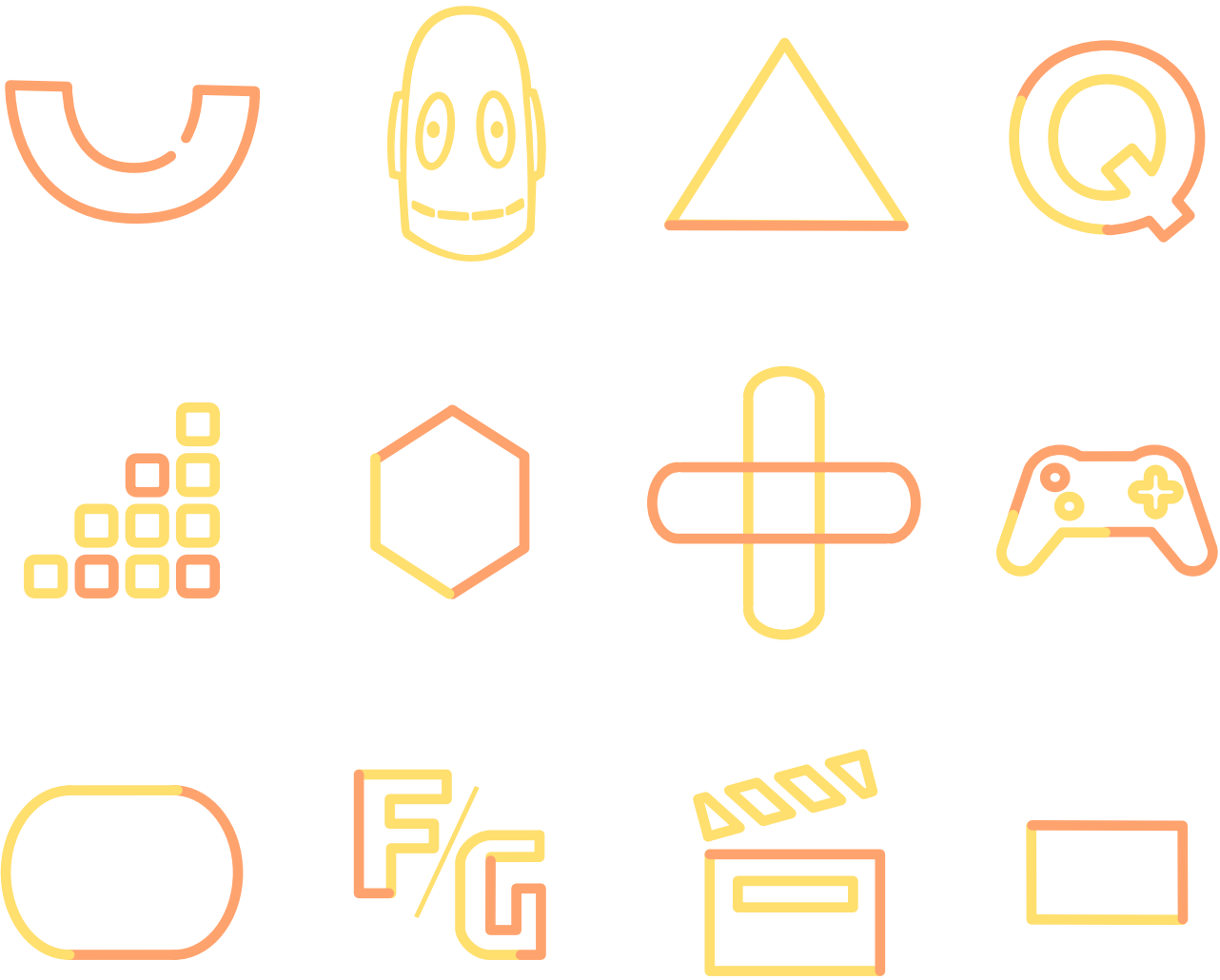
PLAYFUL LEARNING:
FLUENCY GAMES AND BRAINPOP



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For any feedback on this paper, email feedback@brainpop.com.
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Executive Summary

This report looks at how Addition Blocks and Multiplication Blocks, two games by Fluency Games LLC (https://fluency-games.com/) that are available on GameUp®, were interlinked by students with related math content on BrainPOP®. Two main conclusions were reached.

First, there seem to be two main pathways to finding the two games investigated here: **1)** students arrive at the games from a BrainPOP® topic page, where they have watched the movie and/or taken the quiz; or **2)** students go directly to GameUp® and bounce around the platform from game to game.

Second, we found a distinct correlation between performance on the game and performance on related BrainPOP® quizzes. Although a high score on quizzes did not always guarantee a high score on the games, a high score on the games was a reliable indicator of a high score on quizzes. This suggests that game mastery does transfer into mastery of the same content on quizzes, but mastery of quiz content does not always transfer into mastery of the related content in a game.

Further work can investigate these patterns on other GameUp® games, and determine if these conclusions are generalizable across many game titles or specific to the particular fluency practice games analyzed in this report.

Background: Description of Games Used in the Analysis

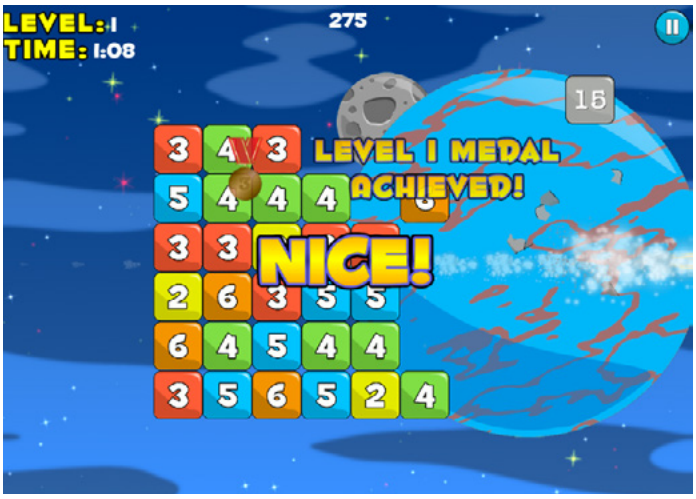
BrainPOP® creates cross-curricular digital content that engages students through animated movies and related features like interactive quizzes, concept mapping, movie-making, and other activities. With GameUp®, a vetted collection of educational games and resources developed both in-house and by leading developers, we provide access to top learning titles that tie into our nearly 1,000 topics. This report discusses three GameUp games: Addition Blocks and Multiplication Blocks by Fluency Games LLC, and our own Sortify®.

Sortify invites students to categorize information from our movies into bins representing key concepts. Scores vary based on combination and difficulty; accrual of a high score indicates that a student understands the topic well enough to strategically group main ideas.

Fluency Games LLC is a company dedicated to making fun and engaging educational games to build fluency in basic math facts. Fluency Games LLC was founded in 2013 by Martin Esterman, a former software engineer and middle school math teacher, who turned his attention to developing games to help kids become better math students. Addition Blocks was created in December of 2010 and won the STEM National Video Game Design Challenge (PBS Kids Stream, Teacher entries) less than two years later. Addition Blocks was also one of the first math titles to appear on GameUp. Multiplication Blocks was developed in 2013 and was added to GameUp in 2014.

Both games were designed with the *"Five Keys to Math Fluency"* philosophy in mind: Repetition, Time Constraints, Immediate Feedback, Allowance for Failure, and Gradual Increases in Difficulty.

According to multiple research papers on math fluency, "educators and cognitive scientists agree that the ability to recall basic math facts fluently is necessary for students to attain higher order math skills." [1] Fluency in basic math operations allow the child to spend more mental energy on the analysis and problem solving, rather than getting "bogged down" by the addition and/or multiplication of the actual numbers.



[1] http://www.scholastic.com/administrator/math/pdf/FM_White_Paper.pdf

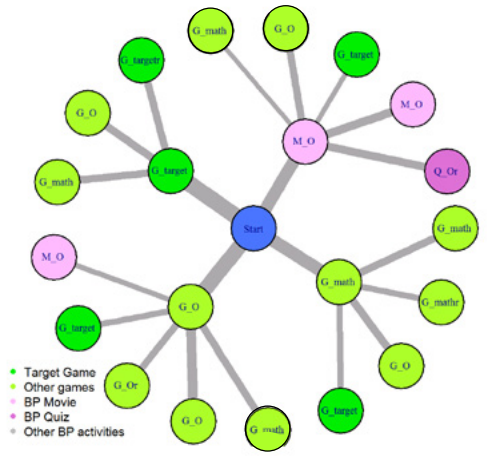
How do these games fit into the BrainPOP® experience?

We start with a question about pathways and interlinking of content: how exactly do games fit into the wealth of BrainPOP content? Do games come first, does other content come first, or are they intermixed together in a seamless pathway?

To answer these questions, we conducted a sequential pattern mining analysis (specific details can be found in the *Methods* section). This analysis constructs sequences of actions that students perform on BrainPOP, and then determines which subsequences occur most commonly in them.

To focus this analysis on Fluency Games LLC (F/G), we looked only at pathways of students who had played an F/G game at least once. After finding the most commonly navigated pathways, we then visually represented the most common pathways in a network diagram (see below). This diagram shows the most common sequential connections of BrainPOP actions, with the thickness of the connecting line related to how common that sequence is.

Here, "G_target" refers to one of the F/G games (e.g. Addition Blocks or Multiplication Blocks), or the targets of the analysis. "G_Math" refers to another math game on BrainPOP (e.g., Lure of the Labyrinth: Employee Lounge), and "G_O" to a game in another subject. Finally, "Q" and "M" refer to quizzes and movies. If the same topic or game was repeated twice in the database, an "r" is attached to the end of the abbreviation.



A diagram of common sequences through BrainPOP content.

Two patterns in the subsequences emerge most strongly. First, there are many game-to-game pathways: students often stay within GameUp once getting there. Second, games do mix with other content on BrainPOP, but that mix is more one-directional: the math movie to F/G game subsequence, for instance, is over twice as common as the F/G game to math movie subsequence. When games and movies mix, it is usually because a student was on a movie page, clicked on the GameUp button, and then stayed on GameUp. There are prominent links on individual game landing pages that take users back to related movies, but students don't often access those links.

Another way of looking at this same issue is to ask what actions are taken close together in time, regardless of their order. Of all students who played F/G games, only a very small percentage engaged with BrainPOP math content in a short period of time. However, if we filter to include only students who played F/G games AND interacted with BrainPOP math content, then we see a high percentage of users engaging in both activities within a short period of time. This indicates primarily that players either *a)* played only games and did no other math activity on BrainPOP or *b)* engaged with both the game and BrainPOP math content relatively close together in time. There are few students who engaged with BrainPOP math content and F/G games with a long period of time in between those activities. Many students are likely playing the game for the game's sake, perhaps as they browse multiple games on GameUp, whereas only a small number of students are connecting the game to other related activities on BrainPOP. See the chart below for a breakdown.

GAME	BASELINE POPULATION	% OF BASELINE WHO ENGAGED WITH BOTH THE GAME & BRAINPOP MATH CONTENT WITHIN...	
		1 day	1 week
Addition Blocks	Amongst those who used BrainPOP math content	67%	78%
	Amongst all game players, whether or not other BrainPOP activity occurred	11%	13%
Multiplication Blocks	Amongst those who used BrainPOP math content	64%	70%
	Amongst all game players, whether or not other BrainPOP activity occurred	23%	25%

Shows percentage of game players that completed corresponding BrainPOP activities within certain time periods.

How does game performance correlate with other performance measures?

With this understanding of how the content is linked together in pathways, we can now proceed to our second question, namely, does gameplay performance correlate with other measures of performance on BrainPOP?

It's worth noting some of the content's peculiarities as we answer this question. F/G games are meant to be replayed many times, and the first playthrough might yield a low score because students are just learning the mechanics of the game—not because they don't know the content. Because of this, an average or first score isn't necessarily the best judge of student knowledge gain in F/G games. Instead, to measure performance, we used max score across all of a student's F/G gameplays. We did look at other performance measures from the F/G games, but analysis showed max score to correlate better than other indicators.

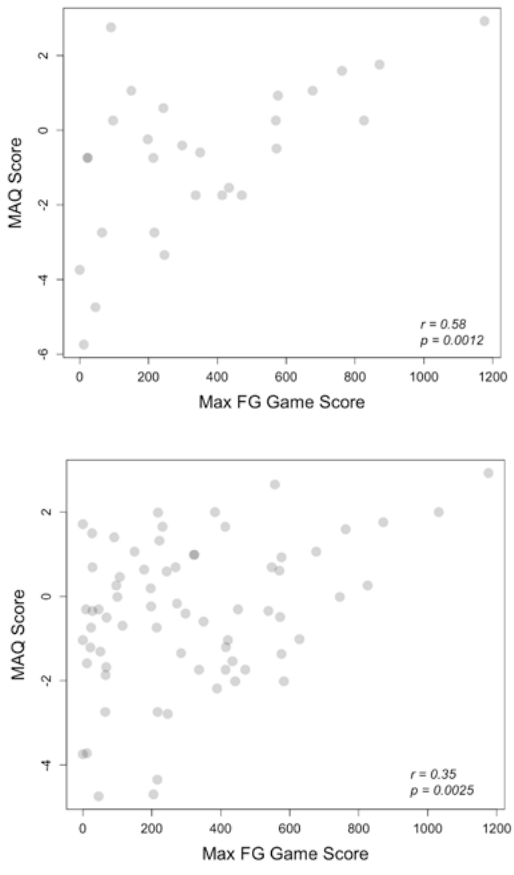
It's also worth noting that the F/G games are, as their name suggests, intended to promote fluency through repeated practice. All conclusions presented here may only hold true for fluency-based games. In particular, different conclusions might be reached for games with a stronger assessment focus or a focus on higher order learning.

1. Quiz

We first attempted to correlate game performance with quiz score. We used a mean-adjusted quiz (MAQ) score, in which we calculated the difference between each student's quiz score from the mean score on that topic amongst all students. We then averaged the difference to get a MAQ score which measured student knowledge while accounting for the difficulty level of a given quiz.

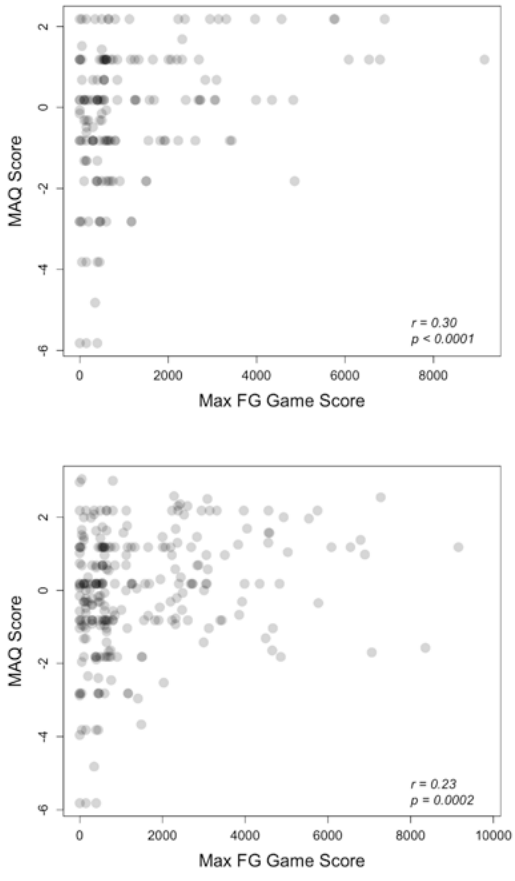
For the game Addition Blocks, we used a very specific (top panel) and less specific (bottom panel) selection of math topics from BrainPOP and BrainPOP Jr.® to calculate average scores. These were topics either closely or distantly related to the mechanics of Addition Blocks (for a full list of topics used, see the *Methods* section). Both graphs (shown below) display the same pattern, though the pattern is sharper (i.e., higher correlation coefficient) in the more specific topics.

Addition Blocks



Shows correlation between game performance on Addition Blocks and score on addition-related quizzes. The top shows an analysis of closely related BrainPOP topics, and the bottom shows a more distantly related collection of BrainPOP topics in order to include more data points. Each data point represents data compiled from one student.

Multiplication Blocks



Shows correlation between game performance on Multiplication Blocks and score on multiplication-related quizzes. The top shows an analysis of closely related BrainPOP topics, and the bottom shows a more distantly related collection of BrainPOP topics in order to include more data points. Each data point represents data compiled from one student.

For low max scores, students could have a wide range of possible quiz scores, which shows that doing poorly in the game is not necessarily a sign that the content isn't mastered, there are ways to gain and exhibit mastery on a multiple choice test that don't involve playing the game. But when a high score was achieved on the game, the score on the corresponding quiz(zes) was exclusively high. In other words, every time a student showed mastery on the game, he or she also showed mastery within the quizzes. This creates a pattern in which the upper left corner of the graph is filled in.

An analogous analysis was done for Multiplication Blocks (max score against MAQ scores on very specific and less specific topics). Essentially, the same pattern emerged: the upper left corner of the graph is filled in, with a stronger pattern for the more specific topics (graphs on previous page).

It's worth noting that we conducted a similar analysis across all quiz scores recorded for students, and observed a similar pattern. In that case, the pattern was again weaker and the correlation coefficient less strong in this even less specific group of topics. On the one hand, this isn't surprising, because we know that students who score well on one quiz are very likely to score well on other quizzes, regardless of the topic (unpublished results). So it makes sense that the correlation would persist. On the other hand, a math game performance should really only be related to a measure of math performance, so this indicates that math knowledge might not be strongly transferring between games and quizzes. This may indicate that students who typically score well on quiz-based assessments are in fact scoring well on assessments, regardless of the content area covered by the assessment. An interpretation of the results is that we are measuring assessment-taking ability rather than content-knowledge.

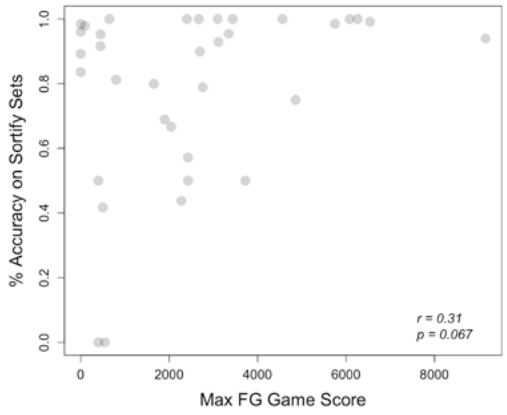
The main result is that students who do well on the F/G games also do well on multiple choice math quizzes (and to some extent, on any multiple choice quiz). But students who do well on a multiple choice quiz don't necessarily do well on a game-based performance measure.

2. Sortify®

We also attempted to correlate performance within F/G games to performance within Sortify (for more info about what kind of game Sortify is, see educators.brainpop.com/bp-game/sortify/). This analysis was limited to Multiplication Blocks, as Sortify did not offer an addition-related set at the time. In total, there were 31 students who played both Multiplication Blocks and one of the two multiplication-related Sortify sets (Multiplication and Factoring). Although this is a small sample size, it's still big enough for us to look for patterns. Those patterns should, however, be taken with a grain of salt.

There are multiple ways to measure student performance within Sortify. Unlike the F/G games, Sortify's in-game score was designed to motivate students in gameplay rather than directly reflect mastery. Beyond the in-game score, several metrics measure student performance, and those metrics appear displayed on the teacher dashboard after a student plays the game. There are several ways to combine these metrics into a single measure of performance for each student, and although we tested several methods, they all produced similar results. Here, we will show only the simplest metric: a total percentage of accuracy in the game, counted as the number of tiles correctly placed across all buckets divided by the total number of tile placements in the game.

If we compare the percentage of accuracy in Sortify to the max score in Multiplication Blocks, we find a similar pattern to the one found when we looked at quizzes. Students who had a low max score within Multiplication Blocks had a range of scores within the Sortify sets. But for students who achieved a high max score on Multiplication Blocks, those students always achieved higher scores while playing Sortify (at least in our limited data set). Although we did find a positive correlation, it was not statistically significant in this case.



Correlation between performance on Multiplication Blocks and on corresponding Sortify multiplication sets.

These results offer some indication that Sortify may behave similarly to a quiz in terms of how it characterizes students' knowledge.

3. Other factors

There may be other factors correlated with performance on Multiplication Blocks. For example, if student's actions on BrainPOP help them become more proficient with multiplication, then the total volume of BrainPOP activity might correlate to the max score on Multiplication Blocks. And the same could be true for Addition Blocks.

To test this out, we used the more specific selection of BrainPOP topics. We counted repeats on topics and features when calculating total volume of activity. We found no correlation between volume of activity and F/G performance measures for either Addition Blocks or Multiplication Blocks (p=0.57 and p=0.68 respectively, pearson correlation test).

We also conducted a test that counted only the amount of BrainPOP material completed before playing each game, and attempted to correlate that to the score in each game. This produced no significant effect for either Addition Blocks or Multiplication Blocks (p=0.90 and p=0.72 respectively, pearson correlation test).

Methods

This data relied on anonymized and de-identified data of students within the U.S. using the My BrainPOP® account system. All data shown in this report was taken from the period between August 1 and November 20, 2015. Data was taken from other time periods to verify the analyses, and we found no major differences from the results given here.

All analysis was completed in R. The sequential pattern mining was performed with the *arulesSequences* package for R. We used the *cspade* function, with a max time gap of two days and a support threshold of 0.2, but varying these parameters did not change the main conclusions of the analysis. For this analysis, we included only sequences from students who had engaged with an F/G game at least once.

The correlation testing between game and quiz scores was completed with a Pearson Correlation test, which tests for correlation without assuming causation. The *"r"* values shown in the graph are the correlation coefficients, and the *"p"* values are the significance values.

The more specific list of BrainPOP and BrainPOP Jr. topics related to Addition Blocks are: "Adding with Regrouping," "Adding and Subtracting Integers," and "Basic Adding."

The less specific list of BrainPOP and BrainPOP Jr. topics related to Addition Blocks are: "Basic Subtraction," "Adding with Regrouping," "Commutative Property," "Order of Operations," "Adding and Subtracting Integers," "Associative Property," "Repeated Addition," "Making Ten," "Counting On," "Basic Adding," and "Subtracting without Regrouping."

The more specific list of BrainPOP and BrainPOP Jr. topics related to Multiplication Blocks are: "Multiplication" and "Multiplying by 0 or 1."

The less specific list of BrainPOP and BrainPOP Jr. topics related to Multiplication Blocks are: "Multiplication," "Factoring," "Order of Operations," "Fractions," "Commutative Property," "Associative Property," "Multiplying by 0 or 1," "Repeated Addition," "Making Equal Groups," "Exponents,"and "Prime Numbers."