INTEGRATED STEM EDUCATION THROUGH GAME-BASED LEARNING

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Science, technology, engineering, and mathematics (STEM) education continues to garner focus and attention from teachers, students, researchers, policymakers, and businesses due to the vast importance of technology in the world. The integration of STEM subjects has the potential to make learning relevant and more engaging for students, which can increase their mathematical knowledge. In this paper, I focus on integrated steM education through open-ended game-based learning within a technological context. Integrated steM education is the integration of STEM subjects with an explicit focus on mathematics. The possibilities for integrating mathematics and technology through open-ended game-based learning has increased in recent years. Recommendations for future work will be discussed.

Keywords: Curriculum Enactment; Middle School Education; STEM

Interest, discussion, and work around technology integration in education continues to grow as advances in technology permeate our daily lives. The way that technology is integrated into the classroom is important in ensuring optimum learning outcomes for students. In game-based learning, technology integration should allow students to engage in more high-level thinking and have new experiences with mathematics that would be difficult without the technology. There is a distinction between how technology is used as an *amplifier* and how it is used as a *reorganizer* of mental activity (Pea, 1985). Technology as an amplifier enables students to perform more efficiently tedious processes that might be done by hand. This does not change what students do or think but does save time and effort and improves accuracy. As a reorganizer, technology is capable of effecting or shifting the focus of students' mathematical thinking or activity. This can enable students to do more higher-level thinking. A recent review of the literature suggests that the potential to integrate technology in a transformative way is not being met. For instance, researchers classified studies based on the ways in which technology has been integrated in mathematics education since 2009. The findings from this work indicated that the majority (61%) of the 139 studies were similar to an amplifier approach in that the technology was used as a direct substitute for traditional approaches with some functional improvement (Bray & Tangney, 2017). This result suggests that although innovative practices undoubtedly exist, the technology that could improve students' learning experience is generally not well implemented in the classroom (Hoyles & Lagrange, 2010). The purpose of this paper is to describe research done with middle school students (ages 11-15) and game-based learning to highlight productive principles for technology integration with mathematics.

Integrated steM Education Framework and Literature Review Integrated STEM Education

Researchers have noted that mathematics is often not emphasized in the integration of STEM subjects (English, 2017; Gravemeijer, Stephan, Julie, Lin, & Ohtani, 2017). In response to this, I have proposed that mathematics teachers and researchers focus on integrated STEM. Integrated STEM is the integration of STEM subjects that has an explicit focus on mathematics (Stohlmann, 2018). It is an effort to combine mathematics with at least one of the three disciplines of science, technology, and engineering, into a class, unit, or lesson that is based on connections between the subjects and open-ended problems. Further, integrated STEM education is an approach that builds on natural connections between STEM subjects for the purpose of (a) furthering student understanding

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of each discipline by building on students' prior knowledge; (b) broadening student understanding of each discipline through exposure to socially relevant STEM contexts; and (c) making STEM disciplines and careers more accessible and intriguing for students (Wang, Moore, Roehrig, & Park, 2011). There are three main ways in which integrated steM can be implemented by mathematics teachers: engineering design challenges, mathematical modeling with science contexts, and mathematics integrated with technology through open-ended game-based learning (Stohlmann, 2018). Each of the three approaches involves the integration of mathematics with a different science, technology, or engineering (STE) focus. In this paper, I focus specifically on mathematics integrated with technology through open-ended game-based learning.

Game-based Learning

Game-based learning has drawn international interest and has been reported as an effective educational method that can improve students' motivation and performance in mathematics (Byun & Joung, 2018; Wang, Chang, Hwang, & Chen, 2018). Students enjoy playing technology-based games whether it is video games or apps on their phones. However, when used in the mathematics classroom, game-based learning is often not implemented with best practices for teaching mathematics in mind (Byun & Joung, 2018). A meta-analysis was conducted to look at the overall effect size of game-based learning on K-12 students' mathematics achievement. Seventeen studies were identified that had sufficient statistical data from a time frame of the years 2000 to 2014. The overall weighted effect size was 0.37, which is a small effect size. There were 71 authors in the studies reviewed for the meta-analysis, with only five of these authors having a background in mathematics education. This research demonstrates the need for further studies on effective game-based learning approaches and best practices in mathematics education.

For example, most of the games used in the studies involved drill and practice (Byun & Joung, 2018). An example of one popular game includes students solving traditional, non-contextual practice problems in order to get more speed for a race car and attempts to take advantage of students' interest in videogames (Math-Play, 2019). However, in this type of game, students only receive feedback if the answers are correct or incorrect and do not receive support for improving their conceptual understanding. These types of games also emphasize that mathematics is about speed and focus on the memorization of ideas (Bay-Williams & Kling, 2015). Game-based learning for mathematics should move beyond drill and practice.

Another area that requires improvement in the implementation of game-based learning is for students to be able to work collaboratively or competitively. This has been suggested to be more effective than individual gameplay (Hung, Huang, & Hwang, 2014). A study in which this collaboration versus individual play was investigated involved 242 students with an age range of 11 to 15 years. There were four conditions in the study: collaboration and competition, collaboration control, competition control, and control. Overall, the game-based learning improved students' proportional reasoning, but the effects did not differ between conditions (Vrugte et al., 2015).

For game-based learning in integrated STEM, I refer to games in which the mathematics is integrated into the gameplay in a substantial way other than traditional practice problems. When structured well through open-ended problems, technology-based mathematics games may engage students in mathematics and help develop their conceptual understanding.

Methods

This study was structured as a teaching experiment (English, 2003). Nineteen students voluntarily enrolled in a five-week Saturday STEM program at a large urban university. The students were audio-taped and student work was collected including screenshots of the students' work in Desmos. Researcher field notes were also collected. Desmos is an online graphing calculator, but also has a suite of classroom activities available with some of the activities being game-based. In the lessons, students can share ideas and ask questions of one another. The principles that guide the Desmos' team lesson development include the following:

- Use technology to provide students with feedback as they work.
- Use the existing network to connect students, supporting collaboration and discourse.
- Provide information to teachers in real time during class (Danielson & Meyer, 2016, p. 259).

Little research has been conducted on these activities, but they have the potential to enable teachers to develop students' conceptual understanding. Research on how students develop conceptual understanding through technology integration tasks is important to investigate. The specific research question for this paper was the following. *How do students use and develop mathematical vocabulary while playing the Polygraph lines game?*

Results

In this paper I describe results from a Desmos game-based activity called Polygraph lines. I analyzed the data with an interpretative approach by looking at the ways in which students used mathematical vocabulary in the game. In this game, sixteen linear graphs are given. One student selects one of the graphs and the other student asks yes or no questions to determine which graph has been selected. Between games students are shown questions that other students ask. The teacher also is able to view and have a record of all questions asked in each game. Table 1 has the initial questions that were asked by 4 of the groups.

Table 1: Initial questions from polygraph lines

Group	1	2	3	4
Questions	-Does your line go through the origin? -Is your line vertical? -Is your line horizontal? -Is your line in quadrant 2 and 3?	-Does your line have a positive slope? -Does your line pass through the origin? -Does your line have a slope of 0 or undefined? -Does your line have an undefined slope? -Is the slope negative? -Does your line have a slope of 0? -Does your line have a slope greater than -2? -Is the slope of your line greater than or equal to 1?	-Is your slope positive? -Is the y-intercept positive? -Does it cross the origin? -Is your slope steep? -Is your line undefined? -Is your slope negative? -Is your line's linear equation zero or undefined -Is your line horizontal? -Is your line vertical?	-Is your line horizontal? -Is your line vertical? -Does your line intersect 2 quadrants? -Does your line intersect 3 quadrants? -Is your line positive? -Is it negative? -Does it go through the origin? -Does it pass through 3 squares?

After playing the game several times, the students discussed what quality questions to ask and strategies for asking the least amount of questions. Several questions appeared in common in the groups: "Is your slope positive?" "Is the slope negative?" "Is your line horizontal?" "Is your line vertical?" "Does your line go through the origin?" Groups also came up with questions of what quadrants the line crossed through, though not all groups used the term "quadrants." Through playing the game and subsequent discussions, students were able to make use of mathematical vocabulary including slope, positive slope, negative slope, horizontal line, vertical lines, origin, and quadrants. Desmos continues to develop their freely available activities, and further research is warranted on the effect of the games on students' mathematical understanding of linearity and motivation to learn mathematics.

Conclusions

It has been found that the use of puzzles and gamification in mathematics increases students' participation and engagement (Bryne, 2016). The research in this study provides early support for game-based learning done through integration with Desmos. This method can encourage students to develop mathematical understanding in an engaging game-based context. Through investigating technology game-based learning I have developed several important principles that should be incorporated to help make it more likely the game-based learning will be effective. First, the technology integration should allow for the creation of new tasks that would not be possible without the technology or for significant task redesign (Puentedura, 2006). Second, the tasks used should be worthwhile tasks. These tasks have no prescribed methods and there is no perception that there is only one "correct" strategy (Hiebert et al., 1997). Third, the tasks should be aligned with grade-level standards. Fourth, the tasks should enable students to work with multiple representations. Fifth, the technology should provide students feedback. Finally, the tasks should be open-ended and allow for discussion and multiple solutions (Stohlmann, 2019). When structured well, technology-based mathematics games can engage students in mathematics and help develop their conceptual understanding.

Too often middle school students perceive mathematics to be dull, irrelevant, and too difficult (Grootenboer & Marshman, 2016). Further research on game-based learning in the mathematics classroom can help to provide one way to address this problem. Students can play video games for hours on end though with the time going by quickly and the students persevering in problem solving. Bringing more game-based learning into the mathematics classroom has the potential to help more students be successful in mathematics.

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