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ABSTRACT

This study explored the collaborative production of mathematical knowledge during computer-mediated learning activities. In particular, it focused on opportunities for undergraduate students from a local university to collaborate with elementary-aged at-risk children on commercially available computer games in an urban after-school club. Two types of qualitative data collection techniques were employed: participant observation notes and videotapes of participants interacting at computers. The study focuses on two participants, a fourth grader and a third-year undergraduate student. Undergraduate participation in the after-school club was found to play a significant role in organizing collaborative activities for children. While many of the strategies for collaboration used by the undergraduates did not necessarily lead to the co-production of mathematical talk or reasoning, that was not the case for explicit requests for explanations. When children had solved a problem, it was common for undergraduates to ask them what they did to accomplish the task; this resulted in the children giving explanations, although they tended to be brief and provide no evidence of deep understanding of mathematics. Results indicate that it is crucial for differences in problems to be systematically explored given that exploration of the mathematical patterns found in solution strategies provides children with opportunities to construct a deep understanding of principles underlying mathematics. (AEF)

Software Design of Computer Games
and
Collaborative Processes of Mathematical Knowledge Production

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> *...the essential stock-in-trade of the educators, can be seen as various habits of punctuating the stream of experience so that it takes on one or another sort of coherence and sense.*
> *Gregory Bateson Steps to an Ecology of Mind, p.163*

Abstract: *This study explored computer-mediated learning in an after-school club In which elementary-aged children worked with undergraduates from a local university. Collaborative participation by undergraduates was characterized as requests for explanations, information, suggestions for off-line tool use, and displays of encouragement. Computer software designed for single-users was shown to constrain collaborative talk-in-activities and the co-production of mathematical knowledge.*

This is an investigation into the collaborative production of mathematical knowledge during computer-mediated learning activities. In particular, this case study focused on opportunities for undergraduate students to collaborate with elementary-aged children on commercially available computer games in an after-school club. Young students participation in the discursive practices of collaborative learning, i.e., the use of talk, tools, and symbols, potentially transforms problematic aspects of computer games into mathematical knowledge. Moreover, social interactions during collaborative learning events involving computers stimulate mathematical knowledge construction by providing children with opportunities to pose questions, negotiate meanings, and utilize mathematical concepts in ongoing game activities. Thus, it is the routine practices used to accomplish computer games and the "affordances"[1] of this mediational tool that create resources and opportunities that both constrain and encourage children's development of mathematical knowledge (Gibson, 1979; Stone, 1996b)[2]. The research findings in this study examines mathematical problem-solving discourse involving

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1. Affordances of artifacts involves how actual properties of material objects and their functional properties link perception and action. Affordances of computers can be viewed as mediating actions by determining how problems are represented graphically (Gibson, 1979).
2. Note that *learning* and *development* in this research, following Rogoff, in press, and Stone 1996b, will be used interchangeably since their underlying processes have been shown to share similar "complexity, organization, structure, and internal dynamics" (Kuhn, 1995, p. 138).

computer games to expand our understandings of the processes of collaboration in computer-mediated learning and our understandings of the interaction between software and activities designed to be collaborative.

Theoretical Background

Sociocultural views of learning and development, the theoretical framework for this research, hold that cognition is socially constructed, socially distributed, and socially organized (Cole, 1996; Crook, 1994; Hutchins, 1996; Leont'ev, 1981; Ochs, 1988; Stone, 1994; Vygotsky, 1978). From this perspective, it is assumed that knowledge production cannot be studied independent of the social context. Further, cognitive skills are considered to be promoted through joint activity in which semiotics (tools and signs) mediate development during social interaction. To investigate collaborative learning with computers, the cultural tools examined closely in this study are computer games and discourse processes. Further, an activity theoretic[1] (AT) approach is used to explore the mutual relationship between individuals, mediational artifacts, and the object (goal) of activity (Leont'ev, 1981). AT allows the researchers to document the transformation process by which children develop understandings of mathematical concepts.

Research Questions:

1. What is the nature of collaboration during computer-mediated learning involving mathematics?
2. How does gaming software influence the collaborative production of mathematical knowledge?

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[1] Activity theory is an interdisciplinary approach used for an analysis of cognition in context (cf. Kuutti, 1996).

Methods

To document the social processes of collaborative learning mediated by computers, qualitative methodologies were used in this study. Specifically, two types of data collection techniques were employed. First, participant observation notes were collected to document routine social interactions and the persistent social and organizational characteristics of game playing practices with computers, see (Spradley, 1980). Second, video tapes of participants interacting at computers were also collected to capture critical details of the social interactional processes. Since the most direct evidence possible about situated reasoning occurs during social interaction, discourse and conversation analytic methodologies were used (cf. Atkinson & Heritage, 1994; Duranti, in press)[1]. These methodologies made possible a fine grained analysis of the microgenetic or moment-to-moment development of cognitive processes and products arising during ongoing game playing activity. Moreover, the communicative processes of situated problem solving became the means to determine how intellectual activity is shaped by interactional opportunities and resources and the design of computer software.

The data in this study are taken from a larger investigation into the development of mathematical and scientific literacy in a non-traditional educational setting, i.e., an after-school club. The after-school club is located in an urban school district with a predominately Latino student population in the southwestern area of the United States. Children in this study are considered to be academically at-risk by the school district. In the after-school club, children

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[1] Transcription conventions used in this study were developed by Gail Jefferson, (see Atkinson & Heritage, 1984). Specifically, ( ) indicates unclear speech, (( )) describes paralinguistic information about context, (.) are untimed pauses, (2.1) is an indicator of pauses in seconds and tenth of seconds, [refers to simultaneous start ups or overlaps, = notes contiguous utterances; :: specifies extension of sound; ↑ or ↓ indicates up or downward shifts in intonation, underlined or bold words indicates increased stressed, ! is an animated tone marker, ° xx ° is quiet talk in relation to surrounding speech, > < are rapid speech indicators.

worked with undergraduates from a local university. These university students were enrolled in a child development practicum that required them to participate in the club twice a week for nine weeks. The goal of undergraduate participation was to connect theory to practice by reflecting on and using social theories of human development as they worked as tutors. The corpus of data consisted of 10 videotaped sessions of approximately one hour in duration. The criteria for the selection of the computer game in this study, Puzzle Tanks, was its mathematical content and emphasis on problem solving (O'Brien, 1985).

Findings

When children participate in mathematics games on computers with more experienced game players, in this case, undergraduates, they have opportunities to develop competent understandings of the salient features of mathematics games, to reason and communicate mathematically, and to begin to use multiple strategies for finding solutions. Moreover, it is children's participation in collaborative activity that demonstrates how change occurs across interactional time and thus illustrates how cognitive skills are interactionally achieved. Further, in this study, it was the participation of undergraduate students that played a pivotal role in children's development of mathematical concepts and ways to communicate about those concepts during computer activities.

To illustrate the significance of pairing undergraduates with elementary-aged children, this study focuses on Ivan, a fourth grader, and Ellie, an undergraduate in her third year. They are playing Puzzle Tanks (PT). PT is a computer game designed for one player and consists of four levels of difficulty. The goal of the game is to measure out a specific volume of liquid by filling and emptying tanks, as well as transferring liquid from one tank to another. The lowest level of difficulty, *Beginner* level, uses two tanks and one storage container. At this level, problems are generated according to a formula that determines the desired amount of liquid to be transferred into the storage container. This formula is $x = m \cdot a + n \cdot b$, where x is the desired volume, constants $m,n \in Z$, and $a,b \in N$ are the tank capacities. Because any values chosen for m, n, a, b will result in a value for x, all problems in this level have a solution. The next level, *Expert*, differs from the Beginner level by generating the desired volume and the tank volumes as random positive integers. This change implies that some problems will have no solution. The remaining two levels, *Grand Master* and *Champion*, eliminate the storage container of the Expert level. Champion level records the number of steps that a player uses in solving the problem. The name of the player who uses the fewest steps is recorded.

The PT example in this paper illustrates the nature of arithmetic problems in this game: children are expected to create a solution to a relatively novel situation by utilizing some sequential combination of addition, multiplication, or subtraction procedures to determine the correct solution. Since each problem could potentially be solved by more than one procedure, it was possible to produce several solution strategies. However, to date, there are no examples in any of the data to suggest that multiple solution procedures were considered by either undergraduates or children. Nonetheless, PT provides complex mathematical problems by combining multiple steps and varying problem forms. For these reasons, contrary to much of the mathematics curriculum in schools, the arithmetic problems in the PT game are characterized with levels of complexity unfamiliar to many elementary school children (Grows, 1992). Notwithstanding the varying levels of complexity of the arithmetic problems in PT, the design of the software, we will demonstrate, made it possible for students to guess without reflecting on the possible solution strategies. It is this constraint on developing effective problem-solving strategies that will be shown to be mitigated, to some degree, by the involvement of undergraduate students.

Before continuing, it is important to note that the after-school club organized the use of computer games through adventure guides (AG), i.e., directions about how to play the game embedded in a fictional narrative[1]. The fictional narrative explanations found in the AGs provided a playful goal structure for the computer game. More importantly, AG's were designed to encourage collaboration and communicate, dimensions of learning that are not part of the software. Although all children read the initial framing of the game as an imaginary adventure that required a systematic approach, it was very common for children play a game by randomly clicking the mouse on various areas of the screen in an attempt to determine specific game procedures. Although productive in initial phases of a game, this random approach tended to persist throughout the duration of the game. Consequently, the constraints of the computer gaming environments tended to limit conceptual understandings of mathematical knowledge.

Countering children's tendency toward a random approach were undergraduate assistance techniques, which encouraged children to develop more reasoned solution strategies. It was common for undergraduates to encourage children to read directions when initiating a game or when problems of understanding arose. An example of how undergraduates assisted children in taking a more systematic approach to game playing is found in the following except. Here, Ivan has just completed several games. Ellie has asked Ivan what they need to do next. To discuss what the next steps are, Ellie has asked Ivan to read the adventure guide. Ivan has just read a portion of the guide.

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[1] The adventure guides drew on both Vygotsky's 1978 work on play or imaginary environments contribution to the intellectual development of children and the recognition that narratives are a pervasive cultural tool used by people to make sense out of experiences, (cf. Riessman 1993).

Ellie: Well you::'ve do:ne that huh?
Now what does it say to do?

Ivan: Go to go to the next one::?

Ellie: What does it say right here on number three?

Ivan: Complete five puzzles correctly at the game Grand Master level. Wow! I'm on Grand Master level.

Ellie Okay. So Grand Master. What do we have to do for this one?

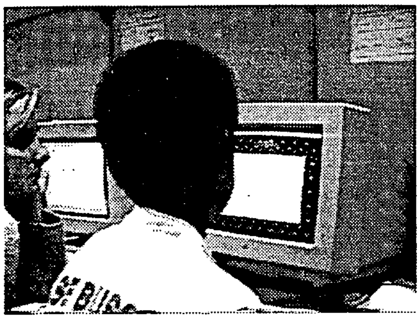
In the above example, Ellie's questions encourage Ivan to use text as a tool and thus structured opportunities for him to read written text as a means to determine next steps in the game. Further, as a consequence of interactional sequences like these, over time, children began to take on the normative practice of reading directions as a strategy both to begin an activity and as a means to explore possible solutions for ongoing problems. It was the continual social support of the more experienced undergraduates that stimulated the use of written text as a solution procedure and thereby provided opportunities for children to extend their literacy skills to direction reading and frame problem-solving as the combined used of off-line and on-line tools.

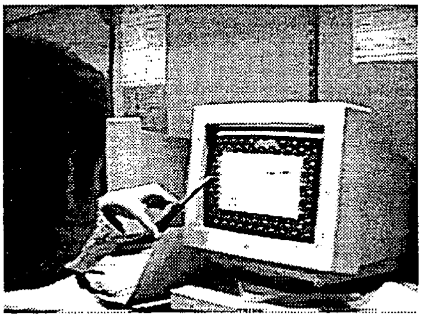
In addition to illustrating how undergraduates encouraged the use of written directions as a way to solve problems, this interaction reveals another interesting aspect of the impact of social interaction on individual participants. It is quite common for motivation to be considered an individual accomplishment, see (Ames & Ames, 1984). However, undergraduates questions and responses to students' actions also created opportunities spaces for the co-display of interest in the game and solution strategies. As a consequence, motivation for continuing a game was not solely an individual construction but a result of the social organization of the collaboration. The significance of the interactional accomplishment of motivation is found in Ellie's participant observations notes where she states that at the conclusion of the after-school club session:

> He [Ivan] said, "I want to play this game tomorrow." I was quite impressed considering, a few times, he desperately wanted to play another game. I am glad that he ended up enjoying the game.

The transcripts of their interactions during the game suggest that Ellie's continual display of excitement and encouragement explains, at least in part, why Ivan's desire to play the game increased over time.

Thus far, we have shown that a more expert other as tutor functions to socialize attention for important aspects of mathematics activities on computers, encourages off-line tool use, and contributes to the joint construction of motivation for continued play. In the following excerpt, we will discuss the interaction between collaborative activities and computer software designed for individual participation. One of the most notable patterns this excerpt illustrates is how software technology designed for individual use constrains activities organized to promote the co-production of mathematical knowledge. In other words, there is an interaction between the affordances of software and how collaborative mathematical activity unfolds in time and space. In the except below, Ellie and Ivan are beginning a new game level, Grand Master.





Ellie: Okay:: Grand master.
((Ellie and Ivan are looking at the computer screen.))
You need nine::: but see you only have two tanks to work with.
((Pointing at the screen)).
Let' see::

Ivan: But where's:: the tank.

Ellie: Uh::mm: Okay: lets see::

Ivan: Oh: I think I think it's

Ellie: Okay, you see these two tanks

Ivan: *((Uses the mouse to fill and empty tanks.))*
(10.0)

Ellie: How many is that: right::: there:?
((Pointing to the screen.))

Ivan *((Continues to fill and empty the tanks.))*

Ellie: How ma:ny do we have there::?
(4.0)

Ivan: Wait:::::.

Ellie: How many do you have there? One, °two, three°

Ivan: *((Continues to manipulate the valves on the tanks.))*
(10.0)
One two: three:: four (0.5) five six:: seven, eight

Ellie: Humm:::: This is a hard:: one:.
(4.0)
°What da ya think?° Do you want to try and work it out on a piece
of ^pa:per.
(5.0)
Think you can do: this one:?

Ivan: *((Continue to fill and empty the tanks.))* 28
Ellie: (hhhh) What happened? 29
Ellie: I don't know how we get eig:ht how we get one from eight and two. 30
Ivan: Can we play a different game? 31
Ellie: Let's see let's see what what will happen 32
Ivan: Hmm::: 33
((The correct solution signal[sounds.)) 34
Ellie: [Hmmmm. 35
Did you do you remember do you know why 36
Did you know why the answer was impossible? 37
Ivan: You couldn't get nine::. 38
Ellie: You couldn't get nine. Because how come you couldn't get nine? 39
Ivan: Cau:se: there's:: none: cause when you try and > get some:< you 40
can't:: get:: nine because when: :(0.9) if you get (0.4) if you put 41
some:: juice in one of these:: and it it comes out in one then: it's 42
imposs:ibe cause it wouldn't give you ni:ne::.
Ellie: Hmm:: 43
(..) 44
Alright::. That was good so you want to try another Grand Master one? 45

In this example, Ivan discovers that there is no longer a truck or holding tank for liquid (see line 6). Once he realizes that there is no truck, he begins to fill and empty tanks repeatedly in an effort to make their contents add up to the number nine. Although Ellie does suggest an alternative approach (see line 24) Ivan uses this strategy throughout the game. Ivan's persistent focus on the screen, we suggest, is due in part to the single-user nature of the software. Moreover, the design of this software fits into the general single-user paradigm typified in current commercial software. Although software of this type will permit social interaction it is not designed to encourage it, in fact, it is oblivious to social interactional processes.

Unlike the underlying single-user assumptions of the software, Ellie views the software as a tool for collaboration. In this activity, she is attempting to implement her growing understandings of the importance of collaboration to learning by using different ways of assisting performance. In particular, she participates by drawing Ivan's attention to the numbers being displayed on the screen (e.g., lines 12, 15, 18), encouraging him to continue (line 32), suggesting the use of a paper/pencil to work out the math problem (line 24), and requesting explanations (lines 36-37; 39). Many of Ellie's assistance strategies (e.g., "How many do we have there?") tend to direct Ivan's attention to salient aspects of the screen as he quickly opens and closes valves in a manner similar to 'video game mode' or random clicking of the mouse. It is important to note that after Ellie asks Ivan to pay attention to the numbers displayed on a screen diagram, he uses this strategy in a similar manner (compare lines 14 and 21). In effect, over time, Ellie socializes Ivan's attention toward critical aspects of the computer screen. This pattern of interactional assessment of children's behavior leading to the socialization of attention is consistent throughout this data set.

"Punctuating the stream of experience" in another way, Ellie's requests for explanations create opportunity spaces for Ivan to participate in a justification activity (see lines 37-38). When Ivan does not provide an adequate response by stating the obvious, "You couldn't get nine", Ellie poses a probing question that created a conversational slot for extended talk (see lines 41-44). Ivan's explanation of why he could not get nine, however, does not reveal any complex understandings of why the problem was impossible to solve. Nonetheless, he did have an opportunity to produce an explanation a part of his participation in the game. Opportunities to explain/justify solutions were consistently found in this data set suggesting that undergraduate participation contributes to children's opportunities to communicate about their mathematical knowledge.

Discussions

Undergraduate participation in the after-school club played a significant role in organizing collaborative activities for children. These collaborative activities evidenced varying degrees of participation by children. For example, it was common for undergraduates to assisting children in focusing on important aspects of computer-games, e.g. screen displays. This form of assistance, however, appears to be successful only when students were experiencing troubles with the game. When problems were not sufficiently difficult to stop play, children would continue to use the mouse to explore in a random fashion paying little attention to the information on the screen. Undergraduate participation also encouraged the use of off-line tools such as paper and pencils to represent of problems However, the computer game's similarity to video games, i.e., single-user approach, made it easy for children to continue using the mouse and to ignore any suggestions offered by the undergraduates. In other words, the software design encourages individual involvement rather than collaboration. Collaborative work-in-talk, then, was not an intended by-product of the software design but rather a product of ongoing problems with understanding or game procedures.

While many of the strategies for collaboration used by the undergraduates did not necessarily lead to the co-production of mathematical talk or reasoning, that was not the case for explicit requests for explanations. When children had solved a problem, it was common for undergraduates to ask children what they did to accomplish the task. Frequently, these question resulted in children producing explanations. Nonetheless, these explanations tended to be brief or provide no evidence of a deep understandings of mathematics.

The significant issue is the interaction between expectations for collaboration and the constraints placed on both knowledge production and collaboration by the software. For example in PT, there is no way to manipulate problems to investigate patterns of similarity and differences. As a consequence, it would be difficult for Ivan to explain why any one problem was impossible outside of stating that no combinations worked. Had the presented problem been directed toward finding a pattern, PT may be a much more valuable tool for providing insights into mathematical principles. It is crucial for differences in problems to be systematically explored given that exploration of the mathematical patterns found in solution strategies provides children with opportunities to construct a deep understanding of principles underlying mathematics (National Research Council, 1989; Steen, 1988; Stone, 1996b).

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