Tug-of-War: a Card Game for Pulling Students to Fractions Fluency

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Abstract

We propose that adoption of game-based-learning principles can be increased by providing standardized-test evidence of learning from gameplay. This paper describes a game called *Tug-of-War* as a candidate for such evidence. *Tug-of-War* is designed to help fourth-grade students build fluency with fractions. Development of the game followed an iterative design process of user testing and rules refinement, culminating in an experimental trial in which a single fourth-grade class was divided into two cohorts. Each cohort played *Tug-of-War* for six or seven weekly 75-minute sessions while the other cohort participated in unrelated research. Results indicate that both cohorts achieved significant learning gains by playing Tug-of-War in addition to the traditional curriculum. Playing *Tug-of-War* was also shown to significantly improve scores on the fractions subsection of a statewide standardized test.

Introduction

Games are compelling both as models for learning and as pedagogical tools. Much good research has been done to explore the educational benefits of gameplay (e.g., Nelson et al., 2005, Barab et al., 2007, Squire & Klopfer, 2007), but there are still relatively few studies showing benefits on traditional measures that skeptics would value—most notably standardized test scores, which are the currency of the realm in today's policy debates (Honey & Hilton, 2011). One strategy for increasing the adoption of game-based learning principles is to provide evidence of learning from gameplay on such traditional measures. Providing this evidence with some methodological rigor could be useful for helping the research gain traction, especially in the policy sphere (Barlett & Anderson, 2009). Of course, not all game-based-learning research need be concerned with addressing skeptics: a few demonstrations of gameplay leading to learning that can be measured by standardized tests would go a long way toward supporting the broader arguments our field makes about the value of the learning that can occur during gameplay. We hope that the research we are presenting here on a game we have designed, called *Tug-of-War*, can serve in that role.

***Figure 1*. Teammate card and Trick card.**

Designing *Tug-Of-War*

The Concept

After mastering natural numbers, students are faced with the daunting task of learning about rational numbers. When confronted with fractions, children often rely on their whole-number interpretations (Mack, 1995). For example, when asked to circle 1/4 of 12 stars printed on a page, children frequently rely on their counting skills to identify and circle both a single star and a group of four stars; such children have not yet grasped the part-whole interpretation of fractions (Kerslake, 1986). Also difficult for children is realizing that different symbolic representations can refer to the same quantity (such as 1/2 and .5). We hoped to design a game that would help children understand fractional operations on whole numbers and reconcile different representations of the same quantity.

The Design

We chose to model our game after popular children's card games such as *Pokémon* and *Yu-Gi-Oh!*, which have been noted by researchers as being both popular (Ito, 2006) and highly sophisticated (Gee, 2010, Buckingham & Sefton-Green, 2003). Gameplay in this genre involves mustering "troops" and choosing cards from one's hand to attack an opponent's troops or defend one's own. In our game, *Tug-of-War*, the "troops" are groups of teammates on either side, and the "attacks" and "defenses" are pranks (e.g., stink bombs) or fibs (e.g., "I hear the ice cream truck!") and their countermeasures (e.g., air fresheners and radios).

Once our game genre was settled, we embedded our learning objectives within the game's narrative and mechanical structure. This technique was described by Malone (1981) as intrinsic fantasy and has been more fully explored by Habgood and colleagues (Habgood, Ainsworth, & Benford, 2005), who term it intrinsic integration and express it in terms of flow, core mechanics, and representations. The basic notion is that the game elements that are essential to learning should be incorporated into the narrative flow of gameplay, linked to the core mechanical operations players undertake in the game, and enacted using pedagogically sound representations to anchor thinking about the learning objectives.

Consistent with this notion, the cards for attack and defense in *Tug-of-War* (stink bombs, air fresheners, etc.) fit into the narrative of a playground tug-of-war. Mechanically, each card contains a rational number (represented as a fraction, decimal, partially filled meter, or ratio) that is applied to one of the whole-number teammate groups, weaving both of our main learning objectives into the basic game mechanic. To explain how the game represents fractional operations on whole numbers, we will use a concrete example. The left image in Figure 1 shows a group of 8 teammates (the Johnson Family), and the right image shows an attack card (a Stink Bomb) with the value 3/4. To play the Stink Bomb on the Johnson Family, players would first decide how to split the Johnson Family into four equal subgroups (the denominator of the Stink Bomb fraction); once those subgroups were formed, players would choose three of those subgroups (the numerator of the Stink Bomb fraction) to be scared away from the tug-of-war by the Stink Bomb. This process of forming and choosing subsets of whole-number quantities is our main representation for fractional operations on whole numbers in *Tug-of-War*. As players repeat this process throughout gameplay, they develop a situated understanding (Gee, 2003) of what it means to take some fraction of a whole-number quantity.

Integrating Learning Principles

Our basic design in place, we piloted with children from local after-school clubs and sports teams to resolve any problems with understanding of the rules, boredom, or unsatisfying gameplay. Once we had a fun, easy-to-understand game, we began working on ways to improve its value for learning about fractions in school. We incorporated learning supports based on observations of gameplay and post-test measures in an iterative design process. We also continually checked to ensure the game remained fun. Below are two brief examples of how learning principles were incorporated.

First, we quickly realized that children had trouble executing the fractional operations that occur in gameplay. To help students visualize and think through the operations, we added manipulatives, which have been shown to support students' transition from natural to rational number interpretations (Martin and Schwartz, 2005). The addition of stylized miniature people both supported our narrative and offered a concrete representation for our central mechanic (see Figure 2). One drawback of the manipulatives was that their appeal risked distracting from our learning objectives; our introduction to *Tug-of-War* now includes a period for children to simply play with them, making towers or using them as dolls, so that they are not distracted during gameplay.

***Figure 2*. Manipulatives**

Piloting also revealed that the expertise children developed in *Tug-of-War* was not transferring to more formal contexts. We needed a bridge that linked the manipulative-based method we taught children for resolving fractional operations to the resources they would have available in school. Our solution was the *paper method*: players draw spaces for each subgroup to be formed, draw dots in each space sequentially until they reach the number of teammates, and then circle the number of subgroups they want. For example, to find 3/4 of 8, players would draw four spaces for subgroups, draw a first dot in each subgroup while counting to 4 and then a second while counting on to 8, and then circle three of the four subgroups. The six circled dots would be the answer players sought. (See Figure 3.) This *paper method* serves as a scaffolding bridge between our initial manipulative-based method and a level of fluency at which students can perform the operations entirely in their heads.

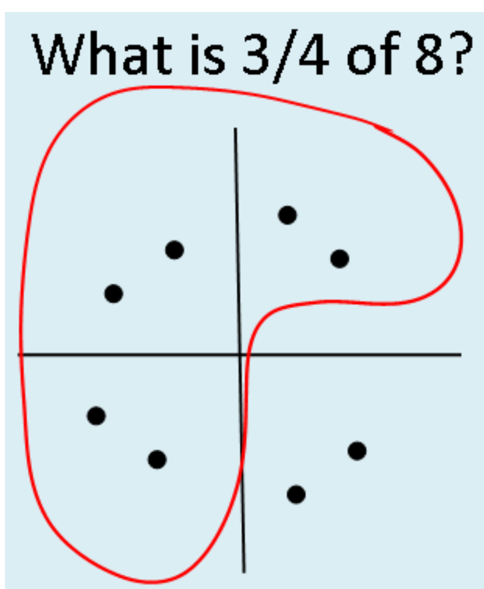

***Figure 3*. Illustration of the Paper Method**

Several other learning principles were incorporated during our cycles of development. Card designs were modified to ensure that children actually interpreted multiple rational-number representations rather than relying on just one. Gameplay became team-based, to foster improved discourse (Barron, 2003) about card choice and strategy. We also refined how children collaborated to encourage them to actively monitor one another's play, mindful that in early learning it is easier to monitor another person's performance than one's own (e.g., Gelman & Meck, 1983; Siegler, 1995; Okita, 2008).

Current Design

The game's narrative is a friendly series of tug-of-war battles between two teams of children on a school playground at recess (each "team" in the story is played by a pair of students). *Tug-of-War* includes two decks of cards: a deck of Teammates, representing groups of children who have been recruited to help one's own team in the tug-of-war, and a deck of Tricks, representing ways to either reduce the number of teammates in one of the other team's teammate groups or defend against such attacks. The game also includes a set of miniature figures as manipulatives, to represent teammates (See Figures 1 and 2 above).

During each round of play, each team tries to have the most teammates by protecting their own teammates while reducing the number of teammates on the opposing team. Points are scored based on the disparity in teammates at the end of each round. The basic game mechanic is to choose and play Trick cards (fractional effects) on opponents' or one's own Teammate cards (whole numbers of children) and to perform the corresponding fractional operations (at first by using the manipulatives, then by using the *paper method* described above, and eventually without any scaffolds); much of *Tug-of-War*'s strategy focuses on choosing when and how to play Tricks to optimally shift the number of teammates in one's favor.

Teams begin each round with two Teammate cards and four Trick cards. Each team starts by playing both of their Teammate cards, gathering the appropriate number of manipulatives to represent each card (see Figure 2). Teams then take turns playing Trick cards on their opponents' groups (or their own, to defend against attacks). After both teams finish playing Trick cards, players must count how many teammates each team has remaining and find the difference, which is the number of points earned by the team with more teammates that round. The winner is the first team to accumulate 20 points.

Experiment

Subjects

Thirty-one students (15 boys and 16 girls) from one fourth-grade class participated in the study. On the students' third-grade Standardized Testing And Reporting (STAR) report, 91% were categorized as economically disadvantaged, and 75% were categorized as English learners.

Experimental Design

We administered a pre-test of fractions concepts to the class (with no feedback about right or wrong answers), which was then divided in half to balance gender and math achievement. One half (Cohort 1) played *Tug-of-War* for one 75-minute session per week for seven weeks, in place of the students' regular math work, while the other half (Cohort 2) participated in unrelated research. We then re-administered the same math test to the entire class (again without feedback) and switched conditions; Cohort 2 played *Tug-of-War* for six weekly

75-minute sessions while Cohort 1 participated in unrelated research. Finally, we administered our math test a third time.

Procedure

In our first weekly session for each cohort, students learned how to play the game by watching a short instructional video and were then assigned to mixed-ability groups of three or four students each. (We used videos to ensure that both cohorts received identical instruction.) One of four researchers worked with each group, forming teams, assigning tasks (dealing cards, organizing manipulatives, and keeping score) to individual students, clarifying rules, and adjudicating conflicts. Subsequent sessions proceeded similarly: videos were played to reinforce various aspects of gameplay, and groups were periodically rearranged to provide novel opportunities for collaboration. Researchers continued to moderate for each group but gradually withdrew to more peripheral roles as students became familiar with the game. The paper method was introduced by video in the fourth session. By the sixth session students were encouraged to rely entirely on the paper method or mental calculations and use the manipulatives only if they became stuck; students were also encouraged to run the entire game session on their own, with researchers observing but not interacting unless absolutely necessary.

Measures

Our own assessment was given as a pre-, mid-, and post-test. Our assessment contained 22 dichotomously scored items testing our learning objectives: performing fractional operations on whole numbers (e.g., "Circle 1/4 of these 12 stars" or "What is .8 of 10?") and reconciling different representations of the same quantity (e.g., "Which one has the same value as 2/3?").

The classroom also underwent its annual state-mandated California Standards Test (CST) administration after only one session of Cohort 2's gameplay, thus providing a rough natural measure of external validity for our game. The specific measure we looked at was the CST subtest dealing with decimals, fractions, and negative numbers.

Results

As shown in Figure 4, the two *Tug-of-War* cohorts did not differ at pre-test, $t(27.55) = -.17$, *n.s.* Students in Cohort 1 showed significant gains from pre- to mid-test, $t(15) = 9.05$, $p < .0001$, whereas students in Cohort 2 did not, $t(14) = .83$, *n.s*. Once Cohort 2 got to play *Tug-of-War*, they showed significant gains from mid- to post-test, $t(14) = 6.71$, $p < .0001$, while Cohort 1's scores did not change significantly from mid- to post-test, $t(15) = -1.35$, *n.s*., even though they had not played the game for almost 3 months. Thirty out of thirty-one students showed learning gains from playing *Tug-of-War*.

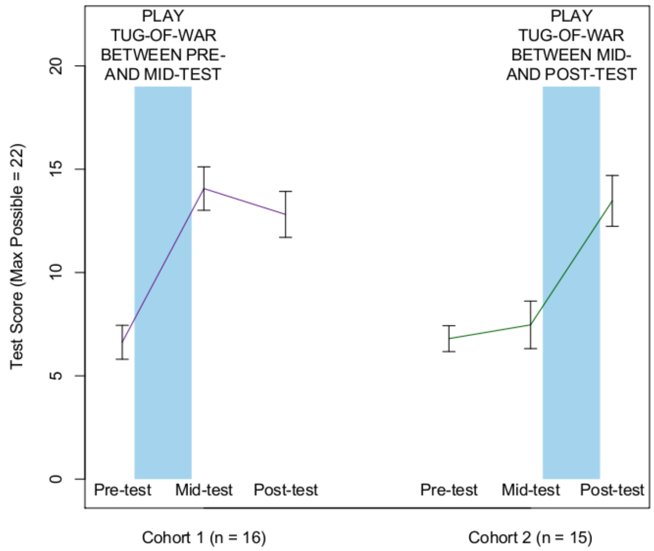

Figure 4. **Pre-, Mid-, and Post-test Means and Standard Errors**

As shown in Figure 5, Cohort 2's performance on this subtest did not differ from that of the classroom teacher's students from the year before, $t(24.81) = 0.32$, *n.s.,* while Cohort 1 outperformed both the previous year's students, $t(40.14) = 3.17$, $p < .005$, and Cohort 2, $t(21.46) = 2.13$, $p < .05$, despite the fact that Cohorts 1 and 2 had been created to balance math achievement, including achievement on their third-grade CST math scores, $t(25.84) = .61$, *n.s*. The *champagne graph* style of Figure 5 (inclusion of individual observations in the bar graph) illustrates that gameplay seems to have reduced bimodality in Cohort 1: one interpretation of this is that playing *Tug-of-War* especially helped lower achieving students.

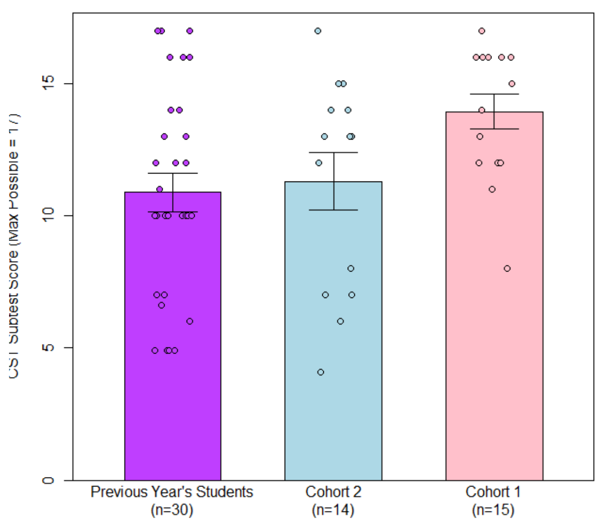

Figure 5. **CST Subtest Individual Scores, Mean, and Standard Errors**

Future Directions/Conclusion

We are currently working on the development of a digital version of the game, for which the existing version has served as a lo-fi paper prototype. This digital version will allow us to greatly increase the variety of fractions available in the game and offer different "skins" and overarching narratives (e.g., a space race instead of a tug-of-war). Perhaps most importantly, a digital version of the game would be able to fill the instructing and moderating roles played by researchers in the existing version, which will allow us to deploy the game in classrooms without relying on specially trained instructors.

In this paper we have described the development, evaluation, and validation of a successful educational game. We hope that the design process we followed—starting by wedding key learning outcomes to core game mechanics, building a fun game around those mechanics, and then tweaking as necessary to support learning—can serve as a model for future educational game designers. We also hope that addressing skeptics' concerns about the benefits of game-based learning by providing evidence of learning on traditional measures that skeptics value can begin to influence policy and provide support for incorporating more game-based learning into school curricula.

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