MEANINGFUL CONTEXTS FOR MATHEMATICAL LEARNING: THE POTENTIAL OF GAME MAKING ACTIVITIES

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Abstract: There is a need for educational researchers to find connections between formal education and the many other activities and contexts which inhabit the "real world" of children. While there has been some research on the potential of game playing for learning, the benefits of game making activities have not been examined. In this paper we present the analysis of a design session in which four elementary school-students designed computer games to teach fractions to other students. We analyzed the design interactions in a microgenetic fashion to identify the progression of students' mathematical thinking. In addition, we paid close attention to the contribution of students' social interactions to the increasing sophistication of fraction representations in the game context. We argue in this paper that not only is the context of game-making itself relevant to children's "real world," but that it also provides opportunities for children to explore mathematical ideas within many other "real world" scenes and situations as they design their games.

Introduction

What is learning for "the real world?" One possible answer to this question has been to identify authentic learning contexts and activities (Lave, 1988; Saxe, 1988). Researchers have studied everyday activities that involve mathematical practices (such as cooking, shoping, and candy selling) with the intention to connect learning inside and outside of school (Resnick, 1987). While these efforts, among others, have led to revisions of the mathematics curriculum (NCTM standards, 1989), there is a need to find connections into the many activities and contexts which inhabit the "real" world of children and are often noticeably segregated from their formal education. This approach is often described as building on students' "informal knowledge" (Mack, 1993).

One starting point to look for such connections is to examine children's activities and interests and their potential for learning. Game playing has always been a central activity in children's lives and many researchers have emphasized the benefit of games for children's intellectual, social, and emotional development (e.g., Brnner, Jolly & Sylva, 1976; Piaget, 1962; Sutton-Smith, 1986). Game playing activities have found a place in the mathematics curriculum, as indicated by the large number of instructional games found in teacher publications (Bright, 1985). Their educational relevance, however, has not been examined extensively (Ainley, 1991). Only now have some researchers started to study children's learning of mathematical concepts and operations in game playing contexts (Saxe & Bermudez, 1996).

A different starting point to investigate the potential of games for learning is to examine the benefits of game making activities. A first study looked at children's design and implementation of fraction computer games as a way to further their mathematical learning (Kafai, 1995). In the following study, we examine a design session in which a team of four elementary-school students designed computer games to teach fractions to other students. In contrast to previous research situated in the same framework, here the children only created games on paper and in discussions but did not proceed to implement them on the computer. We analyzed the design interactions in a microgenetic fashion (Siegler & Crowley, 1991) to identify change in students' mathematical thinking. In addition, we paid close attention to the contribution of students' social interactions to the increasing sophistication of fraction representations in the game context (Granott, 1993). We discuss the results of this analysis by re-examing the meaning of authentic, "real world", contexts to promote mathematical thinking. Furthermore, we look at the pedagogical constraints for implementing such game design activities for learning.

Theoretical Background

Using computer game design as a context for students' investigations of fractions is based on the premise that video games are a significant part of children's culture (e.g., Greenfield, 1984; Kinder, 1991; Provenzo, 1991). Instead of using the activity of game playing to learn about fractions (as it is done in most educational games in mathematics), this study proposed the activity of game making for learning fractions. Developing a computer game to teach fractions to others promotes the activity of designing fraction representations (Kafai, 1995). Many researchers have identified the importance of students' use of multiple representations in developing more sophisticated understandings of fractions and rational numbers (Bell, 1993; Lesh, Landau & Hamilton, 1983; Kaput, 1991; Streetand, 1991; Tierney, 1987).

This approach draws most notably on Harel's study (1991) in which she asked a class of fourth-grade students to design instructional software in Logo to teach fractions to younger students in a four month long intervention. The students in Harel's project chose and designed their own representations according to what they thought were the most important and difficult aspects of fractions to learn. Harel proved that the process of constructing, programming, and explaining of representations facilitated students' significantly better understanding of the representational structure of fractions. However, in comparing the quality of fraction representations between Harel's instructional designers and those of the game designers, Kafai (1996) found that the game designers did not develop as sophisticated representations due to their concentration on game design. Saxe (1992) reported that some strategy choices in game playing also hindered students' later mathematical development.

A central question of this study was whether game making could become a more fruitful context for exploring multiple fraction representations, if one limits the investigations to the game design phase without considering potential software implementation issues. In creating computer games which are both fun and educational, children can become designers and teachers. In this process, they then draw on their "real world" experiences as game players and school learners. We argue in this paper that not only is the context of game-making itself relevant to children's "real world", but that it also provides opportunities for children to explore mathematical ideas within many other "real world" scenes and situations as they design their games.

Learning Context and Methods

The present study was conducted as part of an effort to develop a prototype for educational interactive television in elementary school mathematics (Miller, 1994). The development plan forsaw the involvement of young students as game design consultants for professional designers, programmers, and content specialists. The game design sessions were conducted with a fifth grade class of a suburban elemantary school with an ethnically mixed student population. Before beginning the game design discussions, students were asked to generate ideas for computer games to teach fractions as part of their homework. Worksheets were provided that asked students to describe their game ideas, game characters, and fraction ideas. The class of 32 students was divided by the teacher into eight teams of four students each. Three groups were of single gender (two all-girls teams, one all-boys team), and the rest were mixed gender teams. The design sessions took place on three consecutive days, for one hour each. The sessions were conducted in the after-school room, around a table with five chairs. Large pieces of butcher paper were placed on the table for students to draw on and on the board for the researcher to note students' ideas. All the sessions were video taped by another researcher for later transcription. The present analysis focuses on the first design sesssion of one design team, four girls, that was conducted by the first author.

Results

We analyzed the fraction game development over the whole 50-minute session by looking at the different game scenes. Overall, the four girls developed and discussed 24 different fraction game scenes during their first design session. In order to document change in the students' thinking about fractions, (1) we analyzed and classified the games according to integration of fraction content and (2) we looked at the interactions between the students and their contribution to the nature of the fraction representations.

Fraction Content Integration in Game Idea

One way to document the increasing sophistication of students' thinking about fractions is to examine the integration of fractions into the game context (Kafai, 1995). We defined three categories of fraction integration in the game scenes: extrinsic, intrinsic, and constructivist. *Extrinsic* integration of fractions describes the type of games the girls initially had in mind, in which the game centers mostly around arcade-style action, and fraction questions are asked occasionally but are unrelated to the game's theme or objective. For example, Melanie described a maze game in which different things were chasing the player and in case one bumped into them, the player had to answer a question. Emily came up with the idea of a race track game in which the player had to answer questions in order to progress through the game.

Instrinsic integration describes the fraction scenes shown in the microanalysis--dynamic scenes where fractions are an inherent part of the scenery and game objective. One of the scenes which will be analyzed in more detail in the following section described a beach in which various fractions of people (e.g., ratio) are in and out of the water. Another idea was a landscape scene with trees and animals in which the user had to identify all the fractions hidden in the picture.

Finally, *constructivist* game ideas allow the user to actively create his or her own fractions from what is provided. For example, the player could create his or her own fraction by coloring in different pieces of a given animal. Thus, rather than constantly quizzing, the constructivist integration allows the user to formulate his or her own questions. Both the intrinsic and constructivist fraction games represented a sophisticated departure from the drill-and-practice routine of traditional education and the non-mathematical focus of most computer games.

The importance of this classification becomes clear if one considers to what extent one particular form of content integration provides opportunities for students' thinking about the nature of fractions, different representations, and relations to other rational number concepts. It is a strength and a weakness of extrinsic integration that domains of knowledge become almost interchangeable. It is a strength because the integration is relatively easy; when answering a question correctly is what allows the next move in a game, the question can be on any topic. But this is also a weakness, because it causes the designer to loose the incentive to think deeply about the particular piece of knowledge. As other researchers noted (e.g., Harel, 1991), the flexibility in moving between different representational forms is a sign of better understanding of fractions.

We found that as the 50-minute session progressed, the girls' ideas became more focused on intrinsic and constructivist integration. Extrinsic integration raised its head occasionally later in the session when a new game or story-line idea was introduced, but when the girls began to revise those ideas to include fractions, they were usually instrinsically integrated. Related to this development in content integration is the observation that the type of representations (e.g., generic fraction question, fraction as area, part of set) became more sophisticated as well. In fact, the two developments seemed to be inseparable. The more intrinsic the integration of fractions in a particular game idea or scene, the more sophisticated types of fractional representations were being used to describe them.

In-depth Analysis of one Game Idea

An in-depth analysis of discourse segments during the game-making session provides a window into the types of fractional understandings children developed in this activity. The 10-minute segment of discussion we chose to analyze shows two of the girls, Melanie and Rachel, expanding and improving on an original idea brought in by Caren from her homework sheet. Caren's idea involved the user picking topics about which to answer fraction questions. Her specific example involved a room full of Power Rangers™; however, her question about this scene was grounded in a whole number context--asking "how many?"

Although Caren's idea was not very developed in terms of fractional understanding, it provided a very useful context and scene idea for the other girls to use in exploring how fractions can be used to describe "real" situations. Melanie built on Caren's idea by suggesting a scene with racoons. She described an area with a group of different colored racoons. One question was about what fraction of the racoons were colored the same. Another question asked what fraction of one racoon's body was colored black. The creation of this scene represented a change in fraction investigations, in that Melanie was able to simultaneously explore fractions as parts of sets and as area, since a single racoon could be a part of a larger group, or it could be the whole which is divided into smaller body parts.

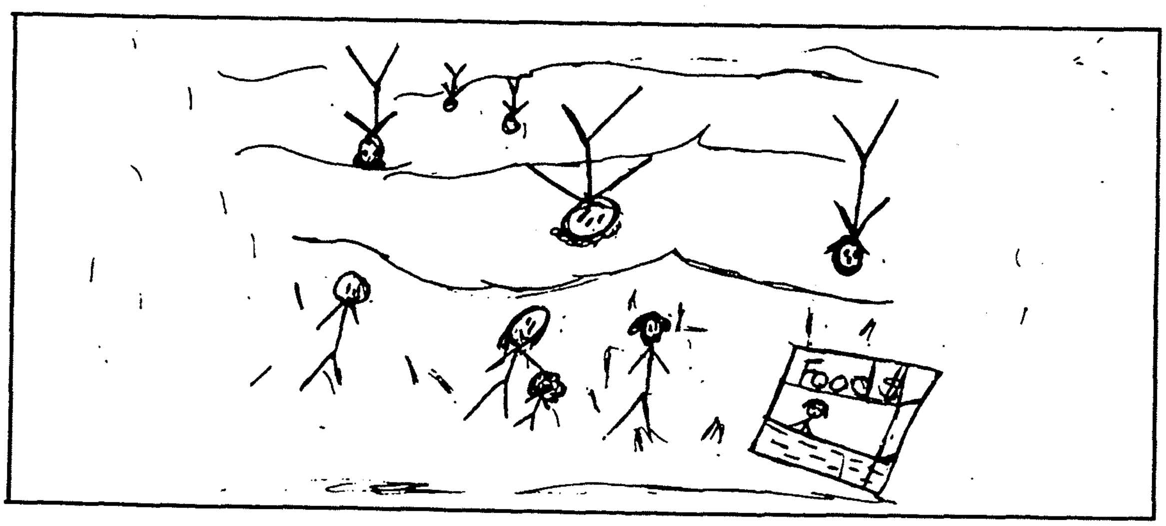

Figure 1: Dynamic fraction representation--Rachel's beach scene

A particularly interesting development occured in Rachel's game scene when she built on Caren's idea after Melanie. Rachel created a dynamic, animated scene at the beach with people moving in and out of the water (see Figure 1). During the animation the user would be asked a question about what fraction of people were on land or in the water. We hypothesize that the context of creating a computer game contributed to the development of such a representation, since most computer games require animation. These animated scenes afford a more flexible view of how fractions can describe "real" situations, in which the parts and wholes are not fixed in time and space.

It is important to situate this development of fractions understanding within an interactional context. Specifically, we were looking at the girls' increasing flexibility in creating rational number representations and how that development is mediated by context and social interaction (see Figure 2). The first important issue to note is that in the span of 10 minutes, multiple ways of dealing with the same concept were explored. The presence of others working on the same creative problem provided each girl with multiple perspectives on how to represent fractions--in this case, fractions as parts of sets being used to describe dynamic scenes.

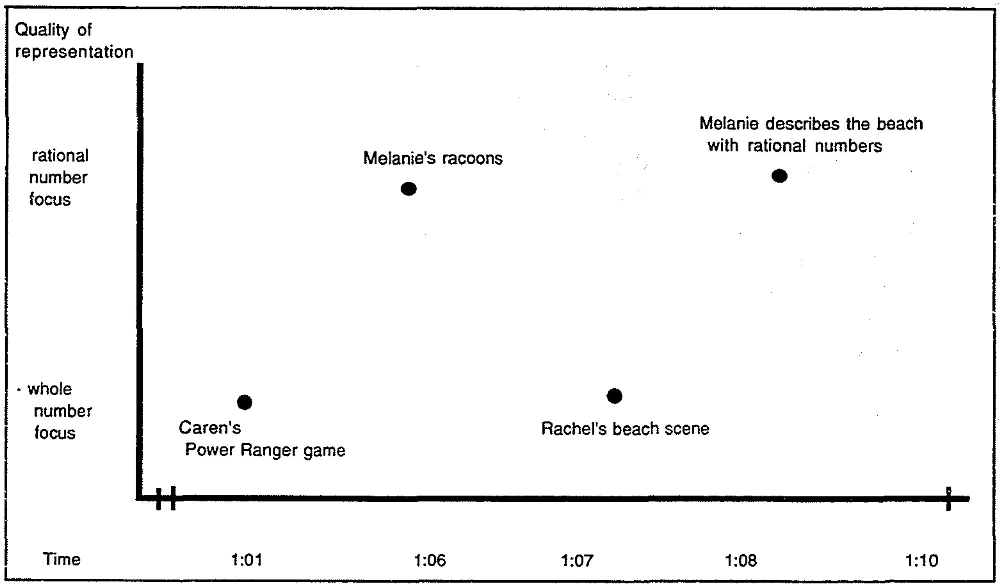

Figure 2: Tracking of rational number flexibility

The second important conclusion to convey about this segment is that not only was the initial idea explored in multiple ways, but it was also improved upon. Development in flexibility in this situation was dependent on interaction and collaboration. We can see how Caren's initial Power Ranger™ representation, which was based on a whole number concept, was extended through Melanie's and Rachel's further idea developments of the racoon scene and the beach scene. In addition, we see how within a brief time period, the fraction scene not only was transformed into different ideas but also increased in its sophistication as each girl contributed. This phenomena could be interpreted as a kind of distributed cognition or co-construction of knowledge (Granott, 1993), which has been documented in other studies of educational game playing and classroom learning (Saxe, 1992; Pea, 1994).

Discussion

As the analyses of the game ideas indicate, this first design session proved to be a productive context for students to generate, analyze and extend their fraction representations. We found evidence of students' increasing sophistication in the nature of fraction integration into their games, the type of fraction representations, and in students' interactions. These results warrant further discussion of the potential of the game context and its pedagogical constraints.

We started the study with the premise that contexts for learning mathematics not only need to relate to authentic activities but also to children's culture. We identified games as a significant part of children's lives in which they practice many important activities. Previous research looked at identifying everyday situations and their potential for mathematical thinking as a way to connect children's learning inside and outside of school and to help them transfer knowledge and skills. Everyday situations such as shopping and candy selling provide relevant contexts for mathematical practice.

Game making activities also provide relevant situations for exploring and investigating fractions: they allow personalization of the learning context (Harel & Papert, 1990). They allow children to relate mathematical thinking to their own culture and personal interest. Within the context of game design, children can chose to relate mathematics to things they find interesting or likeable, whether it be cute animals, a day at the beach, Power Rangers™, or anything else. Similar results have been observed by Harel (1991) and Kafai (1995) in their studies. In this way, game design in education is connected to children's "real world" experiences of familiarity with games (educational or otherwise). What we find here is that children link fractions to their "internalized mental environment" (see Harel & Papert, 1990, p.23-24). Game design also opens up possibilities for connections between formal education and the contents of children's fantasies and imaginations, which often encapsulate their "real world" better than other practice-linked definitions. In the design of their fraction games, children engaged their fantasies and built relationships with other pockets of reality that went beyond traditional school mathematics.

Furthermore, we saw how the game context itself promoted the development of a new type of fractional representation. In Rachel's beach scene we saw the first example of a dynamic fractional representation. The importance of animations in games initiated students' thinking of a context to study fractions that is not considered in traditional school mathematics. If one sees the linking of students' informal knowledge (Mack, 1993) and the flexibility in moving between different representations (Streefland, 1991) as evidence for sophisticated mathematical thinking, then the game context provided a supportive context to develop such skills.

While this particular game design session proved to be very productive, it is necessary to point out some potential constraints. As the result of a previous study indicated, it is difficult for children to develop more flexibility and sophistication in their fraction games (Kafai, 1995). Kafai discussed extensively how games designed with extrinsic fraction integration hindered students' further exploration of fraction concepts. Similar observations were made by Saxe and Bermudez (1995) in their analysis of children's playing of mathematical games. They found that chosen goals and routines sometimes limited the complexities of mathematical environments constructed by the children. But this can be said of most learning environments. The challenge, then, is not only to create activities which can provide the springboard for children to build their mathematical thinking but also to think about interaction modalities with other students and teachers that can enhance the mathematical complexity of their activities.

The first author's pedagogical interventions during the game design session were minimal. They consisted mostly of prompts such as "let's look at this more" or focus questions such as "How can you design a game without asking a question?" These interventions turned out to be crucial in helping students to move from stereotypical and limiting conceptions of game (i.e., ask a question, bump into something, go to the next question) to more constructivist versions. In fact, many researchers have discussed the importance of a classroom discourse culture for mathematical learning (Lampert, 1990; Pimm, 1987). These interventions allowed students to look at fractions, and ultimately learning, in a new light: how can you create learning situation without asking a question? Students learned to "turn the tables" by creating situations or context for fraction representations where the player/learner would be the one identifying or making fractions. In the end, this is probably one of the hallmarks of learning/mathematical thinking, when one can decenter from the passive mode of recognition to active mode of making mathematically meaningful situations.

Conclusion

Making games proved to be a meaningful and authentic context that allowed students to connect their mathematical ideas with their informal knowledge. Most importantly, it allowed children to relate mathematical thinking to their own culture and personal interest.

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