Visualization of "States" in Online Educational Games

Ani Aghababyan[1], Jürgen Symanzik[2,4], and Taylor Martin[3]
[1,3]Utah State University, Instructional Technology and Learning Sciences, Logan, UT, USA
[2]Utah State University, Department of Mathematics and Statistics, Logan, UT, USA
[4]Corresponding author: Jürgen Symanzik, e-mail: symanzik@math.usu.edu

Abstract

In the field of Instructional Technologies, online educational games play an important role. Students who play these games create a huge amount of online data as each mouse movement and mouse click is being recorded. The task of educators who are analyzing these data is to determine whether the participating students have made any progress in understanding the underlying topic. In this article, we will focus on data from the "Refraction" game, accessible at http://play.centerforgamescience.org/refraction/site/. This game is an online puzzle that teaches fractions. Our presentation will focus on a graphical representation of the "states" reached by individual students in this game. For example, to create the fractions of 1/6 and 1/9, it is necessary to multiply 1/3 with 1/2 and 1/3. Nevertheless, many of the participating students try to multiply 1/2 with something else – a starting move that never will lead to the correct solution. Our visualization of the intermediate "states" allows educators to assess which students have been on track and which students got lost with a particular mathematical fraction-based task.

Key Words: Data Visualization, Fractions, Learning, Mathematical Games, Online Data, Refraction Game.

1. Introduction

There is an indication that electronic games have become a regular part of normal childhood and adolescence (Greenberg et al., 2008; Olson et al., 2007). In recent years, the interest in games for learning has grown, and educational games have increased in their popularity as means of instruction (Rodrigo et al., 2008). Nowadays, many educational concepts and topics (especially mathematics and science concepts) are covered by and practiced through educational games. These games are designed as unstructured environments where students can learn educational concepts by trial and error through attractive and fun interfaces and mostly at their own pace. This instructional approach is mainly justified with the knowledge that students love games and they are naturally motivated to play and engage with such environments.

Along with using games for learning purposes, many of the creators of such educational environments are interested in using the data from games to analyze learning processes. Educational data mining and data visualization techniques have the potential to illuminate learning patterns across a big number of students such as our data set (i.e., 3rd grade students from an online academy across the nation).

In this article, we illustrate how data visualization of a gameplay can enable interested parties (e.g., researchers, teachers) to easily identify the learning pathways of their students in order to provide necessary support for their learning and advancement.

In Section 2, we provide an overview of previous research on students' challenges with mathematics, especially with rational numbers and fractions. In Section 3, we present the Refraction game and, more specifically, level 116 of this game. Section 4 introduces the visualizations that are the main focus of this article. We finish with a discussion and conclusions in Section 5.

2. Background

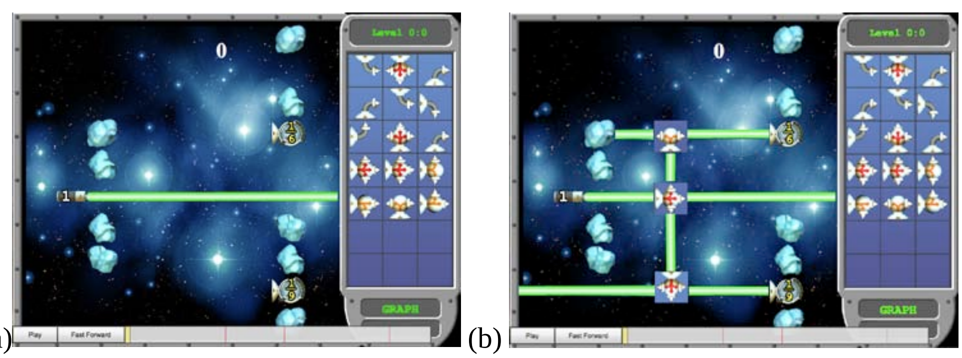
Mathematics proficiency is critical for students' continued success in school (Bailey, 2009), access to postsecondary education (Greene & Forster, 2003), and preparation for future employment (Bishop, 1988). In the United States, middle school mathematics classes, particularly algebra, act as a gateway course for higher education (Norton & Hackenberg, 2010; Siegler et al., 2010; Stigler et al., 2010). Fraction understanding is an essential precursor to success in algebra (NMAP, 2008). Despite its importance, students still struggle, and researchers have found that difficulty with fractions persists into adulthood (Reyna & Brainerd, 2007).

Rational numbers are one of the core concepts in elementary school mathematics, and fractions, in particular, have been described as one of the most challenging areas of the mathematics curriculum (Hiebert, 1988; Lester, 2007; NMAP, 2008).

3. The Refraction Game

Refraction (http://play.centerforgamescience.org/refraction/site/) is an online fraction game based on a model of fraction understanding centered on splitting or equal partitioning idea. It is an open-access, interactive, and spatially challenging game that was developed to help students learn fractions by playing. An educational objective of the game is to discover students' fraction learning pathways.

In Refraction, students' objective is to save different animals whose space ships are stuck in outer space without power. The space ships require different amounts of power supplied by lasers, and students apply combinations of 1/2 and 1/3 splitters to split the laser into the correct fraction of the whole laser beam that is needed by a space ship. Each game level provides the students with splitters, benders (that change the direction of a laser beam), a starting laser beam, and space ships that require certain amounts of power (fractions) to save the animal inside. The splitters are the primary mathematical tool students have. For example, Figure 1(a) displays the structure of level 116 of the game. In this level, students are required to create laser beams of 1/6 and 1/9 out of one whole laser beam using a combination of one 1/2 and two 1/3 splitters. Four 1/2 splitters, four 1/3 splitters, and seven benders can be used to achieve this goal. A possible solution is show in Figure 1(b).



(a) (b)

Figure 1. Refraction level 116 (a) at the start of a gameplay and (b) at the completion of the level.

3.1 Data from the Refraction Game

Our visualization of the data from the Refraction game is based on data from a study by Baker et al. (2013). Their study was implemented with 3rd grade (approximate age is eight years) students from an online virtual academy with national scope. Links to the game were embedded directly within the K12 (i.e., Kindergarten through 12th grade) curriculum, and the game was promoted on Facebook, K12's blog, and teacher newsletters. These efforts were successful, and 4,128 students followed the link and completed the pre-level test. The log file of the Refraction game contains data down to smallest granularity, such as student click information or even hover information. Each student move results in a new "board state" (or just "state") to indicate the change on the game board with every single move. The change between the states is called "transition"; they represent the order of the moves a student made over the course of the gameplay.

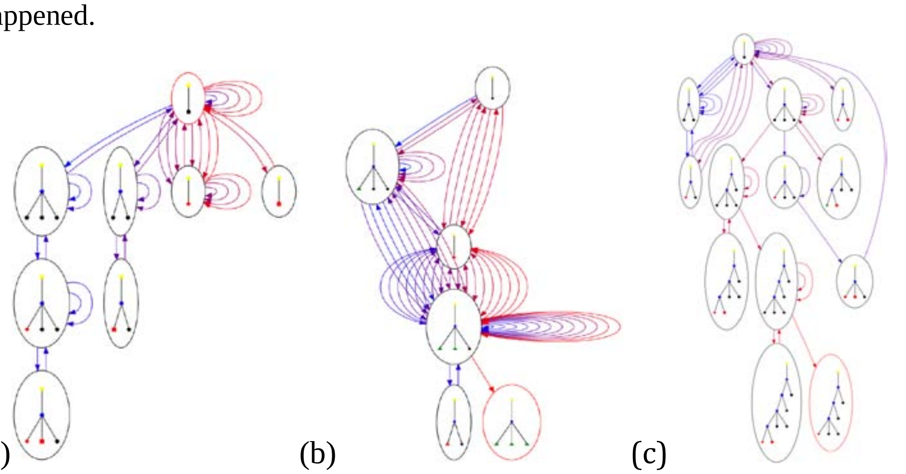
4. The Visualization of Gameplay

A previous visualization of the states of the Refraction game exists and is described in Section 4.1. Our new visualization, introduced in Section 4.2, builds on some of the elements of the original visualization, but also tries to overcome some of its limitations.

4.1 Fraction Man Visualization

States and transitions of the Refraction game were originally displayed via the "fraction man" visualization (Baker et al., 2013). This is based on a directed graph where a vertex (shown as an ellipse) represents a state and an edge represents a transition. The overall idea behind the visualization of the game data is to display the gameplay of a student for a particular level. It should be noted that the addition of a bender does not change the underlying "mathematical state".

Figure 2 shows the fraction man visualization for three students. Shown are all the states representing a mathematical state a student created through an oval shape that contains the resulting fractions. Transitions are displayed through colorful arrows drawn between the states. In Figure 2(a), the student started with the initial full laser (represented by the one pipe, see Table 1). He then made 1/3 through splitting the full laser using one of the 1/3 splitters provided in the game (represented by the symbol of 1/3, see Table 1). Afterwards, the student made a few transitions that did not create any new mathematical state, since he stayed at the 1/3 fraction for several transitions. In this graph, there are three 1/3 states that look alike but are different from each other. The first 1/3 state with one red dot indicates that the student was hitting a space ship with an incorrect amount of power. The second 1/3 state has two red dots, which means he was targeting two ships with incorrect laser power. After several 1/3 transitions, the student took off the 1/3 splitter and went back to the initial full laser state only to continue the game with the 1/2 splitter (represented by the symbol of 1/2, see Table 1). The specific colors of the transition arrows are rough indicators of the transition timeline. Transitions are shown in a sequential color scheme that goes from blue to red: the bluer the arrow, the earlier in the game the transition took place; the redder the arrow, the later in the game the transition happened.



(a) (b) (c)

Figure 2. Fraction man visualization of three students playing level 116.

Table 1. Fraction representations in level 116 of the Refraction game.

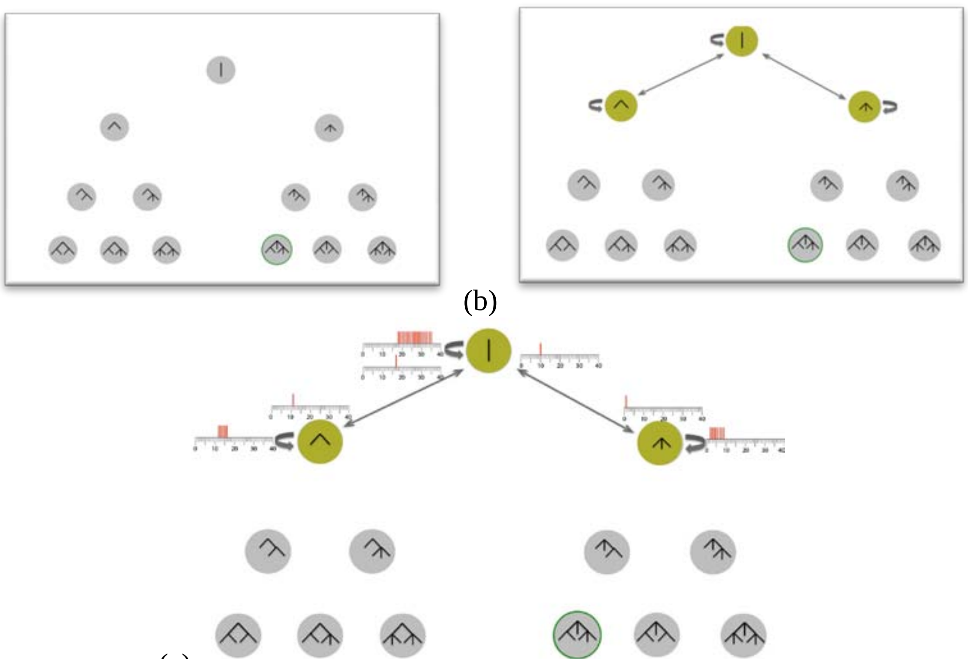
Fraction image	Fraction representation
	Full laser representing 1
	1/2: 1 full laser is split with 1/2 splitter
	1/3: 1 full laser is split with 1/3 splitter
	1/6: 1/3 fraction is split by 1/2 splitter
	1/9: 1/3 fraction is split by 1/3 splitter
	1/6 & 1/9: 1/3 fraction is split by 1/3 on one side to make 1/9 and by 1/2 one the other side to make 1/6

While this is a good start for gameplay visualization, it has several drawbacks that undermine its usefulness. First of all, besides the inappropriate choice of colors, it is also hard to determine which transition happens first due to the impossibility of following the color change, especially if the student made more than 10 transitions (see Figure 2(b)). Hence, in case of many transitions, the visualization becomes very crowded and incomprehensible. Furthermore, the graph in Figure 2(a) has only three unique mathematical states created through student moves; however, this image shows eight states. This is somewhat misleading if we want to interpret fraction understanding. Another critical drawback of this visualization is its lack of structure. There is no actual hierarchy and the location of the ellipses that represent the different states is completely random. This is due to the fact that the Graphviz visualization software (http://www.graphviz.org/Credits.php) displays the directed graphs in an optimal way from a graph-theoretic perspective. In particular, the same state may appear in rather different locations of the graph for two different players as can be seen in Figure 2(a, b, and c). Finally, unless the user of this visualization is the game creator or the researcher who named the levels, it is impossible to know what is the goal of a level. Hence, it is left up to the user to guess whether the student reached the final goal or not. Therefore, although this visualization gave us a starting point, it has several issues that need to be solved. Thus, the resolution of these problems was our primary motivation to create a better tool for visualizing these data.

4.2 Tree Structure Visualization

For our new visualization, we determined the most important features. First, we created an abstract tree-based representation of the states for each level (see Figure 3(a)). Our tree structure visualization is based on the idea of network data visualization (Becker et al., 1995). Moreover, our new visualization is based on small multiples where each state has a fixed position for a series of trees. Tufte (1983, p.170) describes the benefits of small multiples as follows: “The design remains constant through all of the frames, so that attention is devoted entirely to shifts in the data.” This approach makes our new visualization usable for comparison of gameplays across students. In addition, to make the final goal more recognizable, we surrounded it with a green circle in all the instances of the visualization independent of the fact whether the student reaches it or not. If the student reaches it, the goal state is highlighted in yellow, it he doesn’t attain the goal, that state is left grey (see Figure 3(b)). As a final design step, we introduced a timeline as a way of displaying the order of the transitions between game states (see Figure 3(c)). Figure 3(c) shows exactly the same gameplay as Figure 2(a). However, now it becomes immediately obvious that the student never tried to further split the 1/2 or 1/3 laser beams and rather tried extensively to reach the goal via the use of multiple benders. This can be seen in transitions 17 to 35 in the self-loop at the full laser (depth 0) that did not advance the game to a different mathematical state.

Our new visualization will be implemented in R (R Development Core Team, 2012), based on the R package Rgraphviz (Gentry et al., 2012). In an interactive version, the timeline can be made invisible until the user hovers over an edge in the tree to display the hidden timeline. This will keep the visualization neat and consistent.



(a) (b) (c)

Figure 3. Tree structure visualization for level 116 of the Refraction game.

5. Discussion & Conclusion

We have developed a more intuitive way to visualize students' learning trajectories for the Refraction game. Individual level-based visualizations allow us to compare and contrast different ways students' progress through the same game level. This also lets us compare students' progress over time. Thus, we present a visualization tool for both the researchers and possibly the teachers to conduct an exploratory analysis on student learning pathways.

This is work in progress, and as a next step, we plan to create student profiles that will help us predict student success and allow us to identify struggling students along with the areas of fraction understanding they are being challenged with.

Another future goal is to make these visualizations interactive, which will allow the users to customize the information they want to have displayed through the visualizations and be able to look into details without much alteration. As an extension of this goal, we are hoping to provide aggregate visualizations that might identify the levels and game sections where the majority of students make particular mistakes, struggle, or fail. This will shift the focus from individual learning progression to the entire population. Eventually, we plan to develop an R package for visualizing data from state/transition-based educational games along with conducting usability studies for this kind of visualizations.

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