path though the Network of Activity. The final goal of building a network is to trace the historical development and diffusion of the topic of interest (Issue at Hand, Practice, or Resource). Once the researcher has constructed a complete Network of Activity, the next step involves selecting those nodes related to the topic of interest. Figure 5 represents a "tracer network," referring to a network that signifies the tracing of a particular Issue at Hand, Practice, or Resource. This is simply a hypothetical example to illuminate a section of a network. Below we will present actual examples from our research context.

[Insert Figure 4 about here]

In this hypothetical network, all the dark nodes in Figure 5 represent those nodes of a particular Practice. In this hypothetical vignette, Mary is working by herself on "the practice" in the first two time periods, and the other student, are working in a group initiated by José on something else. At time 2, José calls Mary over to show him and Tom how to do the practice. Then, Tom goes back to his computer and does one other thing before he asks José to help him. Susie tags along. Susie returns to her computer to work on the Practice. At this time, Mary and José have returned to their computers and begun something else.

[Insert Figure 5 about here]

In the above discussion, we described the process of constructing networks. In our research, the process from observation to analysis has involved the following steps:

1) Devising a means for capturing interactions—we have found it useful to use video;
2) Reviewing the captured interactions, "chunking" them into discernible units of analysis that we have described as Activity Nodes;
3) Recording information related to the specifics that constitute each Activity Node (see Figure 1);

4) Developing a visual representations of the Network from time bar representations, to abstracted nodes representation, and linking these nodes together to form a complete network (see Figures 2-4);
5) Selecting the particular Issue at Hand, Practice, or Resource to serve as the tracer; and
6) Tracing the historical development of the particular tracer over time by graphing out all the related nodes and examining the path (see Figure 5).

INSTANTIATING THE CATEGORIES (OUR RESEARCH)

To illuminate the use of the CNA methodology within a classroom, we will now describe one of our particular research contexts and how we have used CNA to trace the historical development of various concepts, practices, and resources. In particular, we will demonstrate how we have used the CNA methodology to capture the emergence, evolution, and diffusion of concepts, practices, resources, and objects in our Virtual Solar System (VSS) project (Barab, Hay, & Barnett, 1999; Hay, Johnson, Barab, & Barnett, in press). However, this is an illustrative example of applying the CNA 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/instruction within collaborative, technology-rich, project-based learning environments (Barab, Hay, & Duffy, 1998). The VSS Project is an experimental undergraduate Astronomy course taught at a midwestern university. For this project, we completely transformed this traditional lecture-based course into a project-based course (Barab, Hay, & Barnett, 1999; 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 three VR models of different aspects of the Solar System: 1. the Earth, Moon, and Sun, 2. the entire Solar System, and 3. 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 VR creation software that allowed the projects to be exported directly to the World Wide Web (see Barab, Hay, & Barnett for a full discussion of this course).

We used video cameras to capture each of four student groups as they constructed their VR worlds within a computer lab in which there was a one-to-one student-computer ratio. Although we had a separate video camera directed toward each group, it was not possible to capture all of the information on each of the computer screens along with student gestures and dialogue. Therefore, a researcher was assigned to each group during class time, allowing for much of the coding (selecting interactions and filling out the nodes) to occur "on the fly." Videotapes were later inspected to ensure accuracy of nodes. To increase consistency across group coding and to provide all researchers exposure to each group, we rotated groups on different days and performed member checks by having researchers examine each others' coding of nodes.

Coding Examples

The first step in adapting the CNA 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 on our VSS context). In addition, it is essential that these items be editable and that items can be added as new Issues at Hand, Practices, Initiators, Participants, and Resources are identified. Included in our form are fields for the group number, date, start and stop times, the name of the person coding the form (coder), the Issue at Hand (practices, concepts, and objects), Conceptual Richness, Initiators (objects, students, mentors), Practices (tool-related practices, modeling related, mathematical, group project, instructor, student), Context, Resources (including concepts used as tools such as logarithms), participants (student, mentor), Tracers, and a Description of the Node. The five major category labels were discussed above (see Table 1); however, in making the CNA methodology a useful analytical tool, we have found it necessary to include additional fields to our form. We will briefly explain these additional categories, which include group, date, start and stop, conceptual richness, conceptual tools, and description fields.

The group field is useful for searching and sorting the records when using the CNA 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 from “0” to “9,” with 9 representing nodes involving interconnections of ideas or systems-level understandings of the particular domain of interest. For example, the concept of "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 Activity Node would be judged a 9 when it involves this systems-level appreciation of these nested concepts.

Concepts as resources 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). Here we are making the same distinction as we made with other types of tools, that is, we need to code them differently where 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.

It has also proven necessary to add a field to our database for brief textual descriptions that allow researchers to gain a rich contextual picture when examining nodes constructed at other times and by other researchers. In addition to textual descriptions, our database forms include a field for displaying the segment of video associated with the node.

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). In addition, 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. The 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. 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 Activity Nodes

In this section, we present a scenario from our research program to demonstrate how the CNA methodology has been used to develop rich interpretations of these experiences. We have included four scenarios in this paper to support researchers in applying this approach. However, based on the suggestions of the reviewers, we have included scenarios 2 through 4 as appendices but will refer to all four in this set-up. These scenarios are presented as four different examples, each of which includes multiple interactions coded as multiple Activity Nodes. 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 illustrates the coding of a conceptual tool (e.g., logarithms) and how this tool becomes black boxed into a student-created inscription where it can be used as a table resource by other students. Black-boxed describes the process by which a piece of machinery or a set of commands becomes compiled. At this point, the commands are no longer the focus of the activity, but can be used, transparently, to perform some other activity. The fourth scenario illustrates how project constraints become instantiated into the model, and how the CNA methodology allows researchers to capture the rich history of interactions within which these interactions are built.

In these examples, we will illustrate how we have parsed a scenario into separate Activity Nodes, and how to code each one of the Activity Nodes. In each scenario, we will begin with a set-up that will contextualize the reader to the goals, motivations, and the activities prior to the scenario. Then we will present the collected data from the scenario broken up into turn-taking segments. The far right column indicates how we chunked the data into Activity Nodes. Last, each Activity Node will be coded using multiple category labels. Students include Marvin, Keith, and Roger, and instructor is Igor. Following the dialogue, we then list the particular codes our research team selected for this dialogue (see Table 2).

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 of "camera positions" that can be placed in a virtual reality model, allowing viewers of the model to immediately shift to various locations. The interaction begins after Marvin has built an Earth-Moon-Sun system and animated all the pieces.

Participant	Description	Node
Marvin	[*Marvin is setting a viewpoint so that end-viewers can go to a perspective on the VR world that he determines.*]	1
Marvin	Okay, in a lunar eclipse does the Earth block the light of the Sun?	2
Keith	Yeah, let's see [*then Keith moves next to him and says "show me" as he looks at the computer*]	
Marvin	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.	
Keith	[*Keith shows Marvin what the eclipse looks like by modeling with his hands*]	
Marvin	Oh, so a lunar eclipse is when the Earth blocks the light of the Sun?	
Keith	Yes.	

The dialogue continues.

Participant	Description	Node
Marvin	[*Marvin is viewing the virtual model's viewpoints. He is jumping from one to another. He is visibly frustrated*]	3
Marvin	I thought I set a viewpoint here yesterday, but it is not working [*Marvin's inflection hinted at it being a question*]	4
Igor	Okay, so what did you do to set the viewpoint?	
Marvin	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.	
Marvin	[*They find the two cameras and delete them*]	5

Igor	*[Igor does a just-in-time lecture on setting viewpoints so that students can demonstrate various aspects of their solar system model with the cameras.]*	6

The scenario continues:

Participant	Description	Node
Marvin	[*Marvin sets a viewpoint that illustrates a lunar eclipse*]	7

[insert Table 2 about here]

Interpreting Data

We have found it useful to carry out three types of data interpretations on the database of nodes generated using the CNA methodology (Barab, Hay, Barnett, & Squire, 1998): as a database search tool to support grounded theory development (Glaser & Strauss, 1967); to develop Frequency/History graphs, and to develop the full Network of Activity graphs. The first use involves using the database of nodes 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, Yamagata-Lynch, Squire, & Keating, 1999), or in identifying instances related to a particular issue (Barab, Hay, & Barnett, 1999). The second use involves examining the frequencies of occurrence of one particular element of a node over a particular time frame, for example, nodes of a project as they relate to particular concepts, practices, or resources. This representation is particularly useful for getting a broad look at an element, 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 of 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), or to determine the average conceptual richness of the coded nodes. The other more exciting data interpretation method is to actually trace the emergence, evolution, and diffusion of concepts or practices over time through the entire Network of Activity (see Figure 5). It is with this goal in mind that we developed the CNA methodology, and it is this function that allows researchers to capture cognition in situ.

As a Database Search Tool. Barab, Barnett, Yamagata-Lynch, Squire, and Keating (1999) used the database to identify important interactions, meaningful patterns, and trace their occurrences throughout the semester long VSS course. In analyzing the data for their research, they selected various initiators, practices, and concepts and then used the database, fieldnotes, and interviews to identify when and where in the course they occurred. Based on the node descriptions in the database and tags in their fieldnotes, they then went to the original videotapes and examined complete episodes. Through an examination of the specific episodes and their place in the database, they were able to develop an appreciation for the overall course context in which a particular episode occurred. Then, using Activity Theory as a theoretical lens (Engeström, 1987; Leont'ev, 1974), they were able to examine the relations of subject and object as mediated by the primary components of an activity system. Zooming back out to the larger course context with the database, they were then able to contextualize each episode within the course context, and to identify central contradictions that characterized the course activity system as a whole.

Examining the Frequency/History Graphs. Once the researcher (or, more likely, research team) has coded the experience of interest, she can than select various topics to determine their frequency. For example, in a summer camp in which we had students building VR worlds, we went through the nodes and counted the frequency in which the mentor served as initiator (Barab, Hay, Barnett, & Squire, 1998). In this research, mixed initiative interactions (nodes where both learner and mentor would initiate questions for example) were coded with both learner(s) and mentors as the initiators; thus student-initiated nodes and mentor-initiated nodes are not mutually exclusive. We conducted this analysis by simply adding up the number of nodes that were mentor-initiated (first analysis) or that were student-initiated (second analysis). With respect to mentors, results suggested that there were less mentor-initiated nodes for Group One (107/242 or 44%) than for Group Two (160/238 or 67%). On a related note, there were more student-led nodes for Group Two (216/242 or 90%) than for Group One (140/238 or 59%). From these results, it became apparent that Group One was more successful in empowering learners and more consistent with the learner-driven, participatory framework from which the camp was developed than was Group Two.

In this same research project, we were able to use this strategy to look at group differences with respect to whether teachers or students defined tasks and goals. Through an examination of these networks, we were able to gain a very different view of the groups, with Group Two having more nodes (72 of 242) focused on task definition than did Group One (23 of 238). Frequency counts with respect to which individuals were the initiators are displayed in

Figure 6. We found it easier to represent the data as a frequency chart than as a "tracing" network. However, the data could have also been represented in the network form.

[insert Figure 6 about here]

Connecting Nodes to Form Tracers. In this section, we trace the historical development of students' interactions related to planetary tilt, showing how students operationalized planetary tilts in their virtual models of the solar system. First, a textual account of the activity is produced and then we interpret these activities as a Network of Activities Graph. Initial database searches revealed numerous nodes related to planetary tilts. However, in developing the tracing of tilt, we examined these nodes and found clusters (sets of sequential or nearly sequential nodes) in which large numbers of nodes related to tilt were present. Examining all of these nodes would take too much space, so for this section we focus on a particular cluster of nodes in which students were determining how to represent the Earth's tilt in their models. However, we could have also chosen other clusters (e.g., those related to the five-degree tilt of the Earth-Moon system).

The practice of Planetary Tilt involves students using the VR creation tools to tilt a planet on its axis. To carry out this Practice, the student needs to understand the notion of Planetary Tilt, and then incorporate this into the model. We will now turn to the data to explore how one group accomplished this task.

Participant	**Description**	**Node**
José	*[José is texturing his Mercury.]*	1
Peter & Terence	*[Peter and Terence appear confused with respect to whether the Sun has a tilt and asks Cindi, the instructor. She directs them to a resource and assigns them the task of creating a table of all planetary tilts.]*	2
Peter	*[Peter takes on the challenge and generates the table.]*	3
Terence	*[Terence goes back and attempts to use the numeric tools to try to tilt the Sun.]*	4
Cindi	*[Cindi calls the group together and leads a group discussion on what tilt means.]*	5
Peter	*[Peter uses table to describe tilt in the discussion]*	6
José	*[José uses a paper model to describe what it means to tilt. Here, tilt is*	7

	becoming transformed from an abstract number into an enacted conceptual tool they are using to create a model of the Solar System]	
Cindi	*[Cindi summarizes their discussion, however there are lingering doubts about the direction of the tilt ("clockwise or counterclockwise?").]*	8
Terence & José	*[Terence and José go to their astronomy book resources to understand "which direction you tilt the planet?"]*	9
Terence & José	*[After reassuring themselves that they know which direction to tilt the planet, they turn to CosmoWorlds, and the PPT.]*	10
Terence & José	*[As they start to attempt to tilt Earth, they notice that the rotation option is not available. They have to select the movement option of Relative/Local, because Absolute/World rotation does not make sense since a rotation has to rotate about something, not everything.]*	11
Peter	*[Peter works on rotating the spheres.]*	12
Peter	*[Peter reports back to the other students that the Earth should be rotated 23 degrees about the Z-axis.]*	13
Willie	*[Willie, the technology mentor, confirms Peter's statement and launches into a just-in-time lecture about 3D space.]*	14
Peter	*[Peter develops the Practice quickly and tilts his planets.]*	15
Terence & José	*[Terence and José struggle as they work together to tilt their planets.]*	16
Peter	*[Peter explains, demonstrates, and guides Terence through planet rotation, placing the correct axis, and the issue of relative vs. absolute.]*	17
Cindi	*[Later, Cindi formalizes the reference point as the plane of the ecliptic, the plane of the solar system that is formed by the Earth's orbit around the Sun.]*	18

What can we learn from this interaction through the CNA methodology? On the top level, we can see some general trends that we would follow over the life of the project. These trends include:

1. The mentors' interactions with the students were mentor-led whole-group nodes. There was only one student-initiated smaller group node that included a mentor (Node # 2).

2. Peter worked alone more often (Nodes #3, 12, & 15) and Terence and José tended to work together more often (Nodes # 9, 10, 11, & 16).
3. Of the 18 Activity Nodes, 5 nodes involved isolated individuals and 13 nodes involved two or more actors.

As we push deeper into the data and its visualization we can see that Node #15 is the key operational node (that is the node when Peter accomplished the goal of tilting the Earth correctly) and Node #18 is the key node conceptually where the mentor formalizes the plane they were working with as the "plane of the ecliptic." Through an examination of the historical context of these two key nodes, the power of CNA can be illustrated. We will do this by first generating the Network of Activities Graph for this particular section (see Figure 7).

[insert Figure 7 about here]

Examining the nodes that constitute the Network of Activity shows how the general goal of tilting a planet evolves through the use of resources and transforms the trivial number of 23 into a VR model of the Earth tilted at 23 degrees, then to a general understanding of planetary tilt and the plane of the ecliptic. First, we see how resources evolve and are shared across people and culminate in the operationally-key Node # 17 with all the learners and the conceptually key Node #18 with all the learners and mentors.

Next these nodes can be explored to determine how the building of VR models transformed the number 23 into a robust scientific concept. In Node # 3, Peter collects and reorganizes the textbook information on planetary tilt into a table and then later presents the table as a group resource in Node #6. At this point, Peter has not created meaning for these numbers; rather, they serve as the foundation out of which future meanings and practices can emerge. It is interesting to note that in traditional courses, this would be a point of completion, an answer to an end of the chapter question or quiz question. In the group setting (Node # 7), José takes the first step to embody meaning to the numbers by using a paper model of a planetary tilt, however, he is limited because of the medium. As Terence and José turn to the computational model, they are challenged by the question of direction of the tilt. The computer modeling environment has forced them to confront the emerging and still fragile understanding of planetary tilt. In Node # 9, they use the textbook as a resource to resolve the issue of direction. The model and the software resource push them further as they must use the language resources of the software (Relative/Local and Absolute/World) to deepen their understanding of tilt. They accomplished this by first equating tilting with rotating and then confronting the question of "Rotating about what?" Peter, working by himself in Node # 12, figures out the details, and in Node # 13, reports on the newly-developed Practice of correctly rotating a planet 23 degrees. In Node # 15, Peter develops both confidence and proficiency with the Practice and in Node # 17 the practice is finally appropriated by the entire group. This solidifies the practice of planetary tilts and forms the foundation of Node # 18 for which the main concepts of planetary tilt are formalized by the mentor.

Where formal lecture-based courses typically stop is at the individual-centered activities demonstrated in Node # 6. The power of the CNA methodology is that it captures and represents the situated/distributed cognitions, showing how cognition is contextually-embedded and distributed across concrete experiences. This approach allows us to move beyond capturing ready-made knowledge (i.e., students parroting back that the Earth has a 23° tilt) to capturing the situated dynamics that constitute knowing-in-the-making (i.e., students actualizing this model as part of their VR models).

TRUSTWORTHINESS, USEFULLNESS, 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. After we ironed out many of the details, jointly, on a number of videotapes, individuals 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 labels selected within 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 (1998). In this instance, two researchers collaboratively coded 10 hours 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 (see Figure 6 for an example of group differences in task definition).

Is the Coding Scheme Useful?

In terms of use, our goal was to develop a methodological approach that would capture the emergence and historical development of learning in situ. More specifically, we sought a method for tracking the emergence, evolution, and diffusion of practices, concepts, and resources 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 CNA methodology to be useful. It has helped us understand the learning process that occurs in open-ended learning environments when conceived from the situativity perspective (Barab, Hay, Barnett, & Squire, 1998). 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. In addition, we have been able to trace the evolution of various practices and understandings and to see how environmental particulars (e.g., the development of VR worlds, discourse among individuals) contributed and were bound up within this evolution. On a related note, this has been central to our design experiments surrounding our VSS course, inn which we introduce interventions and use the CNA methodology to examine the role these interventions play in the learning process (Barab, Hay, & Barnett, 1999).

In What Situations is the Coding Scheme Useful?

In the previous section we alluded to the usefulness of the CNA methodology for capturing learning within open-ended environments. Specifically, we examined its utility for tracking the emergence and historical development of knowledge 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. Further, 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 re(negotiation) of practices and understandings. We have been using the CNA 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. This methodology will 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 concepts, practices, and resources.

What are the Limitations?

With respect to the limitations of the CNA methodology, we have already alluded to the need for rich learning contexts in which there is ample opportunity for the historical development of knowledge, 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. Therefore, this approach is appropriate for researchers but has little application, at this stage, to the classroom teacher.

Other limitations include the time-consuming process of training coders, the qualitative nature of determining the boundaries of a particular node, and 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), they found it tenable to hypothesize that most of the meaningful interactions related to the particular tracers of interest happened under the lens of our video cameras. However, 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 ANT more generally. For example, Kaptelinin (1996, p. 46) stated, "the relations between agents and tools cannot be symmetrical," whereas the power of ANT is that is does treat these as symmetrical, serving a useful role in the CNA methodology. Engeström & Escalante (1996, p. 344) had other criticisms of ANT: "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." He 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).

In response to these criticisms, it is important to reaffirm that 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 among human and non-human actors. In this manner, 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, & Keating (1999) used the CNA methodology to identify the frequency of occurrences related to a particular tracer, and then used Activity Theory (Engeström, 1987) to contextualize these in their larger context (activity system).

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. Because 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 understandings 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 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 developing our methodology, we used the structural framework of ANT for the development of our analytical approach. We found this approach appropriate because it allows researchers to position actors (human or non-human) within the larger context in which they function, acknowledging their mediating roles in forming context as well as other actors, networks, and outcomes of these interactions. We found such an approach particularly relevant to our interest in capturing cognitions conceived of as situated through the relations among task, individual, and setting—especially non-human objects (e.g., computers). However, given some of the criticisms of ANT more generally, we did not find it particularly useful as a theoretical grounding for conceiving the relationships among human and non-human actors.

In advancing our CNA methodology, we have adhered to the five standards put forth by Schoenfeld (1992). We began with a description of the theoretical context, 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, in comparing frequency of behaviors among two or more groups. More importantly, 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 a particular practice (tilting a planet model on its axis). We then offered methodological discussion of the trustworthiness, usefulness, scope of application, and limitations of the method.

IMPLICATIONS

Although researchers have typically relied on think alouds, protocol analysis, and stimulated recall to understand cognition, the CNA methodology being proposed here has a unique opportunity to capture cognitive activity on the fly. The ability to capture knowing-in-the-making is becoming increasingly valuable as we see the design and implementation of 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 provided evidence for the trustworthiness and usefulness of our CNA methodology. Future research must continue to examine the applicability of this approach for multiple contexts. More importantly, we need to continue to explore what types of information this method, as opposed to other techniques, provides, and why this information is useful.

We are at a time of paradigmatic shifts in ontology and epistemology and researchers need to continue to look for novel techniques that are able to capture cognition conceived as situated. As we continue to do research that becomes less exploratory and more confirmatory, the descriptions of context, knowing, and the relations among the two will become more refined. 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 in 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 manuscript stimulates discussion and prompts researchers to explore innovative methods for capturing the emergence, evolution, and diffusion of knowing, allowing us to better understand cognition and to improve environments intentionally designed to support learning.

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Footnotes

[1] In fact, in our usage, we are simply using ANT as a structural framework for the development of our analytical approach and not the theoretical framework for conceiving the relationship among human and nonhuman actors.

[2] These distinctions will become more apparent below, when we apply the CNA methodology to examples from our own research.

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

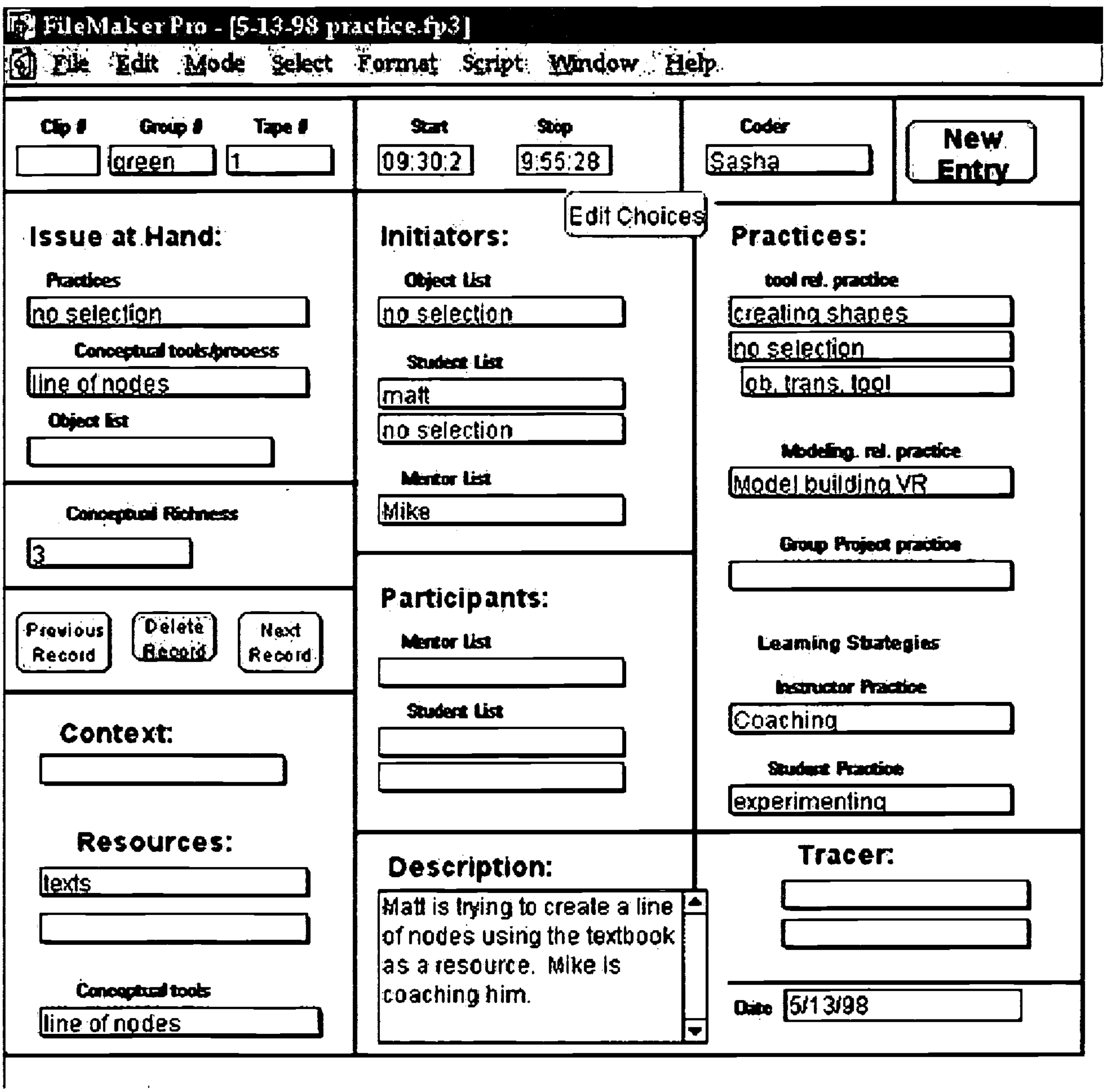


Figure 2. Time duration of Activity Nodes for each initiator. Each time interval on the Y-axis represents one minute, and bars represent time duration of each Activity Node.

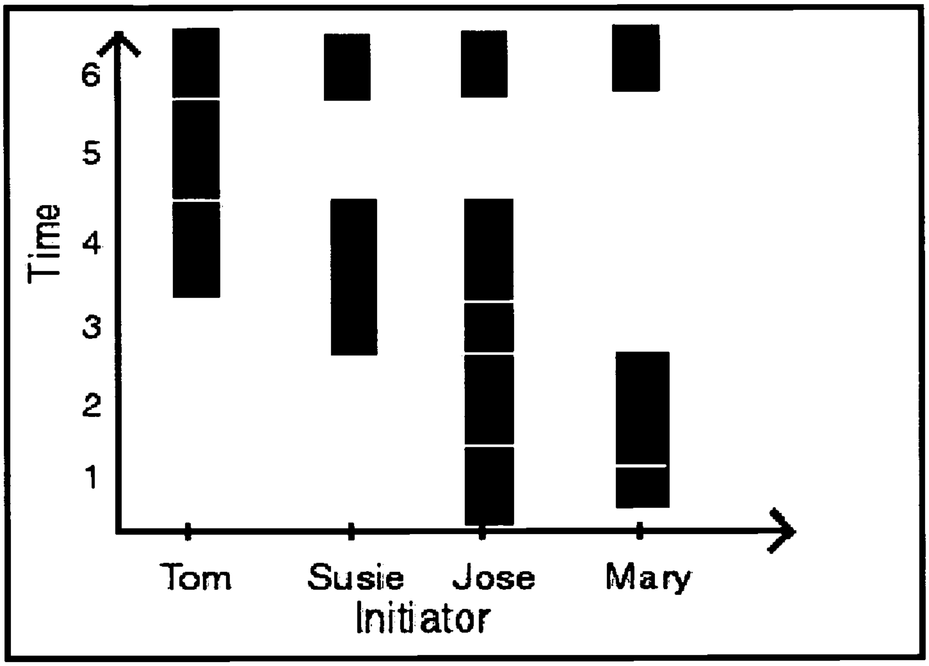


Figure 3. Activity Nodes for each initiator. For this diagram the bars have been abstracted into circles that represent relative position in time.

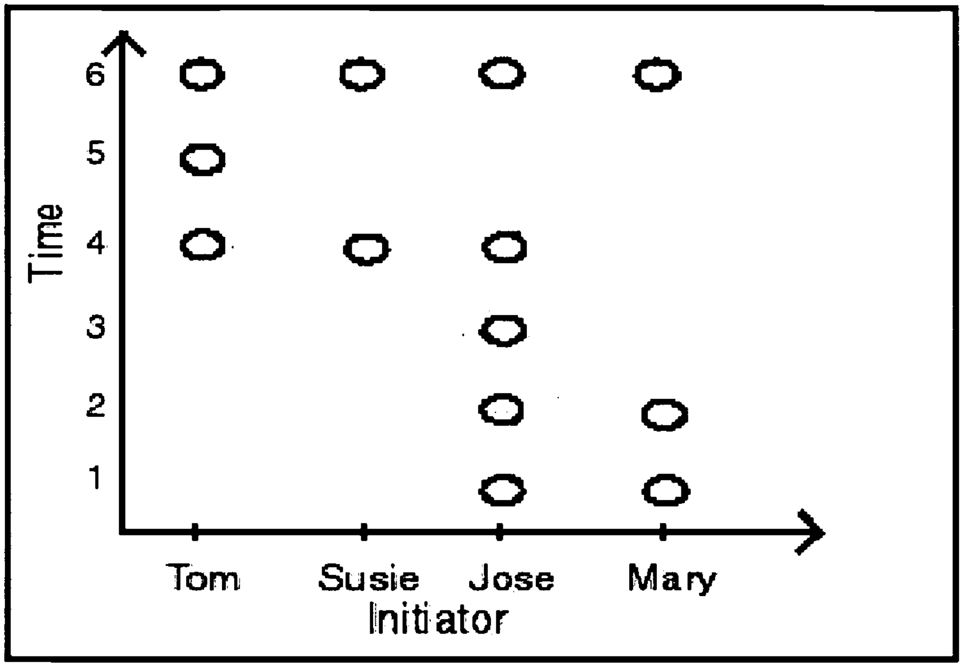


Figure 4. Activity Nodes for each initiator (represented by ovals) with lines corresponding to the movement of each individual. For example, we can see that Tom acts as a participant for nodes 1-3 where Jose is the initiator. At times 4-6, Jose then serves as the primary initiator for each of the nodes he is involved. Examination of this figure reveals which individuals took the most active role in initiating the interactions and what collaboration occurred in the nodes.

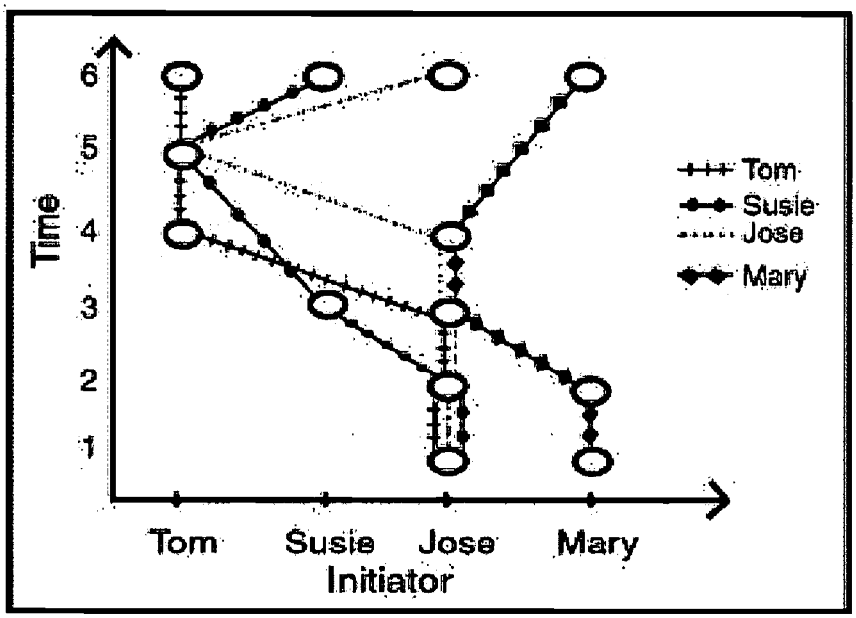


Figure 5. Activity Nodes for each initiator with lines representing the movement of each individual. In addition dark nodes represent those nodes in which a particular practice is being carried out, referred to here as "The Practice." Examination of this network indicates that "The Practice" began with Mary who then collaborated with Jose and Tom at time three. At time four Mary and Jose then collaborated on "The Practice." At time five Jose then collaborated on "The Practice" with Tom and Susie. Susie continued to carry out "The Practice" at time six, while the other three students carried out other practices.

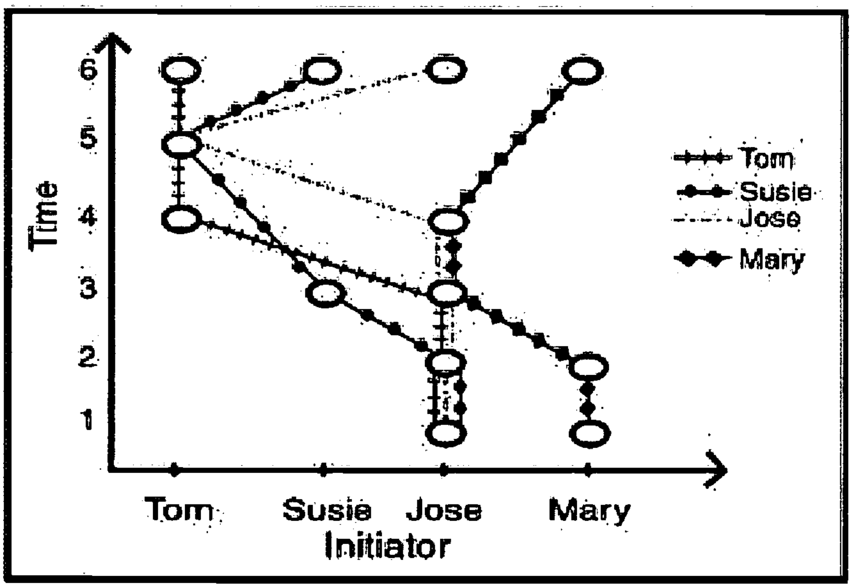
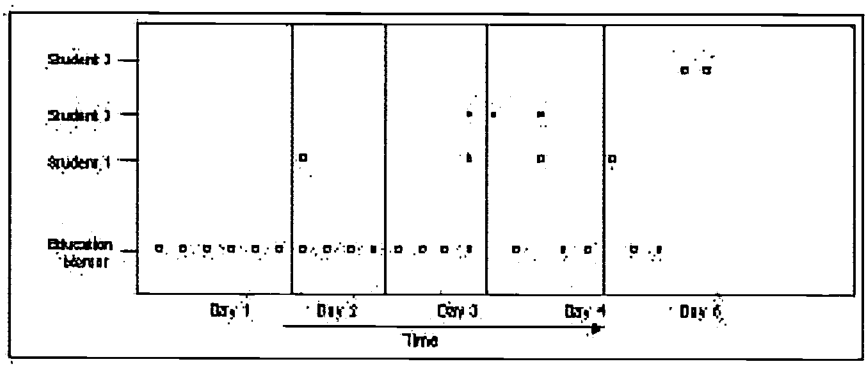


Figure 6. Network Representing the Diffusion of Task/Goal Definition for Students in the Solar and the Theater Groups. Each Box Represents a Node in which Task/Goal Definition was coded as a Practice. The row Associated with Each Box Indicates that Student or Mentor was an Initiator, with a Node Potentially Having Multiple Initiators. Vertical alignment indicates that initiators were collaborating.

a. Group 1



b. Group 2

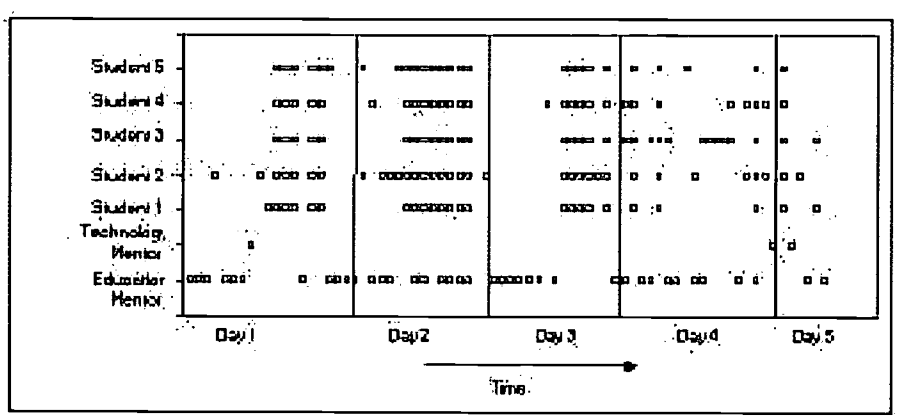


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Figure 7. Activity Nodes for each initiator with lines representing the movement of each individual.

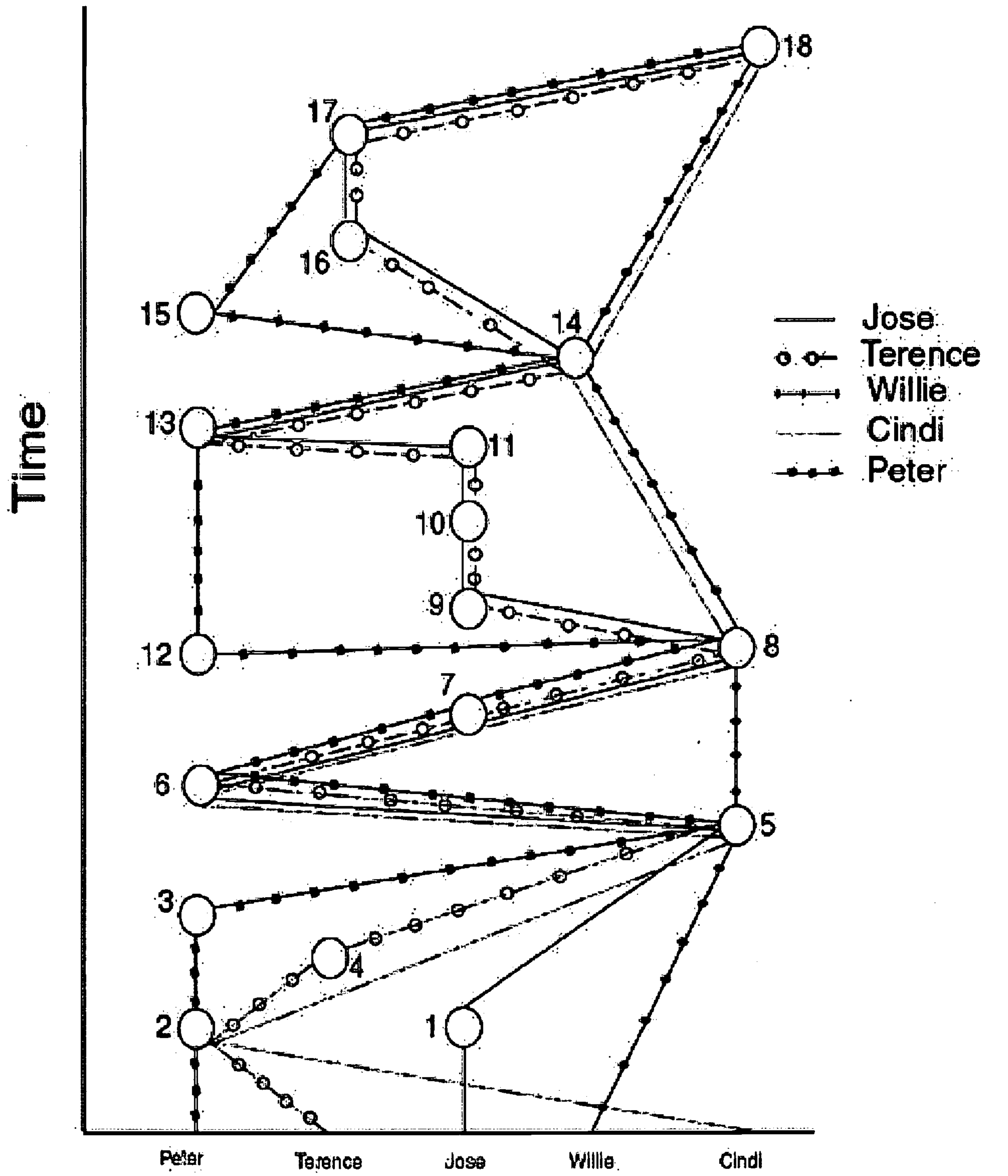

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Table 1. Summary Labels for the Various Features that Constitute a Node.

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/process.
Initiator	an individual, technology, belief, raw material, object, 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 we believe overly presumptuous to define the numerous aspects of cultural influence that interact with the issue at hand. Therefore, we have not included these non-observable (yet potentially important factors) in our coding scheme and must acknowledge this as a limitation.
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). 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), or learning related (i.e., using an inquiry strategy) and always involve the use of a resource.

Table 2. Classification of Nodes, Categories, Sub-Categories, and Types for Example 1.

Node	Issue at hand	Initiator	Participant	Practices	Resource	C. Rich.
1	Object: Earth, Moon, Sun Model	Student: Marvin		Tool-Related: View Pt. Setting Modeling: Model Building VR		6
2	Concept: lunar eclipse Practice: model building VR	Student: Marvin	Student: Keith	Student: Group Discussion	St. Props (hands) Computer Model	6
3	Object: v-pts Concept: lunar eclipse	Student: Marvin		Modeling: Model Evaluation	Computer model	6
4	Practice: setting v-pts.	Student: Marvin	Student: Roger Mentor: Igor	Instr Practice: questioning Student Practice: question teacher	Computer model	2
5	Practice: setting v-pts	Student: Roger	Student: Marvin Mentor: Igor	Instr Practice: questioning Student Practice: retelling	Computer model	2
6	Practice: setting v-pts.	Student: Marvin Mentor: Igor	Student: Roger	Modeling Practices: debugging Instr Practice: coaching	Computer model	2
7	Practice: setting v-pts.	Mentor: Igor	Student: Roger Marvin	Instr Practice: Just-in-time lecture		2
8	Object: Earth, Moon, Sun Model	Student: Marvin		Tool-related Practice: Setting viewpoints	Computer model	4

Appendix A

Scenario II (Line of Nodes): In this scenario, one student (Erin) has developed a Earth, Moon, Sun model that includes a visualization of the line of nodes. We will pick up the interaction as a student from another group (Marvin) comes over to Erin's group for help.

Participant	Description	Node
Marvin	There is a rumor that you're working on the line of nodes in your model. I'm not sure what it is	1
Erin	It's where the plane of the ecliptic between the sun and earth, and the plane of the earth and the moon intersects... [*Marvin nods*]	
Erin	[*pointing to the screen, Erin continues*] The way I made mine, I made a long cylinder and made it a very long line.	
Marvin	Wow, that thing is a cylinder!	
Erin	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.	2
Marvin	That's a good idea. So what you are trying to demonstrate here is when the line of nodes come together ... That's when the eclipse happens.... That's good...Wow!	
Erin	Yeah this is going to be neat when it works. When I did it last time I grouped it wrong so be careful.	
Marvin	Thanks!	
Erin	[*She colors the line of nodes in her model chose a shade of green that would be visually eye catching*]	3

Later the scenario continues when Erin presents her model to explain the difference between a solar eclipse and a lunar eclipse.

Participant	Description	Node
Erin	You can only have total eclipses when the moon is on the line of nodes. 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	4

Node	Issue at hand	Initiator	Participant	Practices	Resource	Con. Rich.
1	Concept: line of nodes	Student: Marvin	Student: Erin	Student Practice: Questioning student	Resource: model	8
2	Concept: eclipse Practice: grouping	Student: Erin	Student: Marvin	Student Practice: Retelling	Resource: Prior Experience	4
3	Concept: line of nodes	Student: Erin	:	Tool-related Practices: Coloring		2
4	Concept: Total Eclipse (lunar and solar) Object: Project # 2	Student: Erin	Student: all students Mentor: Igor	Student Practice: Telling	Resource: Computer Model Line of Nodes	8

Appendix B

Scenario III (The Black Boxing of Logarithms): Keith realizes that scaling is going to become an important issue in his solar system model. He shares his thought with Marvin.

Participant	Description	Node
Keith	We have to think about scale	1
Marvin	I have no idea to what the actual scale is....(is it) like what sizes are relative to each other?	
Keith	If this is Earth [*finds a dead ladybug on the desk and brings it into Marvin's attention*] the sun is...the sun is uh... 200ft away [*has his arms wide open*]	
Marvin	200ft away?	
Keith	That's the scale, we can't demonstrate it on the monitor, so we have to rotate on an orbit, it's too small [*pointing to the bug*].	
Marvin	I will let you handle that.	
Keith (narrative)	[*Based on a question by the researcher, Keith states that he has decided to use natural logarithms to scale his model of the solar system so you can see all objects at the correct sizes and distances on one screen*]	2
Keith (narrative)	[*Keith takes out his calculator, looks up planet sizes and distances for his book, punches numbers into his calculator, and creates a logarithm table of planet sizes and distances*]	3
Keith (narrative)	[*Keith then uses the logarithm table to create objects on the computer*]	4
Marvin (narrative)	[*Marvin takes logarithm table the proceeds to use the numbers to size and position the planets*]	5
Keith	We have to think about scale.	6
Keith	Why are you putting in those numbers? [*points to the computer screen*]	
Marvin	Because I am setting up the scale of my solar system.	
Keith	Yeah, but why do those numbers work so well?	
Marvin	I don't know. You used some logarithm thing that will make size and distance all on the same scale.	
Keith	Logarithms are special numbers that ... [*Marvin cuts him off*]	
Marvin	I don't understand it ... but you did it (he turns back to the computer).	
Marvin (narrative)	[*Marvin continues to use the numbers taken from the table, and makes spheres of the correct distance and sizes*]	7

Node	Issue at hand	Initiator	Participant	Practices	Resource	Con. Rich.
1	Concept: Scaling	Student: Keith	Student: Marvin	Student Practice: on-task checking in	Resource: Current experience	3
2	Objects: Scaling	Student: Keith		Student Practices: Planning		3
3	Practices: calculating Objects: logarithmic table	Student: Keith		Tool-related Practices: calculating Student Practices: creating inscriptions	Resource: calculator logarithms	2
4	Objects: Project # 2	Student: Keith		Tool-related Practices: creating objects	Resource: Student developed log table	2
5	Object: Project 1	Student: Marvin		Tool-Related Practices: Sizing shapes Modeling Practices: Model Building VR	Resource: Student developed logarithmic table	2
6	Concept: Logarithms	Student: Keith	Student: Marvin	Student Practice: Socratic questioning	Resource: Computer model	5
7	Object: Project 1	Student: Marvin		Tool-Related Practices: Sizing shapes Modeling Practices: Model Building VR	Resource: Student developed logarithmic table	2

Appendix C

Scenario IV (Evaluating the Project): The next scenario picks up towards the end of the first project of the course, the creation of a Celestial Sphere. We begin with Ralph and Mary:

Participant	Description	Node
Ralph & Mary (narrative)	[*They are looking at the Celestial Sphere that they have constructed on the screen* (the Equator, the Tropic of Capricorn, the Tropic of Cancer, and the earth's axis to line up). *They look at it from multiple angles to check it for accuracy.*]	1
Mary	Maybe we should go back and check to see if we have all the features that are supposed to be in the model. [*picking up the assignment sheet*]. Let's see, the equator…got that…the Tropics…got those…	2
Ralph (narrative)	[*Ralph, listening to Mary, moves to his computer and opens Netscape. He goes to the course web site and looks for the project link, and begins looking at the resources available for this project.*]	3
Ralph Mary	Ho Ho! Here's what he has on the web. A bunch of labels. An earth with the tropic of Cancer and the Tropic of Capricorn on it. Oh yeah? That's probably what I want. You mean that it's one of those, it shows you how to do it?…	4
Ralph	Yeah, it's on the web. Textures… labels, all stuff for our model.	
Ralph Igor Mary Igor	[*to Igor*] What would we do with these? Those could be textures for the sun. And so, the sun at certain points, creates these wonderful little points that we want you guys to be able to demonstrate with your model. And so maybe you put the sun here, [*pointing to where the label would go on their model*] and you can put a texture on it, so that way, if somebody comes to the web site, which they will do, because this is such a cool class, and that way you can know what's happening, because the sun will have vernal equinox on it. Because what will? I'm sorry If you put the sun here on the vernal equinox and you wrap the texture around it, just like you've done with the Earth, that way the sun will say, oh that's the vernal equinox, that way someone can easily describe what's going on with your	5

	model to someone who doesn't have a clue.	
Mary	Cool. So that you'd be getting that just by using that texture, then that has just about everything we need	6
Igor	Or, you could also do a labeled text. You could take a little arrow and draw a point that go that's the vernal equinox. There's tons of ways to demonstrate it.	
Mary	Sweet...Will we be looking at these projects in the CAVE?	7
Igor	Yes, we may not view the Celestial Sphere because some of the stuff we're doing here isn't really implemented in the CAVE yet. You can't read text in the CAVE, and, uh, transparencies don't work in the CAVE, but in the next project, the Earth moon, sun system, everything we'll be doing there will be viewable in the CAVE. You can go you can stand at the moon, and look at the sun. And so on...	
Mary	You know what I was thinking of doing...it will probably be a waste then because it will be much more simpler there. I'm trying to do a make a cylinder to do the 23.5 degree slant. I was going to use the angle...Will that be too complicated.	8
Igor	Oh no...that's a good idea. But there's a slightly easier way to do it.	
Mary	I need to line this up though, let's see. How did I do that...[*Mary turns to the computer, and calls up the part of the project she was working on.*]	9

Node	Issue at hand	Initiator	Participant	Practices	Resource	Con. Rich.
1	Object: Project 1 model	Student: Mary	Student: Ralph	Model Building Practice: Model testing Group Practices: Project evaluation	Resource: Computer model	3
2	Object: Project 1 model	Student: Mary	Student: Ralph	Group Practices: Project evaluation	Resource: Instructor handout, Computer model	3

3	Object: Project 1 requirements	Student: Ralph		Group Practices: Defining Tasks	Resource: Course web site	2
4	Object: WWW Syllabus	Student: Ralph	Student: Mary	Model Building Practice: Information Resource Gathering	Resource: Course web site	2
5	Object: WWW Syllabus	Student: Ralph	Student: Mary Mentor: Igor	Model Building Practice: Information Resource Gathering Group Practices: Information Resource Sharing Learning Practice: Question Teacher	Resource: Course web site	2
6	Object: WWW Syllabus Practice: labeling	Mentor: Igor	Student: Ralph Student: Mary	Instructional Practice: Just in Time Telling	Resource: Course web site	2
7	Object: CAVE	Student: Mary	Student: Ralph Mentor: Igor	Model Building Practice Planning Learning Practices: Questioning Teacher		2
8	Object: Earth's Axis	Student: Mary	Mentor: Igor	Model Building Practice: Planning Instructional Practices: Just in time		2
9	Object: Celestial Sphere	Student: Mary		Model Related Practice: Planning		4

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