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Math-City: an educational game for K-12 mathematics

Irene Polycarpou[a,*], Julie Krause[a], Cyndi Rader[a], Chad Kembel[a], Christopher Poupore[a], Eric Chiu[a]

[a]*Mathematical and Computer Sciences, Colorado School of Mines, Golden, CO 80401, United States*

Abstract

Recent United States national test results indicate a continuing need to improve K-12 student achievement in mathematics. In an effort to address this need and to expose young students to basic renewable energy concepts, we have developed an educational game called Math-City. Math-City is a simulation-based game in which students can create and maintain their own city with residential, commercial, and industrial buildings, as well as renewable and non-renewable power sources, while practicing different mathematical concepts. In this paper, we present the Math-City game along with the results of a small survey on the game with K-12 teachers.

Keywords: K-12 mathematics education; educational games; mathematics games; renewable energy; technology in education; instructional technologies.

1. Introduction

The future competitiveness of any country is dependent on the kindergarten through twelfth grade (K-12) educational system developing all students' talents in mathematics and science and encouraging all students' interest in these areas. In the United States (U.S.), concerns have been expressed across the nation with respect to K-12 mathematics and science education, since U.S. students are performing below their international peers in comparable levels (Keranchsky 2008; Kirsch, Braun, Yamamoto & Sum, 2007; Martin, Mullis, & Chrostowski, 2004; Mullis, Martin, Gonzalez, & Chrostowski, 2004). Moreover, recent national test results indicate a continuing need to improve K-12 student achievement in mathematics (NAGB, 2009).

The use of educational games is one way that has been shown to be effective for improving K-12 education (Prensky, 2001). Educational games can be designed as fun activities through which students can learn and practice different concepts. With the advancement of technology and the increasing number of electronic games targeting our youth, it is not a surprise that kids spend hours of their leisure time playing electronic games (Etuk, 2008; Rideout, Foehr, & Roberts, 2010) and that many researchers argue educational games' potential to support education (Ireland, Kaufman, & Sauvé, 2006; Van Eck, 2006; Squire & Jenkins, 2003; Prensky, 2001), especially in terms of motivating, exciting, and engaging the students in the learning process. Educational games can capitalize on students' enthusiasm about electronic games and serve as a motivation for their learning as well as serve as a medium for capturing students' interest in a specific subject area.

* Corresponding author. Tel.: +1-303-273-3462; fax: +1-303-273-3875.
E-mail address: ipolycar@mines.edu.

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In this paper, we present an educational game called Math-City, which is a simulation-based game. In Math-City students can "build" and maintain their own city while at the same time practicing different mathematics concepts. Currently, the game includes fifth grade mathematics questions, but it is designed to be expandable to other grades and topics, as well. Teachers can use Math-City as part of their classroom instruction for students to practice and master specific concepts. Students can also use Math-City on their own time and at their own pace to prepare for a test or practice concepts that are more difficult for them to understand. As an additional feature, the game exposes students to basic renewable energy concepts, such as solar and wind energy.

2. Math-City Game

2.1. The Game

Math-City provides an engaging city-simulation environment in which students can build and maintain a city with residential, commercial, and industrial buildings, as well as renewable and non-renewable power sources. The game incorporates many elements of a real city, using a simplified interface designed to be intuitive for young students. As in real life, "city developers" in the game need money to pay for buildings and resources, and a successful city should include roads, houses, places for people to work, and essential services such as police and fire departments and hospitals. All buildings in the city require energy to operate, so they must be connected to a power source (e.g., wind turbines, solar panels, or coal plants) by power lines.

The game begins with an empty grid on which the city can be built and a small amount of money available to start building the city. Throughout the game players can answer different mathematics questions to earn additional money. A toolbar that provides all the necessary construction items (e.g., different kinds of buildings, power sources, power lines, roads, etc.) and game information (e.g., money available) is available throughout the game (see Figure 1). Each item available for the city is associated with a specific cost and students need to have the necessary funds available to add an item to their city.

The main goal of the game is to create a city that maximizes the happiness of its residents. Currently, the game includes five happiness factors: Pollution, Police, Fire, Health, and Big Buildings. For example, when the pollution in the city is too high or when there is not enough police or fire or health coverage, the residents are not happy and they move out of the city. To assist students in reaching the goal of developing a city with happy residents, the game provides constant feedback through the city happiness indicators which are available on the game's main toolbar (see Figure 1). Students can improve the Police, Fire and Health metrics by adding the appropriate buildings (i.e., police stations, fire stations, and hospitals). The Big Buildings metric can be improved by moving large buildings such as power plants or factories farther away from the residential areas. The Pollution metric can be improved by reducing the number of pollution-producing factories and by using wind turbines or solar panels, rather than coal plants. The inclusion of renewable energy sources in the game helps to model the cost-versus-efficiency relationship for current renewable energy sources, while concurrently demonstrating the positive effects of their use on pollution. Renewable energy concepts are also reinforced by the inclusion of fossil fuel-based power sources. These power sources are cheaper and produce more power than the renewable energy sources, but in turn generate pollution that may drive residents out of the city.

In order to offer additional feedback to students regarding the success of their city and to enhance the engagement potential of the game, short video clips have been integrated into the simulation. The video clips in Math-City include short, fun scenes with mock news reports from young newscasters (students) indicating the state of the city. For example, each time the aggregated pollution rises above a given threshold a newscast appears on the screen, warning the player about the high levels of pollution in the city. Similarly, when the aggregated pollution improves significantly a positive-message newscast appears.

In addition, throughout the game there is an Info button available which provides players with information on individual houses, such as the number of residents, the negative and positive factors affecting the happiness of those residents, and if applicable, a hint as to what actions the player can take to improve the happiness factors affecting the desirability of the house.

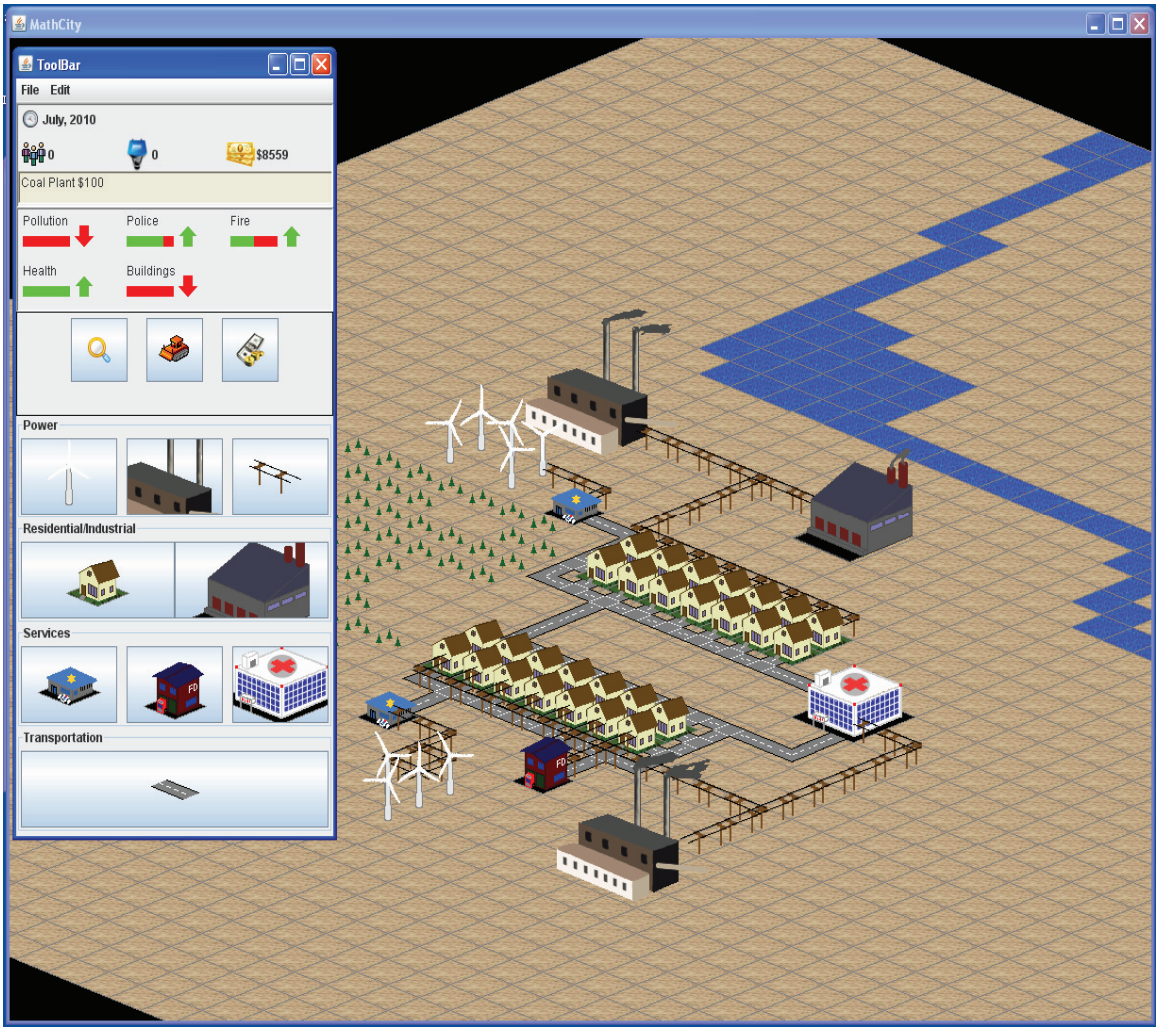

Figure 1. A sample city which is comprised of homes, services (hospitals, fire stations, and police stations), and factories, which are all powered by coal plants or wind mills and are connected to one another by roads. The main toolbar is also shown on the left.

2.2. Mathematics Problems

As mentioned earlier, students begin the game with a small amount of money available to build their city, and each building or resource has a fixed cost associated with it. If students do not have sufficient money to continue building, they can earn additional funds by answering mathematics questions. By answering a question correctly, students earn an amount of money commensurate with the difficulty of the question. Answering a question incorrectly does not affect the amount of money students have available. The type and difficulty of the mathematics questions presented in the game vary and they change dynamically, based on students' performance in previous questions. This ensures that students will not just answer the same type of questions that they have already mastered. Once students have correctly answered a sufficient number of questions at a given level, they progress to the next difficulty level.

Currently, the problems included in the game are based on two major topics, fractions and word problems. Both of these topics are essential in fifth grade mathematics and students have difficulties with them. Fraction problems include adding and subtracting fractions with different denominators as well as identifying fraction equivalency. Word problems are designed to test students' understanding of the four basic arithmetic operations (i.e., addition, subtraction, multiplication, and division) in a problem-solving context. The problems presented in the game are all based on U.S. fifth grade mathematics standards (NCTM, 2010) and they aim at practicing concepts found in U.S.

standardized fifth grade mathematics tests. Problems come in two different formats, multiple choice questions (see Figure 2) and questions for which students type their answers.

The game provides students with immediate feedback on an answer submitted (i.e., correct or incorrect). When students answer a question incorrectly, a Hint button is available and highlighted. The hint provides students with the solution to a simple, related example, so that they can see how that type of problem can be solved.

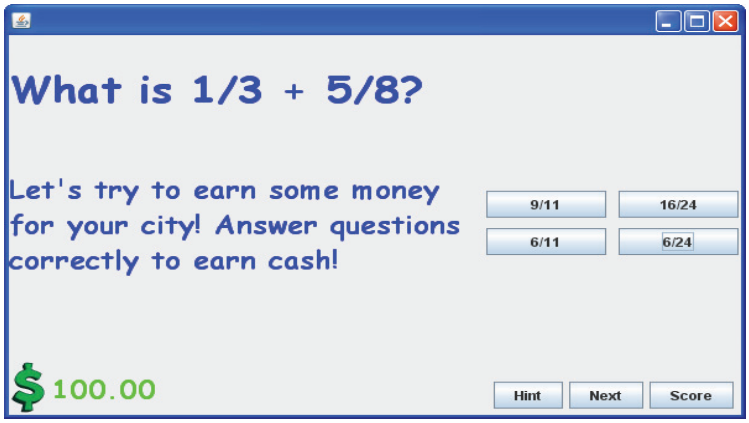

Figure 2. An example of a Level 1 multiple choice math question.

The game also provides feedback on students' overall performance, including the total number of questions attempted, the number answered correctly and incorrectly, and the percentage of correct answers. The category with which the students had the most difficulty is also displayed (see Figure 3). Moreover, to assist teachers in identifying problem areas, logs of students' performance can be generated. The reports contain information about the number and types of problems students answered correctly and incorrectly.

Figure 3. Feedback regarding a student's overall performance.

3. Teacher Survey

Before continuing expansion of Math-City, we decided to acquire feedback from K-12 teachers on whether the game was something they would like to use in their classrooms and to get teachers' perspectives on whether their students would find such a game interesting. Our university offers a two-week professional development summer workshop for mathematics and science teachers from the local schools. During the last summer workshop (Summer 2010), we organized a one hour session on Math-City for the participating math teachers. In this session teachers were introduced to the game and they had the opportunity to play the game for approximately forty five minutes. Ten mathematics teachers participated in this session. At the end of the session teachers were asked to fill out a questionnaire about the game, so as to provide us with feedback on their experience. The questionnaire was composed of seven questions. The results from the questionnaires are shown in Table 1.

Question 1: Did you find the game to be easy to play? Explain	All teachers responded positively to this question, but four of them commented that even though the game was easy to play and "self explanatory," it would be helpful for students if the game included a short tutorial of how to play the game (e.g., explain the goal of the game, the happiness factors, and how to use the items available).
Question 2: Would the necessity to earn money to progress in the game be motivating for your students to answer math questions? Explain.	Eight out of ten teachers responded that this would be motivating for their students. Two teachers responded that this 'may be' motivating (they were not sure) and they suggested that starting the game with no money at all might be more motivating, since students would have to answer math questions to start playing the game.
Question 3: In your opinion, what aspects of the game are the most engaging and fun?	Building and planning the city were the most common responses (seven out of ten teachers). The rest of the responses included "building a community", "balancing the satisfaction of the citizens", and "seeing how the development of your city is affecting the residents.
Question 4: Do you think that this game presents an appropriate level of challenge and motivation for your students? Explain.	Six out of ten teachers responded that the level of challenge in the game is appropriate and motivating. The other four teachers responded that they were not sure. Some of their comments were that the game needs to challenge students more by not offering start-up money and that students should be required to answer more than one question to earn money. One teacher commented that the "payoff is too slow," since students play until they spent their money and then answer more questions.
Question 5: Do you like the idea of introducing students to renewable energy concepts through the game?	Nine out of ten teachers responded positively. One teacher did not respond positively or negatively, but commented that it would be more beneficial to include additional renewable energy sources as well as "green spaces" such as parks, to improve happiness and minimize pollution.
Question 6: Would you use this as a supplemental tool in a classroom setting and/or as take-home practice for your students? Explain."	Eight teachers responded positively, one negatively, and one responded maybe. The positive responses were mostly for using the game in the classroom, as a homework assignment, or to motivate students to work on their own time at home. One teacher commented that the game will be a good way to introduce students to renewable energy, before formal instruction. The teacher who responded negatively commented that the game takes a lot of time with little practice, since students can play the game for awhile without answering any questions.
Question 7: Are there any expansions to the game that you would recommend?	The suggestions included adding more building types (e.g., different types of houses, schools, malls, etc.), parks, the ability to "install green spaces or trees," natural disasters, sports activities, and a module through which teachers can add their own math questions.

Table 1: Results from teacher questionnaires

Through personal discussions with the teachers we also found that the majority of them believe that the game is appropriate for fifth to eighth grade students and for other subject areas such as science, as long as the problems are updated for each grade level and subject area.

The overall feedback from the teachers is encouraging and even though Math-City is just a prototype at the moment, it seems that it is worth expanding and investigating further.

4. Discussion and Conclusion

In this paper, we have presented an electronic game (Math-City) in which students can build their own city while at the same time practicing K-12 mathematics concepts and being introduced to renewable energy concepts. We also presented a small survey on teachers' perception of the game. The overall feedback from the teachers was positive with most of them indicating that this is something they would like to use as a supplement to their teaching material. The results of this survey are encouraging for further investigation and continuation of the project.

One of our main future goals is to test whether the game is effective for improving students' performance with standardized mathematics tests by comparing the test scores of students who use the game and students who do not. Students' perspective of the game is also an important aspect for future developments and we are planning to conduct a study with K-12 students to collect feedback in regards to the functionality of the game as well as its appealing factors to the students. A more comprehensive study with K-12 teachers will also be conducted. According to the feedback we receive from students and teachers, we will update and improve the functionality of the game.

Based on the results of our exploratory survey with K-12 teachers, we are currently working on expanding the items available for constructing the city, such as new buildings (e.g., schools, malls, and transportation), parks, and trees. We are also working on expanding the renewable energy sources available in the game by adding hydro power, as well as making the renewable energy aspects of the game more realistic by including weather variations throughout the duration of the game. Another issue that arose from teachers' feedback was the inclusion of a small tutorial which will explain the different functionalities of the game and how the game can be played in general. We are already working on developing this tutorial and it will be optional for the students. The tutorial will be in a video format and will include a short walk-through of the game.

As for the problem types included in the game, we are working on developing a simple, friendly interface through which teachers can change or add problems. We are still planning to have a set of problems pre-loaded and available in the game, but teachers will have the option to edit and expand the given set of problems. This will provide teachers with the opportunity to adapt the game to the subject area and grade level of their interest.

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