Computer Games, Education And Interfaces: The E-GEMS Project

Maria M. Klawe

Department of Computer Science
University of British Columbia

Abstract

For the past six years the E-GEMS project has studied the design and use of computer games and activities for mathematics education in grades 4 to 8. Our research has involved researchers in education and computer science, professional game developers, teachers and thousands of children. The outcomes of this collaboration include a wide range of research studies as well as innovative prototype games and a successful commercial product. Our results demonstrate that games can be very effective in increasing both motivation and achievement in mathematics learning. They also pinpoint the critical importance of detailed elements of game design, the role of the teacher, and the integration of computer games with other forms of mathematics education. Finally our work has identified important differences, as well as similarities, in girls' and boys' interactions with games and computers. In this paper we highlight some of the recent E-GEMS work with particular attention to the aspects related to interfaces and HCI.

Key words: interactive multimedia, games, educational technology, computer supported collaborative learning.

1 Introduction

E-GEMS, the Electronic Games for Education in Math and Science project, is a collaborative project centered at the University of British Columbia (UBC). E-GEMS involves researchers in computer science and mathematics education as well as teachers, children and professional game developers. In addition to UBC, the E-GEMS participants include Queen's University, Electronic Arts, and several schools in British Columbia and Ontario.

E-GEMS was created in late 1992 to explore the potential of specially designed electronic games to increase learning and appreciation of mathematics and science by children in grades 4-8. This age range was chosen because research indicates that this is when most children lose interest in these subjects. We were interested in electronic (i.e. computer and video) games because of their appeal to children and because they offer excellent opportunities for visualization and exploration of complex concepts. On the other hand, we also had serious concerns about using such games. Most girls, especially aged 10 and older, seemed to be less interested in playing electronic games than boys, and less interested in using computers in general. Moreover, there was little concrete evidence that traditional electronic games were effective in enhancing mathematics and science learning for purposes beyond memorization drills.

The E-GEMS use of the term "educational computer game" encompasses a wide range of computer-based activities. Specifically, we use it to refer to educational software incorporating popular electronic game elements such as a high degree of interactivity, exploration, puzzles, challenges, scoring, graphics, music, sound effects, or narrative. Over the last six years E-GEMS research has included basic studies on how children interact with commercially available computer and video games as well as the development of innovative prototype games which we have used to explore a variety of design issues. Throughout we have paid particular attention to gender issues in order to understand and support the effective participation of girls as well as boys in computer-supported learning environments.

Our project has benefited greatly from the contributions of several teachers who have been part of the E-GEMS research team for several years. The teachers' classrooms serve as ongoing long-term research sites to test the effectiveness of games and strategies for incorporating computer games into mathematics education. Moreover, both teachers and students contribute to the design of prototype games and usage strategies. We use an iterative process to develop game prototypes, alternating among design, implementation and evaluation in the E-GEMS classrooms. We also conduct focused quantitative and qualitative studies with students in other classes and schools to explore specific design and use issues.

Overviews of E-GEMS research can be found in [9] and [10], which, like most of the individual E-GEMS publications, are also available at our website, www.cs.ubc.ca/nest/egems/home.html. In this paper we start with three examples of E-GEMS work on the impact of software and hardware design in educational games. This is followed by a brief section on gender differences encountered in our research. We close with a section describing our current work on multi-user networked games.

2 Exploring the impact of design

A primary goal of the computer scientists involved with E-GEMS is to understand the impact of detailed elements of software and hardware design on children's learning of the target educational concepts as well as on their motivation to play the game. This section briefly describes the main results obtained by three computer science graduate students who recently completed their thesis work in E-GEMS.

2.1 Adapting the human-computer interface to support collaborative learning environments for children

Kori Inkpen's Ph D. research [5] evaluated computer-based collaborative environments for children, using three important criteria: the social environment in which the technology was placed, the technology provided for explicit collaboration, and the low-level interface design. An additional area of focus that crossed all three areas was gender. Three field studies were conducted using a creative problem-solving game as the research vehicle. The computer environment (both hardware and software) was modified to allow the addition of a second mouse to explore how this would affect achievement, learning and behaviour. The major results of these studies include:

- The grouping of children at computers can affect their achievement, namely placing two children at a single computer can have a positive effect on both achievement and motivation compared to having children play on their own. [6]
- The addition of a second mouse can positively affect children's achievement and learning in the game, as well as the temporal patters of who controls the mouse. [8]
- Children are able to perform point-and-click movements faster and with fewer errors than drag-and-drop movements. More children prefer point-and-click over drag-and-drop. [4]
- Choice of interaction style, i.e. point-and-click movements verus drag-and-drop, can affect both achievement and motivation. [4]
- Gender differences were observed in all stages of the research. [5]

2.2 Interface manipulation style in a geometric game

Kamran Sedighian's Ph.D. research investigated the role of interface manipulation style and scaffolding on students' reflective cognition and concept learning through a comparison of the effectiveness of several versions of a game, Super Tangrams, that was designed to assist in learning two-dimensional transformation geometry. The versions utilized three different interface designs. The first was a Direct Object Manipulation (DOM) interface in which the user manipulated the object being transformed. The second was a Direct Concept Manipulation (DCM) interface in which the user manipulated a representation of the transformation being applied to the object. Finally, the third was a Reflective Direct Concept Manipulation (RDCM) interface in which the DCM approach was combined with scaffolding that gradually faded the feedback provided by the interface.

A field study of approximately one hundred grade 6 students was conducted to evaluate the effect of ten forty-minute playing sessions on their understanding of two-dimensional transformational geometry and on their attitude towards the subject area and various aspects of the game design and experience. Data was collected from several sources including written pre-tests, post-tests, and questionnaires, videotapes and log files from the playing sessions, and interviews with twenty per cent of the students using each version of the software. Learning gains were assessed as the difference between scores on the post-test and pre-test.

The learning gains of students using RDCM versions were significantly better than those of students using DCM versions, which were again significantly better than those of students using versions with conventional direct manipulation interfaces. Moreover, the qualitative data from questionnaires and interviews strongly supported the quantitative data on learning gains. All students found the ten playing sessions highly enjoyable, but the students using RDCM versions indicated that they had had to think very hard and felt they had learned a great deal. The students using DCM versions expressed this to a lesser degree, and the others to a much lesser degree. These results are presented in detail in Sedighian's thesis [14] and in a number of papers ([13], [15], [16], [17], [18]).

2.3 The importance of task specification and communication mode in collaborative learning environments

The M. Sc. research of David Graves investigated the effect of task specification and communication mode on learning gains and attitude. An interactive multimedia activity, Builder, was created to allow a pair of students to build a house together, with each student working from their own computer. The activity included an interactive graphical interface, shared two- and three-dimensional views, sound feedback, and real-time written and spoken communication. Several mathematical concepts were embedded in the activity including area, perimeter, volume, and tiling of surfaces. An field study with 134 school students aged ten to twelve found that playing Builder led to learning gains in the target mathematical areas, and that the nature of how the task was specified had a significant impact on the size of the gains. The learning gains were assessed as the difference between scores on written post-tests and pre-tests, and a questionnaire was used to collect information on the socio-motivational outcomes of playing Builder. Log files were also used to collect other measurements such as number of challenges completed, scores achieved on challenges, and number and length of messages that were sent. The mode of communication was found to affect attitudes towards the activity and the student's partner. Gender differences were found in perceived collaboration and attitudes towards the activity and the partner.

These results are particularly interesting for a number of reasons. This is one of the first studies involving the use of a networked mathematical multimedia activity. Significant improvements in mathematical understanding were found after only a short period (thirty minutes) of play with the Builder activity. Perhaps most important of all, a small change in the presentation of the goal of the activity, namely requiring the achievement of a specific numeric goal versus a more open-ended maximization goal, had a significant positive effect on the increase in learning resulting from play. This last outcome demonstrates the impact that detailed elements in the design of software activities can have on their effectiveness as learning environments.

3 Gender differences

Our field studies have repeatedly revealed gender differences in students' use of and attitudes towards interactive multimedia learning activities. Girls and boys have shown different preferences and levels of performance in activities and interaction styles ([5], [3]). Girls often spend more time exploring and communicating with partners, while boys often make faster progress through the activities, completing more levels and puzzles ([1], [10], [3]). Despite completing more puzzles and levels, boys have not shown greater achievement in the assessments of mathematical understanding (see [3] for example). During classroom observations, boys have been more aggressive in seeking or demanding access to computers and in their behaviour while engaged in the activities, but minor interventions such as occasional girl-only play or discussions have resulted in enthusiastic and sustained engagement of the girls with the prototype software ([1], [9], [20], [21]).

4 Multi-user networked games

For the past few years E-GEMS has been exploring the design and use of multi-user mathematical computer games as part of the TeleLearning Network of Centres of Excellence. We have created two networked collaborative game prototypes, Island and Avalanche. The goal of these two prototype development efforts has been to use two very different game formats and platforms in order to compare the effectiveness of various design and use strategies. Island's game format is a microworld with no game-specified narrative, roles or precise goals, whereas Avalanche is a role-playing narrative-based game with clearly specified goals. Island's Mac LAN platform using C++ allows higher levels of graphics, animation and interactivity, than Avalanche's web platform using Java 1.1.

In Island players freely explore an island, obtaining building resources as rewards for solving puzzles designed to engage them in constructing knowledge about mathematical concepts, creating buildings either alone or collaboratively, and viewing those of other players. The activities available to Island players include:

- explore a fully illustrated 2D representation of the island
- communicate with other players via writing or speech
- acquire building resources (bricks, window and door frames) as rewards for completing two multi-user activities, Prime Climb (see Avalanche description below) and Builder Challenge
- select, label, build on (collaboratively or alone) and modify Island sites
- explore 3D representations of all buildings existing on the island

In Avalanche players assume the roles of the four leading citizens who form the emergency response team in a mountain ski town, and work together to attempt to cope with and reduce damage from a series of avalanches. The current set of activities in Avalanche include:

- locating all team members in the town after their communication network has been disabled due to an avalanche,
- Prime Climb: teams of players climb ice-faces by selecting numbers relatively prime to those occupied by other team members in order to collect the data needed to evaluate the critical mountain zones that are possible sites for the next avalanche
- Zone Size: players estimate the area and volume of snow in the critical zones using the data they have obtained and maps
- Snow Release: based on the information from the Zone Size activity, players decide where to place their limited set of explosives and barriers to release snow from the most dangerous zones without

releasing so much snow that another avalanche is triggered

We have conducted a number of preliminary field trials of each game in the E-GEMS classrooms, as well as the field study using the Builder component of Island described in 2.3 above. Although students have generally found the networked games highly motivating, we have encountered significant and persistent difficulties in bringing the games to the level of stability needed to conduct field studies of the games as a whole. We are currently focusing our efforts on achieving the stability needed to begin field studies with Avalanche. We plan to focus these studies on investigating how the specification of roles in the task, and the apportionment of access to resources and control among the roles, affects learning gains, attitudes towards partners, and the degree and form of collaboration.

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