A Classroom Study: Electronic Games Engage Children As Researchers

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Abstract

This paper describes the authors' experiences in using classroom play of electronic games as a central component of a collaborative approach to mathematics learning in a grade four classroom. The authors form one of the pairings (computer scientist, elementary teacher) of university researchers with teachers, in the E-GEMS classroom study, an ongoing long-term qualitative study on the potential uses of electronic games and activities for enhancing mathematics learning in intermediate grade classrooms. We believe the experiences from this study can provide insight on issues of importance to research on computer-supported collaborative learning in the classroom and to mathematics education.

Our experiences echo those of many others on the effectiveness of collaborative use of computers, where the collaboration occurs through small groups of learners working at each computer. We also note the positive impact of connecting the computer activities with related large and small group classroom activities. We are excited by the success of these approaches in stimulating students to talk and write about mathematical concepts, and to view themselves as researchers exploring mathematical ideas. Finally, our experiences reinforce the need to re-examine user-interfaces and other areas in human-computer interaction in the context of computer-supported learning. A more detailed version of this paper is available from the authors.

Keywords — Human-Computer Interaction, Computer-Supported Collaborative Learning, Electronic Games, Mathematics Education, Classroom Strategies.

1. Introduction

The classroom study forms one component of the Electronic Games for Education in Math and Science (E-GEMS) project, a large-scale initiative among the University of British Columbia, Electronic Arts, Queen's University, Apple Canada, several elementary schools, and Science World BC. Other components of E-GEMS include basic research on children's interactions with electronic environments [4, 5], shorter term studies on specific issues related to the use of electronic games in education [2, 3], development and evaluation of prototype electronic games and activities for mathematics education, and the design of commercial electronic games for mathematics education. The first such commercial product, Counting on Frank, was published by EA*Kids in late 1994.

Our reasons for investigating electronic games as an ingredient in mathematics education were their attractiveness to many children, their exploratory and interactive nature, and the ability of electronic environments to facilitate concept visualizations and manipulations that are difficult to achieve with concrete materials. Despite these positive factors, we questioned whether the playing of electronic games, on its own, could bring about other essential components of effective mathematics learning such as reflection and ability to transfer the learning to other contexts. One of the primary goals for the classroom study is to investigate strategies that address this concern. Like others in working in mathematics education [1, 6] we believe that verbal and written discourse are highly effective in stimulating reflection, and that ability to transfer is enhanced by experiencing the learning in multiple modes and contexts. Thus we have focused on strategies that combine playing electronic math games with speaking and writing about mathematics, and with other mathematics activities away from the computer. Our approach uses the playing of games as an integral component of mathematics learning, rather than as a way to trick students into paying attention before the "real teaching" starts, or as a reward for students who finish their work early. The classroom study also influences the other components of E-GEMS, guiding the direction of basic research activities, identifying critical issues, and providing a test-bed for evaluation of prototype games and activities.

The study is being conducted in the classrooms of four teachers in four different schools, three in Vancouver and one in Kingston, Ontario. The teachers (and their schools) were chosen to have some characteristics in common, and to differ in others. Their common characteristics include a commitment to collaborative learning, an interest in participating in research projects, and a reputation as being a good teacher. The teachers differ dramatically in their length of time in teaching (from 4 to 24 years), their comfort in using computers (from computer-phobe to computer-lover), and in their approach to teaching mathematics (from primarily textbook-based to virtually no use of a textbook at all). Their classes also differ in many respects: grade level (from grade 3-4 to grade 7-8), socio-economic status, proficiency in English language (ESL, French immersion, fluent).

The study began in mid-March of 94 with the placement of four LC III Macintosh computers in each classroom. The computers were equipped with a fairly limited selection of software: a word processor and paint program designed for children (Microsoft's Creative Writer and Fine Artist), Hypercard, and E-GEMS prototype games. CD-ROM drives were gradually added, together with a small number of commercial electronic games (The Incredible Machine by Sierra Dynamix, Counting on Frank by EA*Kids). Each teacher established a schedule for the students to use the computer, and encouraged the students to keep a journal of their experiences in using the computer. Because of our interest in collaborative use of computers, the schedules were designed to allow 6-8 students access to the 4 computers at once. In some classrooms students also use the computers during "free-time": recess, lunch, and before and after school.

Each classroom was assigned an E-GEMS university researcher to visit the classroom weekly for one to two hours. During such visits the researcher's activities include observing the students using the computers, interviewing students, and participating in discussions with the whole class about the electronic games and other activities. The Vancouver teachers also participate in monthly meetings, where the teachers and their university partners get together to share their experiences, and to help advise on other E-GEMS research efforts.

2. Students As Researchers

The E-GEMS teachers have used a variety of strategies to emphasize the "student as researcher" approach. We have found this approach to be particularly effective in engaging students' interest in using the computers. When the "student as researcher" emphasis is not present in a classroom for a few weeks, as has occurred in each classroom for a variety for reasons, many students ignore the computers during that time. We consistently find that students choose to play the games that they are guided to play, and the games that are mediated. As others before us have observed, a computer put into a classroom is not a magical thing. It will not, by itself, attract students to the world of learning, or even to the world of games.

In Eileen's classroom, the students are introduced to their role as researchers early in the year. The major research formats used are journal keeping, sign-up charts, tally charts of games played, maintaining "bug" sheets, and weekly class debriefing/sharing sessions. Journal entries serve several purposes. They give a clear record of what activities the students are engaging in; they also let us see whether students are static or changing in their choice of partners. From their writing we learn how students interact with the computers and each other, from how they delegate control of the mouse to what they learn from each other.

The sign-up charts ensure that all students have access to the computers each week. Students sign-up for two periods weekly. This sign-up has been done three times during the course of the year to promote different student groupings. Journal entries and tallying of activities are made in conjunction with sign-up times. The bug sheets are used to record problems the students find in the E-GEMS prototype games. These prototypes are placed in the classrooms beginning in very early stages of development. The university researchers responsible for prototype development then visit the classroom regularly to discuss the games with the students, pickup the bug sheets, and install the latest versions. The students love their role as bug-finders and expert critics. They quickly learn the value of making detailed observations when a problem occurs. They also see they are genuinely respected as researchers.

One of the most effective strategies we have found is the holding of regular whole class debriefing/sharing discussions. In Eileen's classroom the initiation of these meetings marked a significant change in student attitudes. Once regular recording and sharing of ideas was expected, the students started to really listen to each other, to write more detailed comments about their findings, and to think not only about what they were doing, but also about what they were learning. For us, this is of crucial importance. Like many teachers, Eileen is particularly interested in methods that provide her with windows into students' thinking. Her class is very good at verbalizing their ideas. They are weaker at written discourse. For Grade 4 students, it is often onerous to have to write things that are so much more easily shared orally. However, writing about computer research, although not everybody's favorite, is something that they all do.

Recently, when Eileen asked her class to tell her what they knew about being researchers, two ideas kept coming up. "Research is hard and research is fun." At the beginning of the year, these same students were convinced that the only work that was fun was easy stuff. The words "hard and fun" were never spoken in the same breath.

3. Pencil and Paper Game Explorations

Another important component of our classroom research is trying out pencil and paper activities related to the computer games. The EA*Kids CD ROM, Counting on Frank, has four groups of math games which the player may choose to play separately from the overall game. We have used each of the math games as the basis for an activity in which the students work with variants of the game. These activities stimulate students to explore the electronic versions of the games more fully, and provide a clear connection between the computer and pencil and paper approaches to mathematics. They also give students the experience of enjoying themselves while working on mathematical challenges they find difficult. We illustrate these points by describing one of the activities.

The simplest version in one of the four groups of games in Counting on Frank is 9-or-bust, a two player game played on a tic-tac-toe (3 x 3) grid. Players take turns rolling a standard die and placing the resulting number in one of the free squares remaining in the grid. A player can win by being the first to complete a line (horizontal, vertical or diagonal) of 3 numbers that add up to 9 (a hit). A player also wins if the other player completes a line of 3 numbers that add up to more than 9 (a bust). If neither has occurred by the time all nine squares are filled, the result is a draw. The game 9-or-bust has many variants, e.g. change the target to some other number than 9, use a larger grid, and change the numbers on the die. Our pencil and paper activity explored the effects of changing the target to 6 and to 12.

We started the session with students discussing the rules of 9-or-bust, and how they would change for 6-or-bust and 12-or-bust. The class was told that they would separate into pairs, and that each pair would play 3 games each of 9-or-bust, 6-or-bust, and 12-or-bust, using pencil and paper and a regular die. A discussion of what kind of data should be collected resulted in a decision to record, for each variant, the number of games that ended as hits, bust, draws, and first player wins. They also decided to record which variant each student thought was the most fun to play. Asked for conjectures on how they thought the results might turn out, students volunteered that there were likely to be more busts in playing 6-or-bust because "it's hard to get three numbers without going over 6".

After all games had been played, and the outcomes recorded in a table drawn on a flip chart, the class regathered to examine the results. As there were substantially more busts and fewer hits when the target was 6, and substantially more draws and almost no busts when the target was 12. The number of first and second player wins were roughly equal for the target being 6 or 9, but the first player won substantially more often in 12-or-bust. After discussing which version made a better game, we agreed to explore the reasons for differences in outcomes (hits, busts, etc.) at the next meeting. The students agreed that during the intervening week they would work on finding all the ways (roll combinations) to get hits of 6, 9, and 12, ignoring the order of the rolls of the die.

The next week's session began with making a list of all the roll combinations for getting 6, 9, and 12 that students had found. We discussed the strategies the students had used to be sure they had found all the roll combinations. We then explored the connection between the number of roll combinations for a given target, and the number of hits, busts and draws for the game based on that target. The students found the mathematical reasoning in this session very challenging. However, they seemed to accept the difficulty as a legitimate part of the research activity, and were not discouraged. When asked how they felt about the pencil and paper activity at later sessions throughout the year, they remained uniformly enthusiastic about the experience.

4. HCI for Learning Environments

We close with some thoughts on ways in which desirable interfaces and usage configurations for computer-supported collaborative learning may differ from those aimed at work environments. One is the effect of requiring two people to share a single computer, compared to providing them with individual computers. Another concerns the value of a highly intuitive interface versus one requiring more deliberate attention. A third is the effect of providing tools in the computer environment that remove the need for non-computer materials (e.g. paper, pencil, books, calculator) while at the computer. In exploring why these differences may exist, it is important to take into account some of the major elements of effective learning that we mentioned earlier: exploration, reflection, and ability to transfer the learning to other contexts. Our observations of certain interfaces and configurations as good for learning are based on our perceptions of how they stimulated, supported, or enhanced these three elements. There are obviously other important elements in learning, but these three seem particularly germane to computer-based learning.

Like many others we have observed positive benefits from having two students work together at a single computer. These include:

(a) Sharing the computer stimulated discourse about what was being done. We believe enhances learning.

(b) The discourse and the presence of the other learner made the learners remain more aware of and connected to the usual classroom environment. We believe this enhances transfer.

(c) While one learner operated the input device, the other learner frequently took that time as an opportunity for reflection and for using non-computer tools such as pencil and paper, and calculators.

(d) Learners found sharing a computer more enjoyable than playing alone.

Some of the benefits of a) and d) would in occur a groupware environment where each individual used a single computer, and there are some obvious advantages to having all learners being able to perform independent actions simultaneously. However, just as collaborative learning has advantages over individual learning, we believe that in many situations, sharing a computer has some intrinsic advantages over individual computer use or groupware environments.

In work environments, a user-interface for a given task is viewed as good if it is highly intuitive, allowing the user to perform the task with little additional cognitive load. However, our experiences in watching students play a variety of computer-based math games indicate the value of including occasions in which the player must deal with less intuitive interfaces. This is because these occasions seem important in stimulating reflection on the underlying concepts involved in the game. Of course, too much of this can quickly destroy the playability of a game.

A good example of this phenomenon occurred in Garden, an E-GEMS prototype game in which players move their pieces around in a two dimensional coordinate system. The educational objective of the game is to encourage exploration of negative numbers and coordinate systems. A turn in the game goes as follows. After rolling a die, the player is presented with a number of possible moves represented by 2-dimensional vectors. Thus a player might be offered the vector (1,0), which represents moving one unit to the right, and also the vector (-1,2), which represents a knight-move upwards and to the left. When the player chooses one of the vectors the piece is moved accordingly.

In order to help players develop their intuition of the coordinate system and how vectors correspond to moves, we designed the game so that players could tentatively select a vector, and the location that would result from the selected vector would flash. The player could then either confirm the choice, or try one of the other possible vectors. Though this interface worked reasonably well in terms of game play (students simply cycled through the vectors until they found a move they liked), we found that for the most part the players completely ignored the numerical values of the vector coordinates and the coordinate system itself. We remedied this situation by adding bonus moves in which the player selected a location in which a special effect will occur. By requiring that the player type in the coordinates of the desired location, we were able to markedly increase the attention paid to the coordinate system. Students found entering the coordinates cumbersome and difficult, but did not complain because the bonus moves were valuable and only occurred sporadically.

This question of how to stimulate reflection and awareness of the educational concepts underlying a computer game or activity, without adversely affecting usability, is deep and complex. While there are tangentially related problems in designing user interfaces for work applications (for example, the need to alert the user to possibly undesirable consequences of actions such as quitting the application without saving) it needs serious study in its own right.

We close this section on differences between computer-based work and learning environments with an observation about the usefulness of integrating helpful tools into the computing environment. Few will question the value of such tools in the work environment. Consider, for example, the inconvenience of using a word-processor without immediate access to electronic versions of common tools such as dictionaries, drawing materials, and calculators. It is thus natural for educational software designers to provide these kinds of helpful electronic accessories in their products. However, our classroom observations lead us to note that there can be benefits in encouraging students to use non-electronic tools while at the computer. In particular, making notes in their personal journals and using their own hand calculators while solving problems in the games provided effective linkage, one form of transference, between computer and non-computer activities in the classroom. Also, the simple act of switching context between the computer environment and non-computer environment seemed to stimulate reflection.

The above examples all illustrate the point that making computer use more efficient for learners can sometimes result in less effective learning.

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