Activity Centered Design: Towards a Theoretical Framework for CSCL

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Abstract: Computers have not yet had the profound impact on classroom practice that has been predicted. Given the proven potential of computer-mediated instruction, what can account for the lack of progress? This paper explores the theoretical underpinnings of many of the existing computer-mediated learning environments and suggests that the learning theories that lie behind them lead to designs that do not fit with nor change the basic participation structures of the classroom. We argue instead for Activity Centered Design (ACD), a model of design for Computer Supported Collaborative Learning environments, based on the following assumptions: that activity is mediated by cultural tools, that activity must be conceptualized on a number of interdependent levels, and that conceptual understanding is first established socially. We then critique our own existing learning environment, the Probability Inquiry Environment, from the ACD perspective.

Keywords: activity theory, design framework, discourse analysis

Introduction

In the last decade, the field of education has invested an enormous amount of energy and resources to the design of computer-mediated learning environments. The findings from this body of work are both consistent and encouraging. According to both individual researchers' articles and the many meta-analyses regarding the pedagogical effectiveness of computer-based instructional materials, computer-mediated learning environments have increased both student learning and interest (e.g. Berson, 1996; Kulik, 1994; Weller, 1996). However, despite the optimistic rhetoric that computers would change the nature of the teaching and learning enterprise, the daily activities of the average classroom have not changed much. The whole-class, lock step, lecture presentation still dominates the pedagogical landscape of most schools.

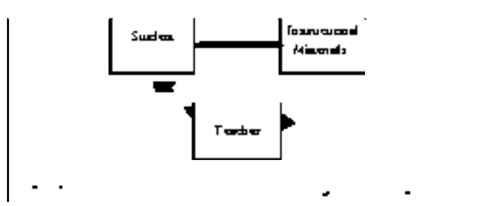
Given the proven potential of computer-mediated learning and the well documented faults of the lecture, what can account for the lack of progress? This paper examines the two dominant genres of computer-mediated instruction and suggests that the learning theories behind much of this software leads to designs that do not fit with nor change the basic participation structures of the classroom. We argue that the goals of Computer Supported Collaborative Learning (CSCL) fundamentally conflict with the underlying cognitive theories of both these styles of design. We then suggest an alternative, Activity Centered Design (ACD). ACD, building upon the insights of distributed cognition (Hutchins, 1995; Pea, 1993) and Activity Theory (Leont'ev; 1979; Wertsch 1979), views learning as a complex process in which an individual's cognition is defined by its relation to the material setting and the forms of social participation encouraged by these settings. Accordingly, ACD emphasizes the design of computer-mediated environments to support and structure the interactions and interdependencies of an activity system, including the interrelations between students, their instructors, the tasks they undertake, and the inscriptions they use. Finally, we critique The Probability Inquiry Environment (PIE), (Vahey, Enyedy & Gifford; 1999) from the perspective of Activity Centered Design.

Domain Centered Design

The most common design for educational technology, especially in the latter half of the 1980’s, has been to "bolt-on" technology to the conventional classroom practices (Giffrod, 1996). The fundamental theoretical assumption of this approach is the transmission model of knowledge transfer. The transmission model suggests that knowledge is an identifiable object that is possessed by a person, detached from any social context, that can be conveyed from the mind of the instructor to the mind of the students. The focus of pedagogy from this perspective is to make the transmission of knowledge more efficient.

The conventional classroom–with its lock-step lectures and textbooks that present the student with facts, theories and explanations–is a natural extension of this theoretical assumption. Educational technology designed from this perspective is best exemplified by Computer Aided Instruction (CAI). CAI aims to make knowledge transfer more efficient primarily by ordering the sequence of information and by elaborating on its presentation. Because of this focus on the structure of the disciplinary domain we call this approach to instruction, *Domain Centered Design* (DCD). It could have also been called Teacher Centered Design, because in most cases it is assumed that the teacher (whether human or a computer surrogate) is the sole possessor of the disciplinary knowledge that must be transferred to the students. Consistent with this perspective, almost all the classroom activities revolve around the teacher or computer as the provider and evaluator of information.

Figure 1 shows the flow of information in a Domain Centered classroom. The teacher is placed at the center of Figure 1 to demonstrate her central role in this type of classroom. The teacher often holds the floor for up to 80% of the class time, leaving little time for a student to initiate and complete a two-way instructional exchange. Technology can be bolted on to each of aspect of the teaching and learning system of Figure 1 (e.g. enhancing teacher lectures with multimedia presentation tools). However, doing so does not alter the basic character of this instructional system.



Domain Centered Design and the transmission model of instruction have been routinely criticized over the years for rewarding imitation and memorization while limiting sense-making and meaningful dialogue. Even the most generous interpretation of DCD– that DCD entails thinking critically about conventional understandings of a domain, and designing tools and representations that help to make the domain accessible in a completely different way than it was before– is still open to the criticism that it ignores the social context of learning and assumes learning is primarily an individual activity (Lave, 1996). This epistemological assumption is the antithesis to collaborative learning. Bolting-on technology to a flawed pedagogical system obviously fails to address these serious criticisms. As a result, the DCD approach to instructional technology has provided only modest learning gains. More importantly, based on the results of the last decade Domain Centered environments seem destined to have only marginal impact on the daily activities of the classroom.

Learner Centered Design

As cognitive science and the learning sciences have matured, however, so has the approach to the design of computer-mediated educational environments. Learner Centered Design (LCD), emerging from the context of User Centered Design of the Human-Computer Interaction community, proposes to design learning technology by focusing in on the cognitive capabilities and needs of the learner. Using this model, LCD has produced a number of innovative computer-mediated tools, visualizations and micro-worlds aimed at helping students learn a specific domain (e.g. Anderson, 1993; White, 1993).

Most of these learning environments are founded on the information processing model of cognition which assumes human intelligence is the result of our ability to operate on and transform the mental representations of a physical symbol system. Instruction is portrayed largely in terms of the processing of large chunks of coded, unambiguous information in the minds of learners. In the field of education, the information processing model has led to many studies that focus on the cognitive capabilities, misconceptions, mental models and learning needs of individual students. This is generally accepted as an improvement over Domain Centered Design because it includes the student as an active participant in his or her own learning. Because of this focus on isolated individuals and the decontextualized minds of learners we call this approach to instructional design Learner Centered Design.

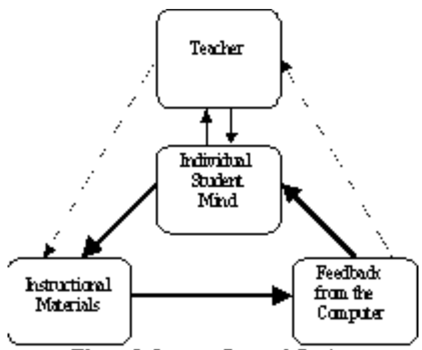


Figure 2: Learner Centered Design

The Learner Centered Design model is depicted in Figure 2. The learner–her goals, misconceptions and cognitive capacities–is placed at the center of the model. Notice that the majority of the elements of the model are the same as in DCD. What has changed is their arrangement. The student is at the center because Learner Centered environments are deliberately organized to increase student control over the sequencing and pace of the materials. As the student progresses through the materials she is presented with feedback based on her actions with the software. Finally, while the teacher is part of the system, the role of the teacher is often minimal. The new role of the teacher in LCD is often described as the, "guide on the side." However, in most cases the types of support provided for this new role are; non-existent, unrealistic (e.g. giving the teacher the technical ability to monitor 30 students' investigations simultaneously), or in direct contradiction to the spirit of LCD (e.g. giving the teacher the ability to control the learner's screen). In most cases, however, the teacher's most effective and direct role is as the facilitator of a classroom discussion after the students' local investigations. However, these discussions are usually not supported technologically, nor are they well integrated with the local activity. The result is a completely fragmented experience for the students, where the learner centered investigations are disconnected with the teacher centered discussions.

Notice also that the student is isolated at the center of the diagram. Collaboration and interaction with peers is not central, nor even necessary, from this perspective. One of the major criticisms of both Learner Centered Design environments and the information processing model of cognition itself, is that they foster a view of learning as a highly individualistic, autonomous, non-social activity (Lave, 1996). The LCD perspective has led researchers to design hermetically sealed learning environments which severely limit the range of social interactions with both one's teacher and one's peers. Developing learning environments based on the LCD model is shortsighted on several accounts. First, it often goes to far in reducing the role that the teacher plays, denying the student access the accumulated wisdom, experiences, and empathy of expert teachers. Second, like Domain Centered Design, it ignores the social context of learning and the important role of conversation and collaboration as part of the active learning process. Third, the environments are focused on individual student misconceptions, which need to be changed to the normative conceptual understanding. While both naive and normative concepts are important to consider in the design process, they are situated in domains of practice–the embodied and contextualized knowledge of how to participate in concrete socially defined activities. LCD's failure to recognize the irreducible, reflexive relationship between conceptual understanding and the activities in which they arise has led to compartmentalized learning activities that do not attempt to build off one another or connect with students' lived experiences.

The Need for an Alternative Framework for CSCL

While the recent work of the CSCL community avoids the narrow focus on the individual, much of the CSCL research is still attempting to build on the ideas and assumptions of Learner Centered Design. Instead of individuals however, at the center of the model are collaborative groups of students. While this is certainly an improvement, it repeats the errors of the bolt-on model of instructional design. In effect, it bolts-on collaboration to an individualistic and narrowly conceived view of intelligence without altering the basic activity structures or assumptions of the Learner Centered model of design.

Activity Centered Design

We propose Activity Theory (AT) as a starting place for a new theoretical framework for CSCL. The basic concept behind a theory of socially-situated and artifact-mediated human activity can be traced back to Lev Vygotsky (1978) and his colleagues A. R. Luria (1976) and A. N. Leont'ev (1979). At the core of AT is the idea that internal activities emerge out of practical external activity and therefore the unit of analysis must include the individual and his/her culturally defined environment (Wertsch, 1979). AT has already made significant contributions to the field of Computer Supported Collaborative Work (e.g. Nardi, 1996; Bodker, 1997) but has yet to make a significant impact on the design of learning environments (for a significant exception see Cole, 1996).

In developing a theoretical framework for CSCL, we propose to build on three of the central tenets of Activity Theory: a) that activity is mediated by cultural artifacts; b) that activity must be analyzed at various levels; and c) that internal activity (i.e. thinking) first occurs in the social plane (i.e. contextualized activity). Each of these insights will be outlined and their educational implications discussed.

The first insight of activity theory is the observation that culturally defined tools mediate all activity. From this perspective, mediation does not make tasks easier but fundamentally changes the nature of the task and can even lead to the creations of new types of activity (Wertsch, 1979). On this point activity theory is closely aligned with distributed cognition (Hutchins, 1995; Pea, 1993; Norman, 1991). This simple observation, that activity is mediated, has enormous implications for instructional design because it redefines the nature of learning. Instead of viewing learning as the rational abstraction of mental representations from one's experience, learning is re-conceptualized as learning to participate in a cultural practice. Learning to participate in a cultural practice means moving from partial participation in that practice–where one's participation is heavily mediated by more capable others (Vygotsky, 1978) and the physical constraints of the physical world (Hutchins, 1995)–towards full participation in the practice.

The second insight of activity theory that has implications for the design of CSCL environments is that activity can be analyzed on least three levels. At the highest level, activities are distinguished by their organizing motives or the object towards which they are oriented. Moving down in grain size, activities can also be examined in terms of their actions and the short-term goals. Finally, at the most detailed level of analysis activity can seen as consisting of specific operations and the concrete conditions in which they are carried out. For a detailed examination of the unit of analysis for Activity Theory see Leont'ev (1979).

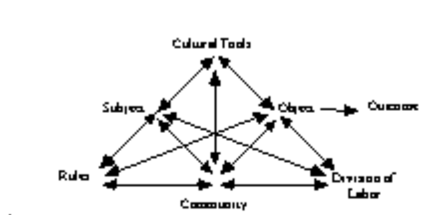
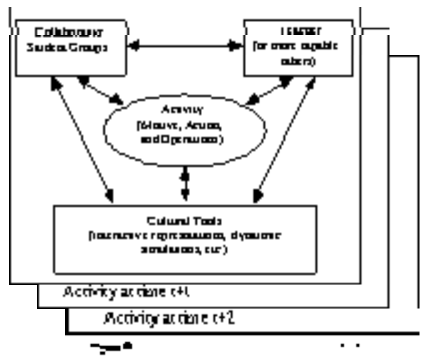


Figure 3: The structure of activity, adapted from Engestrom (1987)

These three levels of analysis contribute a rich perspective on the interplay between cognition and its material and social context. One way to visualize this more inclusive perspective on the context of cognition is the mediated-action triangle shown in Figure 3 (adapted from Engestrom, 1987). The vertex of Figure 3 shows that the "object" or function of cognition is mediated by historically and culturally constituted tools. The bottom three nodes of Figure 3 demonstrate the social nature of human activity– that individuals (subjects) are situated in communities which are mediated by rules of participation and by divisions of labor (Engestrom, 1987). One way the mediational triangle can be used to inform the design of learning environments is as a "checklist" of the connections and interdependencies that must be considered. Applying this checklist to Learner Centered Design, one quickly sees that LCD's myopic focus on the tool's relation to the learner ignores the interdependencies between activity and its context within a community (represented by the bottom 3 nodes of the triangle).

The third insight of Activity Theory is that cognition and the cultural tools that mediate it have their origins in social interaction. In particular, it stresses that the higher order psychological functions develop first interpsychologically, and then are translated into intrapsychological, mental functions (Vygotsky, 1978; Wertsch, 1979). This has two major implications for the design of learning environments. First, it recognizes the fundamental role of social interaction and conversation in learning. This makes it a particularly attractive theoretical framework for CSCL. Second, it implies that the way activity (and cognition) are organized can only be understood by examining the historical context from which the activity has arisen. This means, as designers, we must pay attention to the interaction between multiple trajectories: the sociogenesis of cultural practice; the ontogenesis of people within a practice; and the microgenesis of ways of participating within that cultural practice.



Based on the implications of Activity Theory, we propose to design and analyze CSCL environments based on the Activity Centered Design model depicted in Figure 4. Instead of placing either the teacher or the students at the center of the model, we propose that the focus should be to design activities that help learners develop the ability to carry out socially formulated, goal directed action through the use of mediating material and social structures. From this perspective both other social actors and cultural tools are seen as resources that the students coordinate during activity. The layering seen in Figure 4 is meant to demonstrate that each activity is situated on a learning trajectory, where each activity is designed to build off and relate to the other activities. An attractive aspect of the Activity Centered Model stems from what it is not. It is neither teacher-centered, like the instruction provided within conventionally organized classrooms, nor is it student-centered, like the instruction provided by intelligent tutoring systems. The instructional settings afforded by both of these models of computer-mediated instruction leave intact the questionable presumption that learning consists the transfer of intact chunks of knowledge from either the minds of teachers into the minds of their students, or from computer-mediated instructional materials into the minds of students. In the Activity Centered Model, as students move through the activities they progress from being partial participants, heavily dependent on the material mediation of tools, to full participants, able to more flexibly use the cultural tools of the normative practice.

The Probability Inquiry Environment from the Activity Centered Design Perspective

In this section we briefly critique the Probability Inquiry Environment from the perspective of Activity Centered Design, taking each of the tenets is turn. PIE is a computer-mediated inquiry environment proven to help middle school students learn elementary probability (Enyedy, Vahey & Gifford, 1997; Vahey, Enyedy & Gifford, *under review*; Vahey Enyedy & Gifford, 1999). PIE was implemented as a three week curriculum, which included computer-simulation activities, hands-on activities and whole class discussions. Each computer activity was designed to focus on a particular aspect of probability and to promote specific interactions in the classroom culture (Enyedy, Vahey & Gifford, 1998). In PIE, students actively investigate probability by trying to figure out if particular games of chance are fair to all participants. The students' collaborative activity is structured around articulating their intuitions, systematically testing their ideas by gathering and analyzing empirical data, and communicating their revised understanding of the domain to their classmates. The computer-mediated activities are then followed by hands-on activities in which students flip coins, roll dice, etc. as they investigate aspects of probability without using the computer simulations. Throughout the curriculum the students also participate in whole-class discussions, in which each pair relates their findings from the activities.

It is important to note that PIE's original conception and design was best characterized as somewhere between the Learner Centered Design and Activity Centered Design models. It was during its implementation and subsequent analysis that our own theoretical perspective evolved into the Activity Centered framework presented above. This evolution creates some apparent conflicts between PIE's design and our theoretical framework. For example, Activity Theory approaches to education are often associated with apprenticeship, whereas PIE's approach seems to assume that students learn probability by doing scientific investigations. However, as we attempt to show below, we believe the students were actually learning mathematical practices– ways of perceiving and talking about probability that were accepted by the classroom community as successful methods for justifying claims (e.g. the claim that a given game was fair).

Mediating Probabilistic Reasoning

When we examined PIE from the perspective of how it mediated probabilistic reasoning, we found that by the end of the three weeks most students justified their claims about probability by calculating the probability of a compound event (Vahey, Enyedy & Gifford, *under review*). The students' practice in most cases was structured around the probability tree as an ordered inscription of the fully enumerated sample space (i.e. all the possible outcomes). Elsewhere, we have outlined the trajectory of this particular cultural tool within the classroom (Enyedy et al., 1997) and the different social contexts in which the tool was used (Enyedy et al., 1998).

The Interdependencies of Mediation

However, there is more to an activity system and learning environment than the relationship between a tool and a method of reasoning. In our analysis of PIE, both the division of labor between students and the "rules" by which they interact effect the organization of activity and ultimately the students' learning outcomes. Both of these mediating factors will be examined in turn.

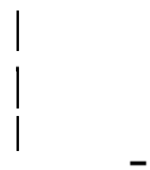


Figure 5: The interdependency of tools and the division of labor

We use Figure 5 to graphically show the reduced set of interdependencies we examine in our analysis of how the different configurations of who did what during the PIE activities effected the students' learning. In the prediction phase of the students' investigations we saw at least two distinct divisions of labor. Although the students worked in pairs, PIE was designed with only one text box to record their predictions. Dissent from their shared answer, was intended to be expressed through the use of "agreement bars." One way in which the students organized themselves to accomplish this task was to alternate who was responsible for that particular question. Alternatively, some students attempted to reach consensus on each and every question. These two ways of dividing the labor within the constraints of the mediating tool resulted in different patterns of interaction and different learning trajectories.

Under the alternating responsibility method, points of disagreement between student understanding often went undiscovered or ignored. Alternating responsibility compartmentalized their answers and eliminated the need for coherence across the questions. This presented a difficulty for a curriculum based on the ideal of students refining their ideas because of cognitive dissonance. It effectively eliminated the social accountability for their answers, and as a result students using this method did not often refine their ideas based on the input of others. On the other hand, trying to reach consensus on each question had its own strengths and weaknesses. While the process of collaboratively reaching consensus made differences between students visible to each other, it did not always lead to deep reflection about those ideas. It has been pointed out that high bandwidth systems, which immediately attempt to reach consensus, tend to settle on a solution nearest to the initial center of gravity regardless of what the evidence suggests as the "best" solution (Hutchins, 1995). In PIE this meant that the students who tried to reach consensus on their predictions, often agreed on the first explanation that seemed sensible to them without fully exploring it or its alternatives.

What is clear from this quick look at some of the ways that students answered the predictive questions of PIE is that the tool that mediated the articulation of their intuitions (i.e. a shared space for answers) was in turn mediated by the way the students divided their labor. While it is unrealistic to think that we can predict or completely determine how students will use a tool, this example shows that in designing CSCL systems it is important to consider how the larger context of the activity system will mediate the tools use and the students learning trajectory.

Figure 6: The interdependency of tools and the rules of participation

We also examined how the participation structures (i.e. rules) for student-to-student interaction mediated the way in which PIE was used and what the students learned from the activity. Figure 6 shows the set of interdependencies we examine in the analysis of two students as they answered a predictive question that asked about the probability distribution of two coin flips. This interaction is shown in Figure 7.

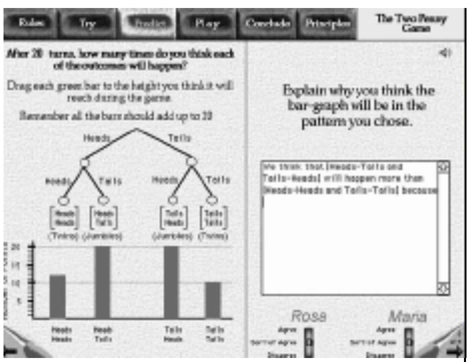


Figure 7: Rosa and Maria setting the frame for their interaction.

The first turn of this interaction shows Rosa attempting to establish a shared understanding of their current task by reading the Predictive Question into the public interactional space. Having a shared understanding of the task has enormous implications for what actually gets done and what the students eventually understand. What is interesting about this interaction is that the students do not read the entire question (In Figure 7, compare Turn 1 to the text on the top left of the computer display). The part of the question that they do not read aloud, is exactly the parameter of the task they end up ignoring. Even though the teacher in Turn 8 reminds them that they need to consider the total number of points of their prediction, the students do not make any attempt to make their prediction add up to twenty. In fact, they do not seem to be attuned to quantity at all.

Nowhere in this interaction to they mention the cardinal value of any outcome or class of outcomes. Rather, they use relative terms like "higher" and "highest" to talk about the ordinal relations of the classes of outcomes. For this interaction, then, their activity only partially corresponds to the intended activity, because they negotiated the task to include only the relative value of the histogram bars. Even so, in Turn 3 and 4 we see that the two girls collaborating to create a preliminary conjecture that is backed by a justification, that in turn incorporates one of the inscription systems of PIE. That is, even though their assertion is incorrect, its form reflects the desired participation structure of a well-formed argument.

The Sociogenetic, Ontogenetic and Microgenetic Context of PIE

Finally, examining how PIE is situated with respect to the possible socio- and ontogenetic trajectories reveals both some of the strengths and weakness of our design. At the sociogenetic level, we find that PIE takes a somewhat restricted view of the context of probability in relation to the larger domain of practice. In all of the PIE activities, the context for probabilistic reasoning was analyzing games of chance. This corresponds well to the historical roots of classical probability in which probabilistic situations, usually games, are analyzed in terms the number of favorable and non-favorable equiprobable outcomes. It does not, however, address the many real world and far less structured contexts where students might profit by leveraging probability, such as the assessment of risk, or understanding the reliability of a medical test. Our restriction of the activities to game playing is likely directly tied to the students' limited success at probabilistic reasoning in contexts outside of gaming (see Vahey et al, *under review*). At the ontogenetic level, however, we believe our choice of games was justified. Games and fairness are authentic interests of students of this age. The gaming context leveraged this interest and helped motivate the students throughout the activities. Finally, we found that students' microgenetic trajectories through PIE were fundamentally conversations anchored by the available material resources. In some cases, the inscriptions of PIE anchored these conversations in ways that helped them realize the relevance of the normative resources of probability which they previously ignored (e.g. the sample space). In other cases, the inscriptions conflicted with the students' intuitive practices and led them to totally reorganize they way conceptualized the domain (Enyedy, *in process*).

Conclusion

There is still an enormous amount of research needed to develop our understanding of how the material, social and mental worlds interpenetrate in mediated activity. Activity Theory begins to lay out some of the dimensions of this task, but it is not yet clear how to apply the insights of Activity Theory to the design (rather than merely critique) of Computer Supported Collaborative Learning Environments. Activity Centered Design is an attempt to move us toward a more appropriate theoretical framework for CSCL environments that will lead to a number of concrete design principles, but this promise is as of yet largely unrealized. What ACD has accomplished to date is to identify and provide a unifying theoretical perspective on some of the major areas where design principles for CSCL are needed. The areas addressed in this article included: how cultural tools mediate cognition, how activity systems (and thus cognition) are mediated by social interactions and different participation structures, and how activity systems are situated in larger communities and their practices.

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References

Anderson, J. R. (1993). *Rules of the mind*. Mahwah, New Jersey: Lawrence Erlbaum.

Berson, M. J. (1996). Effectiveness of computer technology in the social studies: A review of the literature. *Journal of Research on Computing in Education*, 28, 486-499.

Bodker, S. (1997). Computers in Mediated Human Activity. *Mind, Culture and Activity,* 4(3), 149-158.

Cole, M. (1996). *Cultural Psychology*. Cambridge, MA: Harvard University Press.

Engestrom, Y. (1987). *Learning by Expanding: An Activity-Theoretical Approach to Developmental Research*. Helsinki: Orienta-Konsultit.

Enyedy, N. (in process). *Material Structures, Communication and Intuitions: Resources for Learning in the Probability Inquiry Environment*. Unpublished Ph.D. Dissertation, University of California at Berkeley, Berkeley, CA.

Enyedy, N., Vahey, P. and Gifford, B. (1997). Active and Supportive Computer-Mediated Resources for Student-to-Student Conversations. In *Computer Support for Collaborative Learning '97*, R. Hall, N. Miyake, and N. Enyedy (Eds.). University of Toronto.

Enyedy, N., Vahey, P. and Gifford, B. (1998). "...It's fair because they each have two." The Development of a Mathematical Practice Across Two Social Contexts, *In the Proceedings of the International Conference of the Learning Sciences 98*, AACE, Atlanta, GA.

Gifford, B. R. (1996). Bernie Gifford on the changing educational technical landscape. *Educom Review*, *31*(4), 14-19.

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

Kulik, J. A. (1994). Meta-analytical studies of findings on computer-based instruction. In *E.* L. Baker & H. F. O'Neil, Jr. (Eds.), *Technology assessment in education and training* (pp. 9-33). Mahwah, New Jersey: Lawrence Erlbaum.

Lave, J. (1996). Teaching, as learning, in practice. *Mind, Culture and Activity*, 3(3), 149-164.

Leont'ev, A.N. (1979). The Problem of Activity in Psychology. In J. Wertsch (Ed.), *The concept of Activity in Soviet Pyschology*. Armonk, New York: M.E. Sharpe, Inc.

Luria, A.R. (1975). The Historical development of Cognitive Processes. Moscow: Nauka Publishers.

Nardi, B. (1996). *Context and Consciousness: AT and Human Computer Interaction*. Cambridge, MA: MIT Press.

Norman, D. A. (1991). Cognitive Artifacts. In J. M. Carroll (Ed.), *Designing interaction: Psychology at the human-computer interface* (pp. 17-38). New York: Cambridge University Press.

Pea, R. (1993). Practices of distributed intelligence and designs for education. In G. Salomon (Ed.) *Distributed Cogntitions: Psychological and Educational considerations,* (pp. 47-87). New York, NY: Cambridge University Press.

Pea, R. (1994). Seeing What We Build Together: Distributed Multimedia Learning Environments for Transformative Communications. *The Journal of the Learning Sciences*, 3(3), 219-225.

Vahey, P. Enyedy, N. and Gifford, B. (1999). The Probability Inquiry Environment: a collaborative, inquiry-based simulation environment. In the Proceedings of the *Thirty Second Annual Hawaii International Conference on Systems Sciences.*

Vahey, P. Enyedy, N. and Gifford, B. (*under review*). The Probability Inquiry Environment: Learning Probability Using a Collaborative, Inquiry-Based Simulation Environment. Submitted to *The Journal of Interactive Learning Environments.*

Weller, H. G. (1996). Assessing the impact of computer-based learning in science. *Journal of Research on Computing in Education*, 28, 461-485.

Wertsch, J. (1979). The concept of Activity in Soviet Psychology: An Introduction. In J. Wertsch (Ed.), *The concept of Activity in Soviet Psychology*. Armonk, New York: M.E. Sharpe, Inc.

White, B. (1993). ThinkerTools: Causal Models, Conceptual Change, and Science Education. *Cognition and Instruction* 10 (1), 1-100.

Vygotsky, L. (1978). Mind in Society: The Development of Higher Order Psychological Processes. (Eds.) M. Cole, V. John-Steiner, S. Scribner and E. Souberman. Cambridge, MA: Harvard University Press.

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