Nanogenetic Learning Analytics: Illuminating Student Learning Pathways in an Online Fraction Game

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ABSTRACT

A working understanding of fractions is critical to student success in high school and college math. Therefore, an understanding of the learning pathways that lead students to this working understanding is important for educators to provide optimal learning environments for their students. We propose the use of microgenetic analysis techniques including data mining and visualizations to inform our understanding of the process by which students learn fractions in an online game environment. These techniques help identify important variables and classification algorithms to group students by their learning trajectories.

Categories and Subject Descriptors

K.3 [**Computers and Education**]: General

General Terms

Measurement, Documentation, Performance, Experimentation.

Keywords

Measurement, Documentation, Performance, Experimentation. Keywords Microgenetic research, process analysis, mathematics education; rational numbers; fractions; games

1. INTRODUCTION

Fractions have been described as an extremely challenging part of mathematics curriculum [5, 2, 10, 15, 12]. An understanding of fractions is critical to success in Algebra [15], a gatekeeper course to higher education [4, 16, 19].

A variety of models have been suggested to explain how students learn fractions. In our analysis, we draw on the splitting learning model [12, 3, 13, 16]. In this model, students learn fractions by first using their judgments of relative magnitude and their ability to split a whole into equal parts. In this way, students develop an understanding of rational numbers through creating equal divisions of a whole part and considering the numerical values for these dividing splits (see figure 1). Splitting is generally considered to be the most promising concept for teaching rational numbers to students because it draws on children's intuitive understanding of halving and because it is consistent with more advanced rational number concepts [3, 9, 14, 16, 17].

Microgenetic methods allow the discovery of learning processes and examination of how those processes relate to learning outcomes (e.g., [8, 18]). In classic microgenetic studies, researchers examined how participants' strategies and understanding of tasks changed at the problem level over the course of several interviews during critical periods of change for learning the specific content under study [8, 18]. Rather than relying on pre- and post-test performance to determine student learning, microgenetic analy-

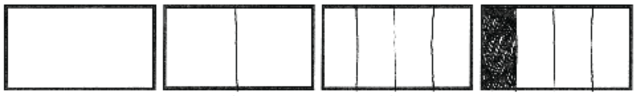

Figure 1: A student splits a rectangle in half, then splits each half in half again, shades one of the resulting pieces, and concludes that it is one fourth of the rectangle.

sis has traditionally documented learning processes through video recordings and human coding—a time consuming process.

We use learning analytics methods to examine how elementary students learn in Refraction [1][1], an online game designed to teach fractions using the splitting or equal partitioning model. The use of online game environments like Refraction simplifies and expands the data collection and analysis process. We were able to collect data at the keystroke level on students' play activity. As we analyze this data, we can expose patterns in students' learning processes at a much finer grain size that was possible before, giving rise to the term nanogenetic analysis [8, 20].

2. METHODS

In this study, ten and eleven year olds ($N = 24$; 13 boys, 11 girls) played Refraction over a period of approximately seven weeks in their classrooms. Refraction levels require users to solve fraction problems using 1/3 and 1/2 "splitters" to divide a laser beam into the required pieces. Figure 2 shows an example of a level solution.

3. VISUALIZING STUDENTS' LEARNING PROCESS

As a first step in examining our log data to understand learning process, we created visualizations of the pathway each student took through each level. Because we wanted to understand students' learning process in regard to fractions, we focused only on the moves that had a mathematical impact on the level (ignoring those moves which merely changed the direction of the laser). To illustrate how we visualized students' mathematical progressions, we will use a level that asked players to use 1/3 and 1/2 splitters to power a 1/6 and a 1/9 ship.

We started by creating representations of the state of the game space after each mathematical move. Figure 3 shows the initial state for each student; the whole laser beam aimed off the screen into space. The yellow circle represents the laser source, and the black circle indicates that the laser goes out in space without striking either target ship.

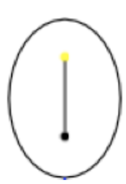

Figure 3: The initial state in an individual visualization.

[1] http://games.cs.washington.edu/refraction/

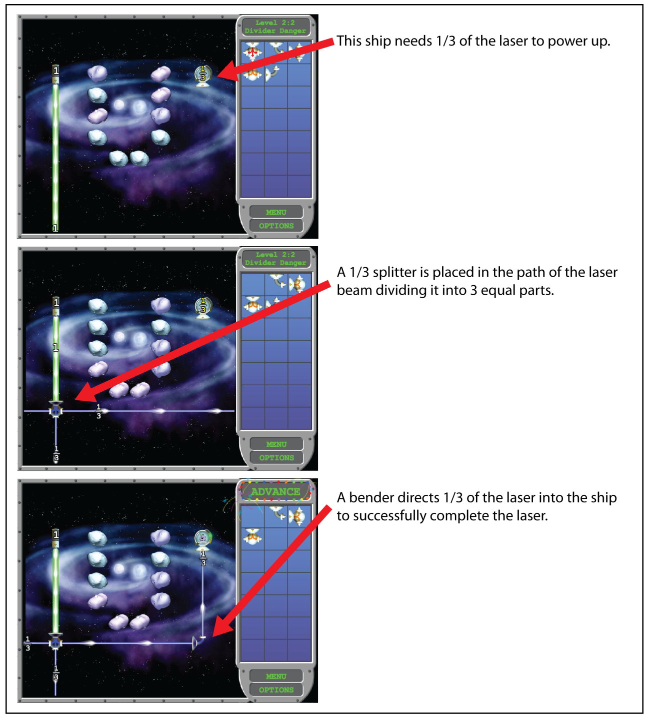

Figure 2: Steps for solving a level in Refraction. As students moved through the levels, the fractions became more difficult to solve.

As the student adds mathematical moves, the visualization became more complicated. In Figure 4, the student has now placed a 1/3 splitter on the laser beam.

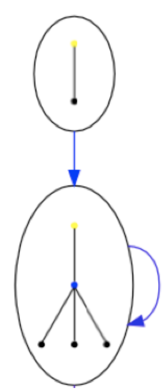

Figure 4: A player places a $1/3$ splitter on the beam.

Figure 5 shows a student's progress through an entire level. The colors of the arrows shade from blue to red to indicate the order of the transitions.

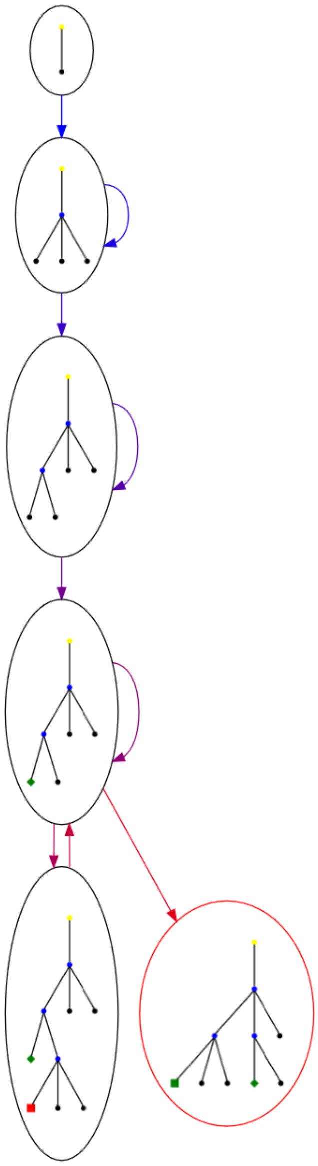

Figure 5: A complete visualization for an individual student on a single level.

This student started the level as described above. Then, she placed a 1/2 splitter on one of her 1/3 laser beams. None of the resulting 1/3 or 1/6 beams hit a ship. Then she removed and replaced splitters to end up with the same resulting state. Next, she used benders to position one of her 1/6 beams so that it hit the 1/6 ship with the correct amount (the green diamond at the end of the beam shows that she hit the 1/6 ship with the correct amount). Next, she placed a 1/3 splitter on the other 1/6 beam and used bender to direct one of her resulting 1/18 laser beams into the 1/9 ship (the red square at the end of the 1/18 beam shows that she hit the 1/9 ship with an incorrect amount). Next, she removed the 1/3 splitter from the 1/6 beam, placed it on one of the 1/3 beams and used benders to direct one of the resulting 1/9 beams into the 1/9 ship (the green square shows this was accurate). The final state of the level has a red border. The color of the border only indicates that this was the final state and not whether the final state was a successful solution for the level.

Comparing visualizations demonstrates differences in how students progressed through the same level. For example, Figures 5 and 6 both show students working on the 1/6, 1/9 level.

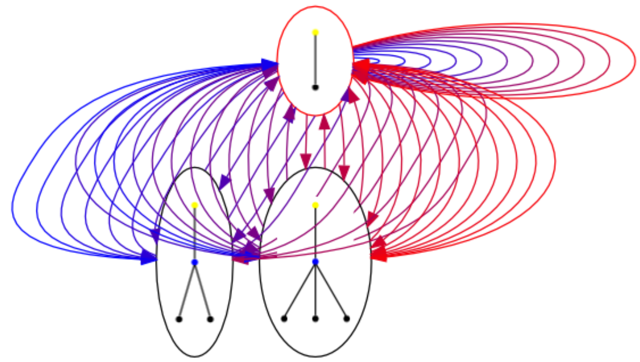

Figure 6: Visualization of a student's in-game pre-level.

First, we can see that Figure 5 shows a successful attempt, while Figure 6 does not. Second, it is noticeable that Figure 6 has many more repeated states (and therefore less states) than Figure 5.

4. CLASSIFYING STUDENTS' LEARNING PROCESSES

Exploratory data analysis comparing and contrasting visualizations of students' pathways through individual levels and across levels helps us see aspects that differ across time and across students. The next step in our process has been to create variables that capture these aspects in ways that allow grouping of students in order to generate categories of learning pathways. For the dataset reported on here, students' individual process visualizations showed a variety of patterns. However, many of these patterns were either (1) not repeated frequently enough in our small sample to provide a good basis for grouping, or (2) not meaningful. However, one pattern we noticed was that students tended to explore the space of the game in different ways. Some students seemed to avoid exploration and move quickly to solutions, while others seemed to experiment more with different types of moves. This phenomenon captured our interest because there is significant debate about the role of exploration in learning (e.g., [6, 7, 11]). To begin to understand these types of exploration better, we developed a coding scheme for transitions and a classification scheme for patterns of transitions over time.

4.1 Coding Transitions

First, we identified each unique transition between states in the students' individual process visualization data described above. Then we coded each transition based on whether the move added or removed a splitter in a way that led the resulting game state to be potentially closer to a successful solution or not.

The primary coder created the coding scheme and coded all of the transitions. A secondary coder independently coded one-third of the transitions. The two coders reached 90% agreement on their transition coding.

4.2 Categorizing Pathways

Next, we developed a scheme to classify students' trajectories of transitions over the course of their pre- and post-levels. We categorized a student as experimenting with failure if he made at least three transitions in a row that added potential failure. Similarly, we characterized a student as experimenting with success if she made at least three transitions in a row that added potential success. We also noticed that some students did not experiment much, but simply solved the problem.

Applying these simple criteria resulted in 3 trajectories:

- Rapid success;
- Experimenting primarily with success;
- Experimenting primarily with failure;

Figures 7-9 show examples of these patterns.

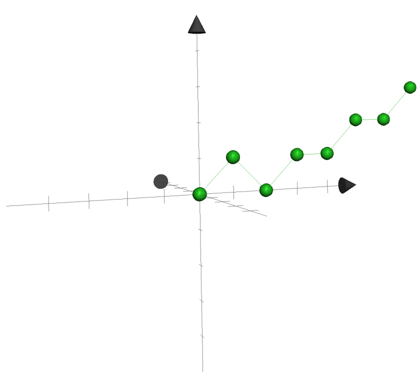

Figure 7: Rapid success.

These patterns are intriguing in that they represent different ways of exploring the space of the game. However, in this small dataset, it is difficult to draw conclusions relating type of pattern to outcome measures such as success on a level or time to complete a level.

5. CONCLUSIONS AND NEXT STEPS

In this iteration of creating visualizations and categorizing pathways of learning, we developed our process of work and 1) illustrated that students can develop better fraction understanding using the splitting construct and 2) that nanogenetic approaches to data analysis do illuminate fine grained patterns showing that students explored the space of the game in a variety of ways.

Our small sample size and choice of using human coding for this iteration of our work were clear limitations. We are currently taking several steps to mitigate these limitations.

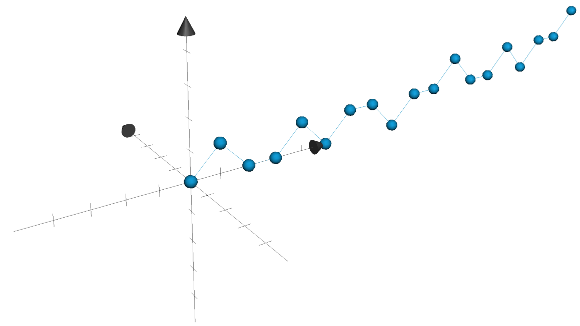

Figure 8: Experimenting with success.

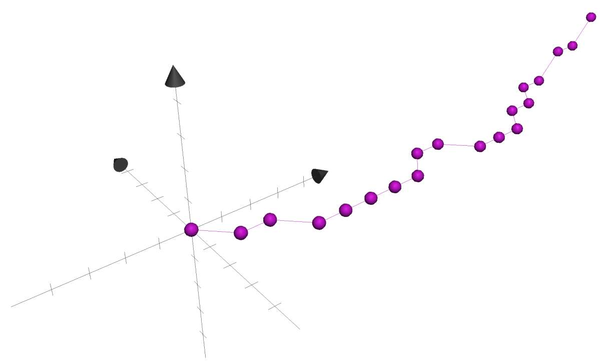

Figure 9: Experimenting with failure.

In our exploratory analyses, we are developing visualizations that make discovery of important variables easier. For example, our new visualization scheme shows the entire state space of the level as well as the states in that space that an individual student progressed through while solving that level. This allows us to compare areas of the state space across students and for the same student over time more easily.

In our work to develop better classification schemes, as we see patterns in learning pathways, we are analyzing these patterns to generate potential variables of interest such as time in state, number of unique states in a level, number of repeat moves, and distance between each state and the goal state. Using these variables, we are creating classification algorithms to group students based on patterns of behavior with a new larger dataset ($N > 3000$). To better understand splitting, we plan to characterize the development of fraction concepts using the individual trajectories through the levels, classify students based on how they do splitting, and investigate whether different patterns are more or less associated with success.

6. ACKNOWLEDGMENTS

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