International Journal of Game-Based Learning
Volume 14 • Issue 1

Open-Ended Mathematics Learning:
Implications From the Design of a Sandbox Game

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ABSTRACT

Mathematical learning has an important role and is often prioritized in education. In K-16 education, algebra is one of the most vital mathematical content domains: it represents one of the top barriers for students pursuing a postsecondary education. Game-based learning has been effective in fostering classroom math learning environments that are collaborative and focused on conceptual understanding. Sandbox games provide open-ended learning environments where players can set their own goals and level of effort. As part of the project "Math Snacks," the team designed Agrinautica, a sandbox game to enable constructivist-informed early algebra learning. This article identifies design recommendations for creating meaningful sandbox games for learning, considering students' and teachers' needs. Researchers discuss the decisions to create a sandbox game and describe challenges inherent in math learning through sandbox-type gameplay. This study provides impact results from a large-scale study of users of the game, and shares recommendations for developing future sandbox learning games.

KEYWORDS

Agrinautica, Constructivism, Early Algebra, Educational, Gameplay, Math Snacks, Sandbox, Transformational Games

DOI: 10.4018/IJGBL.337795

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INTRODUCTION

Mathematics maintains an important and prioritized role in K–16 education, and algebra is perhaps one of its most vital content domains. As such, algebra has risen to the top in maintaining a gatekeeper role that has kept many students from basic levels of access to post-secondary education, thus further disadvantaging the most vulnerable students (Moses & Cobb, 2001). To support students in overcoming some of these challenges, early algebra can provide an important gateway through which students may excel in the domain of algebra.

In addition to recognizing the importance of learning early algebra concepts within a constructivist-oriented learning environment (e.g., National Council of Teachers of Mathematics [NCTM], 2000; Blanton et al., 2015), educational technology has become ubiquitous not only in schools (Gray & Lewis, 2021) but also in homes and among the general public (Rideout, 2014). The use of digital games to learn mathematics has been increasing in popularity (Byun & Joung, 2018). However, there is much to learn, in particular when it comes to understanding the impact of such games on students' mathematics achievement and conceptual understanding (Byun & Joung, 2018). For example, all games are not necessarily built to reflect or enable a constructivist approach to learning. Some games may focus on memorization or practice, and may use a more behaviorist approach in motivating students to do routine tasks with the aim to get a reward.

As educators face the need for effective educational early algebra games and strive to understand the impact that some game genres have on players, research is emerging on how to connect constructivist approaches to math-based games, including ways to build games that foster classroom learning environments that are collaborative, dialogic, and focused on conceptual understanding of important and rigorous mathematics, such as early algebra.

In an attempt to address these complex mathematics teaching and learning needs, an experienced team of education researchers and developers created a highly successful suite of mathematics animations and games, called Math Snacks (Wiburg et al., 2016). Building on these past successes, the team moved on to the Math Snacks project, which sought to prepare learners for algebra by exposing them to foundational concepts earlier in their mathematics learning. All the games in the Math Snacks suite were designed from a constructivist perspective—attempting to enable the user to build their own understandings of how algebra concepts work. As part of that work, the Math Snacks Early Algebra project team wanted to create a sandbox game through which learners could experiment with different approaches to writing, manipulating and interpreting expressions; understand the role operators and parentheses had in those expressions; and become experienced in creating many different kinds of expressions. The game was eventually named Agrinautica.

In this article, we share the theoretical underpinnings of designing the game Agrinautica and provide results from multiple studies of students' and teachers' experiences using the game in the classroom. Sandbox games are more open ended than traditional goal- or score-oriented games and tend to give players greater autonomy in deciding how to play the game and in setting their own goals. Thus, a collection of students in a given classroom could all have different experiences playing the same game. As such, it was important for the team to review the different ways players approached Agrinautica gameplay, identify the impact of those choices on the player, identify the impact of the gameplay on teachers offering the game, and determine best practices for developing sandbox-style games for learning.

This study addresses three main questions: What is the impact of gameplay in Agrinautica on student cognitive and affective outcomes? What is the impact of the intervention on teacher affect and pedagogical practice? In what ways does the sandbox nature of the game influence these impacts? A mixed-methods approach was used across the project to analyze the formative and summative data to investigate these questions. We share what has been learned through these findings in the form of recommendations for the development of future sandbox learning games.