The Candy Factory Game: An Educational iPad Game for Middle School Algebra-Readiness

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Abstract: The *Candy Factory*, an app developed for the iOS platform targeting iPads, is an educational game intended to prepare middle school students for algebra-readiness. The *Candy Factory* differs from existing educational games along three dimensions: 1) the app is designed following evidence-based theories of cognition and engagement; 2) the app scaffolds learners to approach fractions with deep understanding; and 3) the app leverages game mechanics and device hardware for formative assessment purposes.

Overview

According to the U.S. National Mathematics Advisory Panel (2008), students' development of measurement concepts for fractions marks a critical point in their progression toward algebra-readiness. Most grade 6 students in the United States commonly rely on part-whole conceptions alone. Conversely, students who learn to coordinate partitioning and iterating to produce fractional sizes go on to construct splitting operations, developing a distinct advantage for algebra-readiness (Hackenberg. 2010). Thus, a major goal of our efforts is to support the construction of splitting operations by designing educational games that require students to coordinate partitioning and iterating operations in goal-directed activities. In our session we describe the underlying theories of our work, the hypothetical learning trajectories and engagement states that drive the design and development process. Below, we provide an overview of the game mechanics of the *Candy Factory Game*, an educational game developed to motivate grade 6 students (approximate ages 10-12) to engage in deep understanding of fractions. Next, we share data and results from several rounds of pilot tests using teaching experiment, observational techniques, and interview protocol in a mixed-methods design (Creswell & Plano Clark, 2007). We conclude by suggesting how the *Candy Factory Game* contributes to the learning sciences knowledge base on educational mathematics games by leveraging theories of cognition and engagement to deliver a simple, yet purposeful game, to help struggling youth learn fractions.

The Candy Factory Game: Supporting Splitting Operation Via Play

We have developed a functional prototype, the *Candy Factory Game*, to run on iOS devices targeting primarily iPads, but available for iPod Touches and iPhones. The educational game is designed to engage students in goal-directed activity that elicits potentially novel uses of existing mental operations, specifically partitioning and iterating. Students are shown a part of a candy bar ("customer order") and asked to reproduce that candy bar by partitioning a whole "candy bar" into an equal number of parts and then iterating one of those parts the appropriate number of times. At Level 1, the customer order and the whole candy bar contain partitioning marks so that students can employ existing part-whole concepts to make sense of the task. Furthermore, at Levels 2 and 3, those candy bars are truly continuous, requiring students to estimate the relative sizes of the bars, using partitioning and iterating operations with the game's drag and drop interface. See Figure 1.

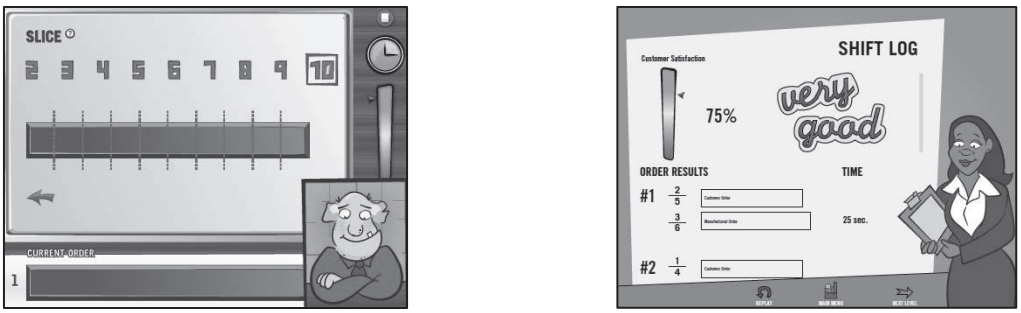

Figure 1: Level 1 screen captures in the Candy Factory Game (l: iterating operations; r: player reflection screen).

Results from Teaching Experiments and Survey Pilot Tests

We began testing the educational game in Fall 2011, using whole-class observations of two sixth-grade classes. Classroom observations involved 30-minute weekly episodes in which students paired up to solve game tasks,

requiring them to produce fractions of a specified size from a given whole. Whereas about half of the students started the semester using only part-whole reasoning with fractions, we found that virtually all students began coordinating partitioning and iterating operations in the intended way within the first five weeks (Authors, in preparation). We also conducted intensive, videotaped interviews with one pair of students after school, to characterize such changes. The two students were chosen because a written assessment indicated that they lacked measurement concepts at the beginning of the semester. Indeed, the first clinical interview provides evidence that neither student could formulate appropriate estimates of fractional sizes. For example, one student guessed 2/5 for a piece (customer order) that was clearly larger than one half. However, the students began to correct such errors when they noticed that they needed more iterations of a 1/5 (or another unit altogether) to fit the customer order. In later interviews, the students even began providing alternate names for the same fractional size and demonstrating their equivalence. We also have developed a protocol for quantifying individual differences in students' engagement with the device and game. Working in the same classroom, we observed four pairs and four individuals using the device and game in 10-minute periods. We also collected field notes from observing students working in pairs in the classroom. From these data, we identified variance between students in the following aspects of behavior and emotion that now comprise the dimensions of our new observational measurement tool. For individuals, these include attention, persistence, positive affect, frustration, gross/fine motor, touching device, aggression, verbalization, intrusiveness, responsiveness, and autonomy. For dyads, this includes cooperation, competition, conflict, and reciprocity. In addition, we piloted our math engagement instrument that measures the three domain of mathematics engagement (cognitive, behavioral, and affective). The instrument is comprised of 16 items that ask students to rate their own mathematics engagement level on five-point Likert scale scores (1=Really Disagree; 5=Really Agree). We collected data from 18 fifth-grade students using the hard copy of the instrument from one classroom. The data were analyzed for the item quality and reliability of the instrument using jMetrik (Meyer, 2011). The analysis results show that Cronbach Alpha (item reliability) was defensibly high (0.844), indicating that all the items show high consistency each other. The current version of The Candy Factory Game app prototype focuses on the core mechanics of supporting partitioning and iterating operations. In addition, the application will need to support social elements such as allowing students to share and compare scores. The full version will include data collection and reporting features to support the research plan for proficiency and engagement.

Conclusion

What are the video game elements that youth find engaging as they interact with pre-algebra topics? According to Jones (1998) video game features that attract youths' interests include: graphics, music, visual effects, and interesting animations. Nevertheless, one of the most engaging features is a challenging problem to solve with scaffolds that propel players to a solution (Hoffman & Nadelson, 2010). In this way, video games provide sufficient challenge and guidance to be engaging and are a sought-after enhanced learning technology. In this proposal, framed as a mixed-method design, we have documented the theoretical and evidence-based approach to developing and testing an educational game, the *Candy Factory Game*. Pilot results suggest that the video game prototype is engaging and that core mechanics propel learners along the predicted hierarchical learning trajectory. Nevertheless, these findings come from a limited set of interventions from a distinct sample. Thus, we continue to revise the video game based on pilot tests, end-user feedback, and refined instruments and observation protocols. To that end, we are now in the process of developing the *Candy Factory* v2.0 (Figure 1), which enhances the game experience intended to heighten engagement while attending to the fundamental requirement to scaffold requisite mental actions required for algebra-readiness in middle school and beyond.

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