Tan, S. C. et al. (Eds.) (2013). Workshop Proceedings of the 21st International Conference on Computers in Education. Indonesia: Asia-Pacific Society for Computers in Education

Strategies for Leveraging Learning Game Data for Middle School Mathematics Instruction

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Abstract: Middle school mathematics education is subject to ongoing reform based on advances in instructional technologies, leading to recent calls for investment in *learning games*. The pertinent issues focus on the device-based data collection potential of these dynamic, innovative learning environments to improve classroom instruction. Through an extensive literature review, we identified three priority areas where data collected from learning games could assist teachers to make informed decisions: *providing students with personalized feedback*, *assessing student learning*, and *promoting deeper learning*. These requirements are used to highlight potential empirical and practical implications for leveraging collected gameplay data to improve instruction, demonstrating how the *CandyFactory* app could be harnessed to support classroom-based decision-making. Investigators have partnered with a school district in rural southwest Virginia, testing how students (n=306) from two middle schools in six mathematics classrooms benefited from *CandyFactory* and how it influenced mathematics engagement and achievement. Through a series of three participatory design workshops (occurring from June 2012-June 2013), partnering teachers (n=6) confirmed that having access to data from the three identified priority areas would allow for an integrated adoption of learning games into instruction, potentially leading to achievement gains. We conclude by proposing future research directions in developing targeted learning games to support evidence-supported decision-making, which in turn could benefit how middle school students engage with and achieve in mathematics.

Keywords: evidence-supported decision making, learning games, mathematics education, middle school, tablet computing, teaching analytics

1. Introduction

A trending issue in education is to leverage the potential data collection opportunities available to technology-enhanced learning environments (TELEs) to promote classroom-based evidence-supported decision-making. For our purposes, we focus on learning games for tablet computers where this agenda could be rigorously developed, implemented, and evaluated. We define *learning games* as those that focus on gaining knowledge inconspicuously to foster habits and understanding for the classroom and have “learning as the primary objective” (Young et al, 2012, p. 63).

As a result, investigators have developed a learning game for the iPad called *CandyFactory*, targeted toward middle school-aged children learning fractions. Players traverse five increasingly complex levels, completing factory orders by fractioning off candy bars into the requested amounts. The fraction concepts reinforced are: *partitioning of a whole*, *copying*, and *measuring*. Prior efforts have focused on the effects on learning (Evans, Norton, Chang, Deater-Deckard & Balci, 2013; Norton, Wilkins, Evans, Deater-Deckard, Balci & Chang, in press). Moving forward, where support of teacher decision-making is prioritized, it would be beneficial to articulate what data could and should be collected in learning games to enhance instruction. The *CandyFactoy* app is available for download via iTunes.

In the following sections we highlight a *design-based implementation research approach* (Cator at al, 2012) that focuses on, first, the potential data-collection features of *CandyFactory*, then the systemic decision-making process as a co-design activity with teachers and investigators. The following report is a third phase of iterative refinement to integrate design principles, co-design with teachers (n=6), and analyze results from a medium-scale intervention (n=306). Details of these results are reported elsewhere (Evans, Chang, Kim, Samur, Deater-Deckard, Norton & Balci, 2013). Our goal is to highlight how instructional technologies and organizational systems could work together to improve middle school mathematics instruction *and* learning. This proposal aligns well with the call for submissions that report changes to research design and implementation, and how efforts are conducted in dynamic, innovative learning environments.

Table 1: Summary of data categories prioritized in learning games to enhance instruction.

Category	Definition	Data Collected	Benefits
Personalized Feedback	"Personalization is instruction that is paced to learning needs, tailored to learning preferences, and tailored to specific interests" (Cator et al., 2012, p. 26).	• Attitudinal Data • How a concept is represented and its difficulty • Supplementary exercises • Student's ability to make adjustments • Evaluation from multiple sources at multiple points • Positive, immediate feedback	• Personalization • Reassess student's understanding • Content can be customized
Student Assessment	"Assessment should be used to gather evidence that informs instructional decisions, and encourages learners to try to learn" (Woolf et al., 2010, p. 21).	• General Trait Variables (abilities and capabilities) • General State Variables (prior knowledge, etc.) • Situation-Specific Variables (engagement, etc.) • Student improvement • Success in implementing rules • Quickness/change of response time	• Reveal what and how players learned • Students' understanding of rules applied • Evidence of 21st century competencies
Deeper Learning	"Deeper learning is defined as the ability to acquire, apply, and expand academic content knowledge and also to think critically and solve complex problems, communicate effectively, work collaboratively, and learn how to learn" (Hewlett Foundation, 2012; Cator et al, 2012, p. 11)	• Students' attempts/# of attempts • # of hints and feedback given • Time allocated across each part of the problem • Whether or not student is "making sense of problems" • Whether or not student is "constructing explanations"	• Ability to transfer knowledge • Students thinking about concepts on their own • Thinking shifts from practice to problem solving

2. Priority Areas for Data Collection in Mathematical Learning Games

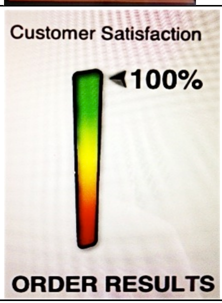
Recent reports suggest that data types to be collected in learning games should fall primarily under three categories: *personalized feedback*, *student assessment*, and *deeper learning* (Cator et al., 2012; Hewlett Foundation, 2012; Woolf et al., 2010). In the sections below, we combine findings from literature review with feedback gathered from participatory design workshops with teachers. We also highlight how *CandyFactory* could be leveraged to enhance evidence-supported decision-making innovations. These sections are summarized in Table 1.

Personalized Feedback

The first priority area for data collected is providing *personalized feedback*. Cator et al. (2012) describe personalization as instruction that is paced to learning needs, tailored to learning preferences, and adapted to specific interests (p. 26). A learning game requires the function of responsive algorithms to cater to a student's interactions with a pre-determined learning goal (Shute & Ke, 2012, p.46). Two types of feedback that promote game responsiveness are *performance feedback*, whether a behavior is right or wrong, and *informative feedback* that provides information on how to correct that behavior (p. 50). Performance feedback better fits learning games as it allows for rapid, immediate interaction, keeping students alert and thinking about gameplay, associating the feedback to the action, while teachers use it to determine what learners understand (Okita & Jamlian, 2011, p. 50, 52; Cator et al, 2012, p. 11).

Table 2: Data *CandyFactory* could capture to enhance *personalized feedback*.

Certain data should be collected to enhance personalized feedback: attitudinal data to determine a students' initial response to the game (Plass et al, 2013, p. 699); the type and number of feedback

Data Set	**Picture**	**Why collect it?**
Boss smiling or frowning when student completes order		• Feedback on whether the student completed the order correctly or not • Allows the student to see their level of performance as the game-play commences • Teachers can easily see the amount of problems the student gets correct versus incorrect by level or total game play
Number of times boss told student to work faster		• This reveals to the student whether or not they are working at a constant pace throughout the level • Teachers can easily identify a student's confusion at specific points in a level
Percentage given at end of level		• This percent along with the rating they are given, like "excellent", provides the student with an easy way to gage their overall performance • The teacher can see the passing percentage of the student and whether or not there has been improvement from the last time they played [The Math App].
Number of correct and incorrect responses & time it took for response		• The time the student spent on each response indicates whether time spent on a problem affects the outcome of the student's answer • Did the student take their time in completing the problem in order to earn the correct answer or were they just trying to complete the orders as fast as possible?

provided (including hints, examples, visual representations, etc.); the concept's difficulty (Cator et al, 2012, p. iii), allowing teachers to compare student performance on varied questions; and how quickly the feedback was given (immediate or delayed). This data should show if students make adjustments, thinking conceptually and practically about the concepts, while playing the game (Woolf et al, 2010, p. 32).

Data for personalized feedback that the teachers suggested include: real time data of students playing, a record of individual student data, a child's right vs. wrong list of fractions, and percent of accuracy. Taking into account the teacher's wishes and what the literature says, there is specific data that *CandyFactory* can collect in order to provide the students with the best, personalized feedback (see Table 2).

Student Assessment

The second priority area for data collected is *assessment of student learning*. "Assessment begins by figuring out what [teachers] want to assess and clarifying the intended goals, processes, and outcomes of learning" (Shute & Ke, 2012, p. 52). According to Okita & Jamalian (2011) student performance can be assessed in two ways: a student's performance while using the learning game, allowing student potential to be evaluated, and when a student's cognitive ability is challenged (p. 52), revealing what, how, and why they have learned (Plass et al, 2013, p. 700). Learning games do this by recording and monitoring student activity without interrupting gameplay or the student's thinking (Shute & Ke, 2012, p. 51), revealing whether students understand the rules they are applying without assistance (Okita & Jamalian, 2011, p. 52; Plass et al, 2013, p. 722). Assessments should infer whether students acquire competencies (collaboration, innovation, intellectual curiosity, self-regulation, self-direction, etc.) that the 21st century demands from playing learning games (Cator et al, 2012, p. 11). Shute & Ke say that a teacher should assess "student knowledge, skills, and understanding along with beliefs, feelings and other learner status and traits" (p. 53).

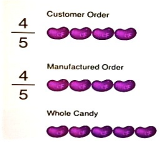
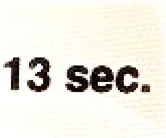
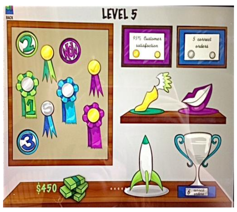
Data that should be collected for assessment include: general trait variables showing a learner's initial abilities; general state variables that include prior knowledge, students' awareness, and motivation; situational-specific variables showing cognitive load, the student's situational interest, and level of engagement (Plass et al, 2013, p. 699-700); and a student's improvement seen in implementation of rules, speed of work, change in response time, use of operations, and the amount of scaffolding (Cator et al, 2012, p. 52; Plass et al, 2013, p. 712). Okita & Jamalian (2011) suggest, "assessment becomes [an] important contributor to designing personalized learning environments" (p. 52); assessment helps benefit student learning by providing a personalized education.

Student assessment data that our partner teachers would like to see captured includes student performance for every task including level, customer order, produced candy, times, and times pushed the back button; the rate of success on various levels; time spent on a single fraction; the time spent on a level; and points in the game where students get stuck and/or give up. *CandyFactory* could collect data to facilitate student assessment based on overlapping priorities expressed via the literature and participant teachers (See Table 3).

Deeper Learning

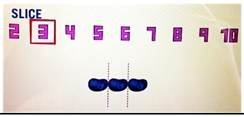
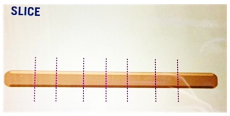
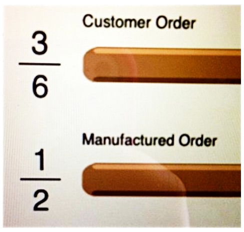
The third priority area for data collected is *promoting deeper learning*. Expectations in education have dramatically changed in recent decades, students should learn more, faster and teachers should discover new, exciting ways to teach, emphasizing the importance of deep learning. There are two approaches to learning: surface learning, where a student tries to "memorize given information by details" or deep learning "involv[ing] critical analysis of new ideas, linking them to known concepts, leading to long-term retention of concepts to be used for problem solving in unfamiliar contexts," and learning how to learn (Vos et al, 2011, p. 128; Cator et al, 2012, p.11). Deep learning approaches allow students to perform better in the classroom because they retain, integrate, and transfer information at a higher, quicker rate (Vos et al, 2011, p. 128). Learning games are a prime opportunity for deep learning because "play is voluntary, intrinsically motivating, and involves active, cognitive, and/or physical engagement allow[ing] for the freedom to fail (and recover), to experiment, and to fashion ideas" appealing to "decision making, knowledge transfer, and analytic, critical thinking, and problem solving skills" (Shute & Ke, 2012, p. 44; Vos et al, 2011, p. 50; Okita & Jamalian, 2011, p. 128). Games also facilitate the "trial-and-error" approach supporting development of logical thinking and problem solving (Vos et al, 2011, p. 128). Learning games provide the opportunity for knowledge to be applied (Cator et al, 2012, p. 60; Devlin, 2011, p. 53), shifting from straightforward practice problems to solving real-life questions (Plass et al, 2013, p. 722).

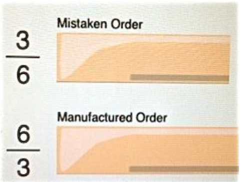
Table 3: Data *CandyFactory* could capture to enhance *student assessment*.

Data Set	**Picture**	**Why collect it?**
Number of correct, incorrect responses vs. number of responses completed	 	• This shows the basic principle of did the student get more questions correct than they got incorrect.
Time spent on each response/level/game		• Identifier of understanding • Total time spent playing the app could show whether or not they are enjoying learning through the game play and are interested in continuing to play.
Time spent on/number of times visited instructions page		• Can show a lack of understanding of fraction rules, so the student is fishing in the directions for some kind of hint on how to complete the fractions correctly • Can show poor game design, so the student is trying to figure out how to navigate the gaming processes correctly
Time spent on/number of times visited trophy page		• Good indicator of a student's motivation • Visit the trophy page consistently- motivation may stem from a desire to gain all the trophies available in order to "beat the game." • Rarely visit trophy page- motivation must come from somewhere else

Data that should be collected to show evidence of deep learning include: student inputs, number of attempts, and number of hints indicating what a student has learned; the amount of time a student takes to complete parts of a problem, showing strengths and weakness of concepts; and a student's rationale to the answer chosen, revealing their thought process and whether they are "making sense of problems" (Cator et al, 2012, p. 10). "In summary, games seem to comprise all elements for a learning environment in which students are stimulated to use deep learning strategies" (Vos et al, 2011, p. 130).

Table 4: Data *CandyFactory* could capture to enhance *deeper learning*.

Data Set	Picture	Why collect it?
Number of times student went back a screen		• Understanding of fractions compared to guess-and-check • If the student truly has a deep knowledge in fractions, back button won't be used as often
Time spent on each screen		• Time spent on: partitioning, copying, or measuring- struggle with a specific concept of fractions may become evident • Are they understanding that a fraction is a part of a whole or that [illegible] is bigger than [illegible] ?
Level 1: Number of different slice numbers chosen		• Shows whether or not the student could visualize partitioning the candy into the correct fraction.
Level 2: Number of times player "measured out" swipes/where were swipes placed		• Understanding of partitioning • Are they using the swipes as a visual guide or as guess-and-check and are they placing the swipes in a logical manner? • Do they understand the amount of swipes it takes to partition the fraction correctly?
Level 3: Equivalent fractions AND success on smaller vs. larger fractions		• Success on smaller ([illegible]) or larger ([illegible]) fractions • Use of equivalent fractions • Correctly visualize pieces of a whole • Use of most simplified form of fraction (using [illegible] instead of [illegible])
Level 4: speed of completing and number of correct/incorrect partial vs. improper fractions		• Success on partial fractions vs. improper fractions • Understanding of improper fraction format ([illegible]) compared to a mixed number format ([illegible]) • Able to visualize that an improper fraction is still part of a whole added to another whole?

Level 5: time to complete all 6 fractions		• Shows whether or not they know the difference in the numerator and the denominator and that rearranging them is not equivalent (Student must fix $\frac{6}{3}$ to $\frac{3}{6}$).

Participant teachers desired evidence that students were gaining deeper knowledge of fractions by playing *CandyFactory*, beyond conventional differences between pre-/post-test results. Teachers prefer progress data for individual students, showing improvement in student knowledge to track progress and growth over time; length of time a student spent on each fraction; amount of on-task working versus off-task working; and the speed of completing problems. There are also more specific data by level that *CandyFactory* could capture to show deeper learning (See Table 4). Having the teachers' perspectives after implementing *CandyFactory* in their classrooms has provided preliminary evidence of how the three data categories – personalized feedback, student assessment, and deeper learning – could be potentially used to facilitate learning of core mathematics concepts.

3. Enhancing Decision-Making in the Middle School Mathematics Classroom

Our position is that the data collection capabilities of learning games alone are an insufficient technological solution that does not fully account for the institutional requirements for innovation in technology-enhanced learning environments. Subsequently, Anfara (2010) suggests four phases to prepare teachers in their professional capacities to adopt evidence-supported decision-making processes: *organization for success*, *building assessment literacy*, *identifying the data that should be used*, and *altering instruction* (p. 56). In the following sections we highlight how [The Team] is using this framework to co-design a potentially successful implementation of learning games in the middle school classroom. Our review of the literature has indicated that calls for data-driven instructional innovations have neglected matters of organizational learning and change.

Time is a barrier for teachers. Thus, organizing for success allows for efficient decision-making (Anfara, 2010, p. 57). A solution to lack of time is to create meetings, or data-routines (Anfara, 2010, p. 57; Goren, 2012, p. 234) that foster an environment for data discussion, learning from others' experiences, and altering teaching techniques to help with implementation in the classroom (Spillane, 2012, p. 113). Investigators have begun to provide the teachers with an example of data routines in the PD sessions, allowing for discussion on data potential for *CandyFactory*. Combining the second and third phase, assessment literacy and identifying data to be used, *CandyFactory* has provided the three data categories to alleviate the burden of analyzing every data point a learning game could collect, focusing teachers on the identified data that is important to learning. The final phase, altering instruction (Anfara, 2010, p. 56), is the primary goal for *CandyFactory*. The teachers expressed that the ultimate goal for *CandyFactory* should be embedding the game into curriculum, having lesson plans and assessment and reflective questions to go along with the game. Investigators intend to implement this idea into the project to help teachers better use the app to enhance instruction. The three data categories and the steps investigators have taken to help fulfill Anfara's (2010) four phases of decision-making will allow teachers to make decisions in the classroom more efficiently.

"Data do not objectively guide decisions on their own—people do"— "the interpretations teachers make from data, especially the implications they will draw for instructional change, are influenced by teacher knowledge" (Spillane, 2012, p. 114; Goren, 2012, p. 234). Data-use is not effective without teacher background knowledge, in our case in mathematics and education. Coupling teacher experience with the techniques provided in this manuscript, evidence-supported decision-making can be easily implemented in middle school mathematics classrooms to help better students' learning.

Acknowledgements

This material is based on work supported by the National Science Foundation (NSF) under Grant No. DRL-1118571, and the Scieneering Undergraduate Research Program, the Institute for Creativity, Arts, and Technology (ICAT), and the Institute for Society, Culture, and Environment (ISCE) at Virginia Tech. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of sponsoring organizations. The Learning Transformation Research Group at Virginia Tech includes the authors and a talented team of co-investigators (Kirby Deater-Deckard, Anderson Norton, Osman Balci), and graduate and undergraduate research assistants.

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