Using Games to Support STEM Curiosity, Identity, and Self-Efficacy

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ABSTRACT

In this study, we examine how we might design and use games to support Science, Technology, Engineering, and Mathematics (STEM) learning as well as relevant social and emotional learning skills such as self-efficacy, curiosity, and STEM identity. We investigate a deck-building card game, *Assassins of the Sea* (Killer Snails, 2017), which teaches about marine biology, ecology, and environmental science. 178 middle school participants played the game and took an assessment before and after the game. Our results suggest that players' STEM knowledge increased significantly. We also share social and emotional learning results, identify gaps, and make initial recommendations for creating and using games for STEM learning.

INTRODUCTION

How can we use and design games to better support the learning of Science, Technology, Engineering, and Mathematics (STEM) fields, while **also** supporting social and emotional skills—such as self-efficacy, curiosity, and identity—which have been found to be interrelated to STEM performance, learning, identity, and career interests? This paper investigates a STEM game, *Assassins of the Sea* (Killer Snails, 2017), which has both digital (mobile) and physical versions, and was created by game developer Killer Snails in partnership with the American Museum of Natural History. *Assassins of the Sea* is a deck-building card game, where players need to compete to find a winning cure from the peptides of deadly marine snails. The game is targeted toward middle and high school students and is connected to Next Generation Science Standards (NGSS; https://www.nextgenscience.org/).

The goal of *Assassins of the Sea* is to help support STEM learning, particularly of ecological and environmental processes, as well as to spur innovative thinking and scientific curiosity. As a country, the United States has simultaneously dropped out of the top 10 innovators globally (Jamrisko & Lu, 2018) while American 10th-graders are currently ranked 25th in science worldwide (Kastberg, Chan, & Murray, 2016). Moreover, a full 46% of the American Association for the Advancement of Science (AAAS) scientists rank K-12 STEM in the United States as “below average” (Funk, Rainie, & Page, 2015). Lagging student achievement in STEM is compounded by recent findings that 57% of middle school students say “science is not me,” suggesting that a majority of students do not identify as having a “STEM identity” and further fueling the need for improved STEM curriculum that engages learners while providing teachers with feedback to inform future instruction (Aschbacher & Tsai, 2014). Regardless of whether these data points are correlational or causal, they indicate a concerning trend around STEM that is detrimental for our youngest learners. Strategies to increase the U.S. ranking in STEM are complex and have largely focused on improving rigor in STEM teaching (Honey, Pearson, & Schweingruber, 2014; Klahr, Zimmerman, & Jirout, 2011). As schools of education are tasked with educating future STEM teachers, they continue to seek out the most effective methods of engaging learners and are quick to embrace technologies that teachers may use to engage their students more deeply (Yasar & Veronesi, 2015).

Recent research suggests that shifting from a focus on teachers to the system of teaching has the potential to significantly improve student learning outcomes (Hiebert & Stigler, 2017). This suggests that simply looking at individual educators without observing the methods and practices they employ or larger systemic factors (such as social and emotional components) may limit our ability to improve educational outcomes for our students. Given a similar curriculum, teachers themselves did not account for as much of a difference in learning nor did the teacher's ability to polish each lesson to perfection. While finely honed systems of teaching seem to improve knowledge, research suggests that content alone is not enough to tip the scale toward more successful learning outcomes (Demetriou, 2018). What are some methodologies that may also support STEM learning, social and emotional learning, and purposeful learning? Research suggests that these can include problem-based learning and implementing digital tools. What effective methodologies have in common are mutually agreed upon learning goals aligned to instructional objectives that allow for rich assessments to improve the practice of teaching in a particular domain (Gotwals & Songer, 2013; Kloser, Borko, Martinez, Stecher, & Luskin, 2017). Learning goals provide a target for learning while formatively assessed objectives scaffold each student's pathway and provide a feedback loop for learners to improve their understanding.

For instance, instead of delivering rote lessons, effective teaching may instead include individualized and active instruction that is presented in the context of solving a problem. Presenting a lesson in this way helps students feel more purposeful in their learning. Furthermore, this sense of purpose taps into a student's sense of social-emotional wellbeing. Cohen (2006) suggests that pedagogical practices have the opportunity to embed important skills of self-expression and empathy into current methodologies. In fact, a growing consensus suggests that focusing on the social and emotional states of learners may significantly impact learning outcomes including sense of efficacy in the classroom (Riem, Ciotto, &Abbott, 2017). Enhancing social-emotional learning (SEL) outcomes can improve learning outcomes while building a sense of autonomy and competence in coursework (Zins, 2004). According to Zins and Elias (2007), SEL relates to the "capacity to recognize and manage emotions, solve problems effectively, and establish positive relationships with others" (p. 234), SEL has been shown to increase reasoning, raise academic achievement, and positively impact behavior and attitudes of learners (Zins, Elias, & Greenberg, 2003).

In this paper, we investigate results from a study on students playing *Assassins of the Sea* in middle school classrooms. We seek to better understand how to use games to enhance SEL alongside STEM learning, and how enhancing SEL, self-efficacy, and STEM identity with games may be connected to greater STEM learning outcomes and interest in STEM careers. We ask, are games are an effective way to support STEM knowledge while also supporting SEL skills?

GAME-BASED LEARNING AND STEM

Games have increasingly been used to teach content and skills in a variety of contexts, including school, afterschool programs, home, and libraries (Schrier, 2018). Takeuchi and Vaala (2014) found that 74% of K-8 teachers use games, and 55% of teachers use games at least once a week, in their classroom to improve instruction. This makes sense given 91% of young children are considered gamers, making games for learning an ideal medium to engage learners and broaden STEM participation (Reisinger, 2011). With 64 million kids playing games nationwide it is important to meet students where they are while clearly delineating pathways for teachers to successfully implement technology in the classroom to improve instruction. While a significant number of students and teachers use digital games for learning, 33% of K-12 teachers have shied away from integrating technology into the classroom due to issues of implementation, curricular fit, or lack of professional development to support implementation (Cohen & Hill, 2008; Rebora, 2016). Broadening technology access is one way we can increase wider participation in STEM while providing critical skills for our students to be competitive in the global economy. To address this issue, there is a need to carefully define practices for the implementation of innovative technologies while providing evidence-based research on how these tools improve student learning to transform the process of teaching and learning (Hiebert & Stigler, 2017).

Games have been used to teach topics such as history and historical thinking (Schrier, 2014), literacy acquisition (Ferdig & Pytash, 2014), and music (Hein, 2014), as well as STEM knowledge and skills such as computational thinking skills (Werner, Denner, & Campe, 2014) and medical and health information (Bertozzi, 2014). Games that are used for learning can be made specifically for educational purposes, such as *Assassins of the Sea* or the Federation of American Scientists' *Immune Attack* (2008), or can be commercial off-the-shelf games that are adapted for an educational purpose, such as *Civilization* (MPS Labs, 1991) or *Assassins Creed* (Ubisoft, 2007). They can come in all shapes and sizes, genres, and platforms, from large MMO (massively multiplayer online) games like *World of Warcraft* (Blizzard Entertainment, 2004), to mobile math games such as *DragonBox* (WeWantToKnow AS, 2012), to classic outdoor playground games like hopscotch. Games can be made to teach almost anyone: from preschoolers and babies, veterans, college students, or older adults. Many terms have been applied to these types of games, from educational games, to serious games, or "gamification." Regardless of the term used, these are games that are used or designed to help a particular audience learn a new skill, topic, concept, attitude, behavior, and/or express, connect, and/or develop in a substantive way.

Games, at least theoretically, seem appropriate for learning about complex systems, such as those related to the STEM fields. Biological processes, such as photosynthesis and nutrition, are often not straightforward concepts but complex "'living, breathing' social, cultural, economic, political, and scientific systems with many interconnecting parts, which—to be fully understood—need to be embraced holistically and systemically" (Schrier, 2018, p. 896). Likewise, games are dynamic systems that can help contextualize meaning and simulate the complexity of a STEM-related field. While games cannot possibly simulate every aspect of a dynamic, rapidly-changing system, they can help us to grapple with some of these complexities using authentic data, information, tools, contexts, actions and skills (Schrier, 2018).

Although research has suggested that games can be effective for learning skills or shaping attitudes (Crocco, Offenholley, & Hernandez, 2016; Sitzmann, 2011), efficacy often depends on a number of factors, including context, teacher expertise, student prior knowledge and attitudes, and the design of the game (Clark, Tanner-Smith, & Killingsworth, 2016; Schrier, 2018). For example, Crocco et al. (2016) analyze English lessons using games in math, science compared against nongame lessons. They found that using games in lessons correlated with enhanced enjoyment of learning, which related to higher-order thinking and deeper learning, showing that perhaps the increased enjoyment that games inspire can also support greater learning (Crocco et al., 2016). A meta-analysis of 225 studies found that active learning, including game-based learning, increases student learning outcomes by 6% overall in STEM fields with even stronger impacts for underrepresented students (Freeman et al. 2014). There is significant evidence of the impact of digital games on amplifying student interest (Klahr et al. 2011; Squire & Dikkers, 2012), increasing the collaborative construction of knowledge (Duncan & Rivet, 2013), and extending inquiry (National Research Council, 2011).

On the other hand, Wouters, van Nimwegen, van Oostendorp, and van der Spek (2013) compared the use of games to typical methods (such as lectures, and skill and drill practice, and found that while games were more effective in learning (from a cognitive perspective), they were not necessarily more motivating. Rather than the game itself being the cause of whether learning happens, Clark et al. (2014, 2016) found that it is the design of the game and the learning environment that mattered more, suggesting that there are many complex factors, around and within a game, which can work to support or limit learning. A question, therefore, is the extent to which SEL is a factor around gaming that may contribute to (or even limit) learning.

SOCIAL EMOTIONAL SKILLS, STEM, AND GAMES

As mentioned in the previous section, SEL outcomes and skills, such as motivation, may be factors in whether a game (or any learning experience) is effective. Are STEM games more effective when they support the cultivation of social and emotional skills alongside STEM-related skills and concepts? To understand this, we need to first understand the interconnections among STEM learning in general, and social and emotional skills. For instance, how do one's identity and self-efficacy around learning STEM (seeing oneself as "good at STEM") affect achievement in STEM fields and desire to work in STEM fields, regardless of actual STEM ability.

SEL programs can be effective for overall learning and academic performance. In a meta-analysis, Durlak, Weissberg, Dymnicki, Taylor, and Schellinger (2011) investigated 213 SEL programs at schools and found that these types of programs can enhance social and emotional skills, behaviors, and performance in academic achievement. Likewise, a more recent meta-analysis done by Taylor, Oberle, Durlak, and Weissberg (2017) looked at 82 SEL programs in and out of the United States and found that social-emotional skill development was the best predictor of well-being for students and benefits were seen regardless of socioeconomic status, race, or where the school was located.Self-efficacy has been shown to affect academic achievement (Shams, Mooghali, Tabebordbar, & Soleimanpour, 2011; Xu & Jang, 2017) and motivation and performance in general (Komarraju & Nadler, 2013; Xu & Jang, 2017). In particular, self-efficacy plays a key role in shaping interest and achievement in STEM fields, as well as in the pursuit of careers in STEM (Lent, Brown, & Hackett, 1994; Roue, 2007; Skaalvik & Skaalvik, 2006, 2015). Social Cognitive Career Theory (SCCT) explains that self-efficacy and interest in STEM, coupled with environmental and individual attributes, may affect how someone decides on a career path (Cantrell & Ewing-Taylor, 2009; Hayden, Ouyang, Scinski, Olszewski, & Bielefeldt, 2011; Lent et al., 1994; Wang & Degol, 2013;).

Self-efficacy also affects one's social identity around STEM topics (Flowers & Banda, 2016) and gender, race, class, and ethnicity factor intersectionally into whether students feel a sense of inclusion in their learning experiences (Delgado & Stefancic, 2017[2001]). One's social identity affects and drives learning and growth (Kim, Chang, Choi, Park, & Kim, 2018), including one's sense of belonging (Cheryan, Master, & Meltzoff, 2015). Stereotype threat (Shapiro & Williams, 2012) is also useful to mention, as social identity and self-efficacy are factors in how students may navigate this challenge. Stereotype threat, the fear of living up to the negative stereotypes that an individual hears about one's group or one's identity, affects the performance and achievement of those belonging to marginalized groups (such as women and people of color) and may lead to disengagement in STEM and other domains (Woodcock, Hernandez, Estrada, & Shultz, 2012; Woodcock, Hernandez, & Shultz, 2016). Kim et al. (2018) looked at STEM experiences in middle and high school. They found that social environment affects STEM identity and concepts about who belongs in STEM can be changed with interventions. This research suggests that games that teach

STEM knowledge should couple STEM information, models, and simulations of a game with ways to support social and emotional skills—such as increased self-efficacy around STEM, greater STEM curiosity, and enhanced identity around STEM—as these may as important to the success of the game.

Research from games and intervention programs also support this. Enrichment programs can excite interest in STEM by enhancing scientific curiosity, which in turn leads to high scores of self-efficacy around science and also higher STEM knowledge (Ogle, Hyllegard, Rambo-Hernandez, & Park, 2017). Leonard et al. (2016) used robotics and game design to enhance self-efficacy around STEM for middle school girls and indigenous populations. They looked at middle school students' self-efficacy in technology, attitudes toward STEM/STEM careers, and computational thinking strategies. They found that students who participated in blended robotics/gaming clubs had higher self-efficacy scores, which was related to their participation in the construction of videogames and creating effective game prototypes (Leonard et al., 2016). Likewise, Çakir, Gass, Foster, and Lee (2017) used a game design workshop to help support young women's interest in computing by encouraging them to develop identities as computer scientists.

More generally, feeling a sense of belonging and inclusion in a game community may also contribute to learning (McGonigal 2011; Schrier, 2016). Social interactions and a supportive community of learners in a game, can in turn also motivate further game playing and problem-solving, (Eseryel, Law, Ifenthaler, Ge, & Miller, 2014; Yee 2006). For example, according to Inkpen (1994), players who shared a computer while playing a game were more motivated and exhibited greater learning, possibly because they had to express ideas out loud, helping to reinforce their learning.

Other authors suggest that games can support the development of social and emotional skills in addition to more disciplinary skills. Skills related to compassion and empathy such as perspective-taking, cultural awareness, and reflection (Belman & Flanagan, 2010; Darvasi, 2016; Schrier & Farber, 2018); ethics and ethical thinking, such as argumentation, deliberation, and consideration of others viewpoints (Ryan, Staines, & Formosa, 2016; Schrier, 2015, 2017); other skills such as communication, social awareness, personal expression, and collaboration (Foster & Shah, 2016a; Foster & Shah, 2016b; Shah & Foster, 2018; Steinkeuhler, 2007; Steinkuehler & Oh, 2012;) and emotion expression and emotional and mental health (Dunlap, 2018; Isbister, 2016; Vacca, Bromley, Leyrer, Sprung, & Homer, 2014;). However, more work is needed to understand how to better design games that both support these types of social and emotional skills, while also supporting and encouraging STEM knowledge acquisition and understanding. In this paper, we seek to share initial findings of a STEM-related game that aims to support the enhancement of STEM curiosity alongside STEM knowledge. We also share best practices and recommendations for moving forward with understanding this relationship, and how we can use games to better support it.

METHODS

To analyze the STEM learning goals and STEM interest and identity, 197 middle school participants were invited to play a game, *Assassins of the Sea*, in their classroom. Pre- and post-tests were used before and after the game. *Assassins of the Sea* was chosen for several reasons: (1) We had free access to the game; (2) The game was designed to support both STEM learning and SEL learning; and (3) The game aims to support skill development related to the five core SEL competencies including relationship skills, self-management and decision-making (CASEL, 2018; Dunlap & Rivers, 2018). Dunlap and Rivers (2018) share best practices and a checklist for analyzing games for use in social and emotional skill development in teens. We found *Assassins of the Sea* to meet twelve of the thirteen categories in their checklist (please see Appendix I).

About Assassins of the Sea

Assassins of the Sea is a deck-building card game created in partnership with the American Museum of Natural History through iterative playtesting with middle and high school students. The goal of this game is twofold. First, the game uses extreme creatures (cone snails) to engage students in science learning. Second, the game places students in the role of scientist and in doing so, improves their efficacy and their belief that they can take on the role of scientist. While there are tabletop and digital versions of the game, the digital version has been researched within both public district and charter schools. In this study, the digital version of the game was used for our investigation. In the game, players play as scientists racing to create a winning medicinal cure drawn from the peptides of venomous marine snails. Players must conduct research to identify the peptide solution and feed their snails specific prey to generate peptides in the winning solution. Just as in real life, the peptides that are deadly to the snail's prey are also the source of palliative treatment for humans. The student plays as a scientist trying to collect the peptides that will create the winning peptide cocktail. The peptide solution is revealed during game play through various actions.

Student scientists can use research cards to peek at specific peptide groups called "cabals." When certain snails are fed they may reveal peptides to all players. Over time more peptides are revealed as a result of additional action cards and players can then see which peptides their snails must generate to create the winning treatment. Snails have varying diets of fish, mollusks, or worms which also generate different peptides. Game play moves quickly as players may only make one move per turn which includes: putting a snail into play, feeding a snail, purchasing cards from the market, or using an event card. Players learn from one another, revising their strategies throughout game play. Event cards allow players to enact different strategies while modeling various aspects of scientific inquiry from research to publications and replicating real-world phenomena impacting the snails' habitats from tidal waves and tsunamis. The goal of gameplay is to use science to keep your snails alive and fed until they are able to successfully generate the winning peptide solution resulting in a palliative treatment.

Participants

The study took place at two middle schools across a socioeconomically and ethnically diverse metropolitan public school system in the northeast United States, a public school and a public all-girls charter school. A total of 197 students (137 females, 60 males) engaged in game play for this research (see Table 1). Students from 6th-, 7th-, and 8th-grade were included in this sample of convenience, with significantly more female than male students. Classroom teachers self-selected to participate in this experience as a substitute experience for a life science class where topics of biodiversity, predators and prey, and scientific methods were typically instructed. A total of ten different groups of students participated, five from each of the two schools.

Gender	Grade	*N*	%
Female	6th Grade	16	8%
	7th Grade	33	17%
	8th Grade	88	45%
Male	6th Grade	15	8%
	7th Grade	45	23%
Total		197	

Table 1. Descriptive statistics for participants engaged in AOTS game play

Materials & Procedures

To conduct the study, researchers instructed the participants at the beginning of each 45-minute class period to collect their own laptop computer from a laptop cart at the front of the classroom. A do-now was written on the board prompting students to independently respond to a pre-assessment through Google forms. The "do now" was a pre-test used to establish a baseline of prior knowledge before game play (e.g., what is a cone snail, what are its predators and what are its prey, why are scientists interested in studying cone snails). Students were encouraged to give their best possible answers or leave responses blank if they did not know the answer. Table 2 includes the items used to assess knowledge, pre and post gameplay.

Once students submitted their pre-assessment responses they were instructed to close all but one laptop per group. Once extra laptops were closed, students were invited to begin playing *Assassins of the Sea* in small groups of three to four. Students launched the digital version of *Assassins of the Sea* from a single shared laptop per group and took turns manipulating the laptop during their turn. Teachers and researchers circulated to observe students during game play and assist in technical issues. Students were asked to end gameplay 10 minutes before the end of the class period to take the post-assessment. The post-assessment included the same seven questions as the pre-assessment. In addition, there were three open-ended questions about scientific identity and interest in STEM careers.

Results

To determine whether or not there was a significant change in student understanding of STEM concepts after AOTS gameplay, we conducted a repeated measures ANOVA with pre- and post-assessments collected over time as a within-subjects variable and gender and grade as between-subjects variables (Table 3). The analysis revealed a main effect of gameplay on student scores between pre- and post-assessments ($F(1, 192) = 234.46$, $p = .000$), where student scores improved after a single session of game play. Results also indicate a main effect of grade ($F(2, 192) = 6.34$, $p = .002$) where students in 8th grade had higher mean scores both pre- and post assessment (respectively, *M*s = .98, 2.57) than students in the 6th- (respectively, *M*s = .32, 2.35) or 7th-grade (respectively, *M*s = .41, 1.98). A post-hoc Tukey test indicates a significant difference between the scores of 7th- and 8th-grade student ($p = .000$). No significant between-subject effects were found between student score and gender and no significant between-subject interactions were found between the three factors of score, gender, or grade level.

	Mean Pre-Test	SD	Mean Post-Test	SD	*N*
What makes cone snails deadly?	0.16	0.37	0.64**	0.48	196
What are the three types of prey that cone snails hunt?	0.01	0.07	0.47**	0.42	196
What are some predators of cone snails?	0.02	0.12	0.26**	0.44	197
What are three ways that scientists share their findings?	0.36	0.45	0.40	0.44	195
Why do scientists study cone snails?	0.04	0.20	0.19**	0.39	197
What are some environmental factors that affect cone snails?	0.03	0.11	0.24**	0.38	197
How do the environmental factors listed above affect cone snails?	0.29	0.45	0.38*	0.49	197
Total Score	0.65	0.73	2.31**	1.50	197

* $p = .001$; ** $p = .000$

Table 2. *Paired t-test for question asked before and after AOTS game play across all students*

Once an overall significant difference in student scores between pre- and post-assessments was established, we looked closely at each specific question to determine which aspects of science knowledge were most impacted by game play. A series of paired t-tests were conducted to evaluate changes between pre- and post-assessment scores on each of the individual test items (Table 2).

Time	Gender	Grade	Mean	SD	*N*
Pre-Test	Female	6	0.36	0.43	16
		7	0.45	0.54	33
		8	0.98	0.82	88
		Total	0.78	0.77	137
	Male	6	0.28	0.46	15
		7	0.38	0.58	45
		Total	0.35	0.55	60
	Total	6	0.32	0.44	31
		7	0.41	0.56	78
		8	0.98	0.82	88
		Total	0.65	0.73	197
Pre-Test	Female	6	2.24	1.53	16
		7	1.78	1.29	33
		8	2.57	1.56	88
		Total	2.34	1.52	137
	Male	6	2.47	1.23	15
		7	2.18	1.53	45
		Total	2.25	1.45	60
	Total	6	2.35	1.38	31
		7	2.01	1.44	78
		8	2.57	1.56	88
		Total	2.31	1.50	197

Table 3. Mean pre- and post-test scores for students engaged in AOTS game play

Student understanding significantly increased across six of the seven assessment items including the average score between pretest (M = .65, SD = .73) and post-test (M = 2.31, SD = 1.50), t(196) = -17.10, p = .000. Students showed significant improvement between pre- and post-tests demonstrating an improved understanding of why scientists study venomous cone snails, their predators, and their prey, and a greater understanding of what and how environmental factors impact the snails' livelihood. Specifically, student understanding about why the snails are deadly increased significantly between pre-test (M = .16, SD = .37) and post-test (M = .64, SD = .48); t(195) = -12.65, p = .000). Student knowledge about the snails' prey also improved significantly between pretest (*M* = .00, *SD* = .07) and post-test (*M* = .47, *SD* = .42); *t*(196) = -15.74, *p* = .000. Students understanding of predators significantly improved between pretest (*M* = .01, *SD* = .12) and post-test (*M* = .26, *SD* = .44); *t*(192) = -7.45, *p* = .000. After a single round of game play student understanding about why these snails are studied improved significantly between pre-test (*M* = .04, *SD* = .20) and post-test (*M* = .18, *SD* = .39); *t*(196) = -5.22, *p* = .000. Additionally, students were significantly more likely to identify environmental factors that impact these snails between pretest (*M* = .03, *SD* = .38) and post-test (*M* = .24, *SD* = .45); *t*(196) = -7.50, *p* = .001. What's more, not only were students significantly more likely to identify the environmental factors impacting venomous cone snails, they were also significantly more likely to explain how these factors impact the ecosystems of these extreme creatures between pretest (*M* = .29, *SD* = .45) and post-test (*M* = .38, *SD* = .49); *t*(196) = -3.37, *p* = .001 assessment. The only question that did not show significant changes in score between pre and post-tests was the question about how scientists share their findings. Implications for this result will be shared in the discussion section and provide an opportunity for educators to further elucidate the process of scientific inquiry and discovery and for designers and developers to consider mechanics that better elaborate on these topics.

Grade level differences in pre-post assessment score

In order to determine which of the question items contributed to the significant difference in scores by grade level, a set of paired t-tests was conducted by grade level (Table 4). For sixth grade only participants, all of the changes in means for the questions (from pre- to post-game) are significant except for the seventh question ("How do the environmental factors you listed above affect cone snails?"). For seventh grade participants, all of the changes in means for the questions (from pre- to post-game) are significant except for the seventh question ("How do the environmental factors you listed above affect cone snails?"). For eighth grade participants only, all of the changes in means for the questions (from pre- to post-game) are significant except for the fourth and fifth questions ("What are three ways that scientists share their findings?" and "Why do scientists study cone snails?")

	Mean Pre-Test	SD	Mean Post-Test	SD	*N*
6TH GRADE STUDENTS					
Venom of cone snails	0.13	0.34	0.74**	0.44	31
Cone snail prey	0.00	0.00	0.59**	0.39	31
Cone snail predators	0.00	0.00	0.39**	0.50	31
Science research methods	0.16	0.29	0.34*	0.38	31
Cone snail science	0.00	0.00	0.19*	0.40	31
Environmental factors	0.03	0.09	0.10*	0.16	31
How factors impact snails	0.35	0.49	0.39	0.50	31
Total Score	0.32	0.44	2.33**	1.38	31
7TH GRADE STUDENTS					
Venom of cone snails	0.22	0.42	0.58**	0.50	78
Cone snail prey	0.00	0.00	0.51**	0.43	78
Cone snail predators	0.01	0.11	0.35**	0.48	78
Science research methods	0.12	0.22	0.19*	0.28	78
Cone snail science	0.01	0.11	0.28**	0.45	78
Environmental factors	0.05	0.13	0.11*	0.17	78
How factors impact snails	0.50	0.50	0.50	0.50	78
Total Score	0.41	0.56	2.01**	1.44	78
8TH GRADE STUDENTS					
Venom of cone snails	0.13	0.33	0.67**	0.47	87
Cone snail prey	0.01	0.11	0.40**	0.40	88
Cone snail predators	0.02	0.15	0.14*	0.35	88
Science research methods	0.66	0.48	0.60	0.49	88
Cone snail science	0.08	0.27	0.10	0.30	88
Environmental factors	0.01	0.11	0.40**	0.49	88
How factors impact snails	0.08	0.27	0.27**	0.45	88
Total Score	0.98	0.82	2.57**	1.56	88

* $p < .01$; ** $p = .000$

Table 4. Paired t-test mean scores by grade and question type

Gender differences in pre-post assessment score

While there was no significant main effect of overall score by gender, researchers were curious to see if any differences in gender emerged when looking at the change in scores between pre- and post-tests. A set of paired t-tests were conducted to compare differences in mean scores in pre- and post-assessment by student gender (Table 5). Results indicate that for female students, significant gains were made across each question except for the fourth question ("What are three ways that scientists share their findings?"). For male students, significant gains were made between pre- and post-assessments for each question except question seven ("How do the environmental factors you listed above affect cone snails?").

	Mean Pre-Test	SD	Mean Post-Test	SD	N
FEMALE STUDENTS					
Venom of cone snails	0.15	0.36	0.65**	0.48	136
Cone snail prey	0.01	0.09	0.43**	0.41	137
Cone snail predators	0.02	0.15	0.18**	0.39	137
Science research methods	0.49	0.48	0.47	0.48	135
Cone snail science	0.05	0.22	0.15*	0.35	137
Environmental factors	0.02	0.11	0.29**	0.43	137
How factors impact snails	0.23	0.42	0.37**	0.48	137
Total Score	0.78	0.77	2.34**	1.52	137
MALE STUDENTS					
Venom of cone snails	0.20	0.40	0.63**	0.49	60
Cone snail prey	0.00	0.00	0.56**	0.42	60
Cone snail predators	0.00	0.00	0.43**	0.50	60
Science research methods	0.09	0.18	0.23**	0.29	60
Cone snail science	0.02	0.13	0.28**	0.45	60
Environmental factors	0.05	0.12	0.11*	0.16	60
How factors impact snails	0.42	0.50	0.42	0.50	60
Total Score	0.35	0.55	2.25**	1.45	60

* $p < .01$; ** $p = .000$

Table 5. Paired t-test mean scores by student gender and question type

Student perception of self as scientist

Gains in science knowledge following game play demonstrate the potential of games as a tool for learning. Researchers were also interested in understanding student perceptions of themselves as scientists. Specifically, researchers were curious to discover if students' beliefs about becoming scientists are related to grade level or gender.

At the end of the post assessment students were asked two questions: (1) could you see yourself as a scientist, and (2) why or why not? Only 6th- and

7th-grade students responded to this inquiry as a result of timing yielding a total of 86 students responses. Overall 43% of students said that that yes, they could see themselves as scientists while 57% responded that no, they could not see themselves as a scientist. Of those stating they could not see themselves as scientists 67% were male students and 33%were female students (Table 6).

Two separate analyses of variance (ANOVA) were conducted to determine if student responses to ‘Could you see yourself as a scientist’ varied as a factor of grade or gender. As Table 6 shows, while student responses did not vary significantly by grade level, student responses did yield significant variation as a result of gender, $F(1, 84) = 5.18$, $p = .03$, where female students more often indicated that they could see themselves as a scientist.

	Yes	No	*N*	M	SD
Female Students	21	16	37	1.43	.50
6th Grade	8	6	14	1.42	.51
7th Grade	13	10	23	1.43	.51
Male Students	16	33	49	1.67	.47
6th Grade	2	10	12	1.83	.39
7th Grade	14	23	37	1.62	.49
Total	37	49	86	1.57	.50

Table 6. Could you see yourself as a scientist?

DISCUSSION & ANALYSIS

For all groups, across gender and grade, STEM understanding around snails and other content related to the *Assassins of the Sea* game increased after game play. In terms of qualitative feedback from students, they were asked to identify the salient aspects of the game and provided several categories of responses including having a better grasp of predator-prey relationships, spurring curiosity about other organisms, and seeing themselves as scientists. Although the post-game assessment increased in accuracy after the game was played, we cannot say that the game itself was the reason as we do not have a proper control condition. Other limitations of the study are that only 6th- and 7th-grade students were asked to respond to the open-ended questions about themselves as scientists.

We looked at self-efficacy and STEM career interest and identity by asking the participants if they see themselves as a scientist. Although participants were split between seeing and not seeing themselves as a scientist, reasons for or against this varied greatly. Females were significantly more likely to state that they saw themselves as a scientist. For instance, those who had higher STEM self-efficacy and saw themselves as scientists said things like, “I like to learn new things,” “I always have questions,” “I am very curious,” and “I like to experiment.” Those that had lower self-efficacy around STEM and did not see themselves as a scientist said things like, “I think it’s boring,” “It’s too much work,” “it doesn’t seem fun,” and “I don’t think I’m skilled enough to be a scientist.” Additionally, 20 participants who had a higher mean change score (3 or above) on their post-game assessment said they wanted to be a scientist (20/35 or 57% of those who said they wanted to be a scientist), whereas only 10 of the participants who had a higher mean change score said that they wanted to be a scientist (10/46 or 22% of those who did not want to be a scientist), suggesting that perhaps there is a relationship between comprehension (higher scores) and self-efficacy around STEM, and perhaps a game can help to support this.

There are a number of gaps in this and similar research that should continue to be explored. One, how are self-efficacy, identity, curiosity, and SEL skills around STEM related to increased STEM knowledge? Does greater STEM knowledge increase self-efficacy, or does self-efficacy increase knowledge, or is it both? We need to understand further how these types of skills and learning support each other, and, we need to understand how games can specifically support both of these types of skills and learning, as they seem to be interrelated. Second, what are the specific design principles and contexts for games that further enable the support of SEL and STEM learning? Are there specific ways that we can design games to better support these skills, such as through problem-based learning, teacher/mentor involvement, and generating a sense of purpose. Third, we did not find gender differences in how the students performed on the post-game assessment, but we found that more females identified as wanting to be a scientist than males. Are there gender differences in how a game may support self-efficacy around STEM? Are there specific ways that games can support more self-efficacy around STEM for particular populations or marginalized populations? We did not measure self-efficacy before and after the game, or compare it to a control condition, and it would be useful, moving forward, to add this into the analysis to better understand how this particular game may support it.

Based on this study, our literature review, and our observations of the use of *Assassins of the Sea* in the middle school classrooms, we make five initial recommendations for designing and using games for STEM:

Balance. Designers and educators may want to consider how to balance the need for STEM accuracy and learning STEM-related knowledge, processes, and facts, with encouraging STEM curiosity, identity, self-efficacy, and other social and emotional skills. More research is needed to understand how this balance is best achieved through games and game design, with consideration to classroom and other learning contexts.

Meaning. The design of the game should contribute to the sense of purpose for the player. Goals, obstacles, problems, and possible solutions posed by the game should be meaningful to the player, both in terms of the game's play, and to the player more personally. The game's design should help the player feel a sense of purpose—such that they need to solve a STEM-related problem, but also that their actions and contributions personally matter.

Role-play. While the game does not need to be a role-playing game, it may be useful to incorporate interactions with STEM knowledge in the game, with an exploration and understanding of the role of a STEM researcher/practitioner. Players should understand the processes and mechanisms behind the STEM problems they are trying to solve, while embodying what scientists and engineers do. The game could enable the players to authentically act in these roles, use related tools, or address real-world data, so that players can more easily see themselves as a scientist, as this may also connect to their learning effectiveness.

Assessment. When assessing the game, researchers and educators should consider assessing both STEM knowledge and learning along with STEM self-efficacy and curiosity, such as their willingness to participate in science or their interest in a career in STEM. The SEL-related skills need to be seen as just as worthy to investigate as the STEM learning and knowledge building. Game designers may even want to build these assessments through the game's play itself, and should consider how to assess STEM SEL skills through a game's play.

Scaffolds. Consideration for scaffolds that would support educators in extending student inquiry outside game play would be beneficial to students, designers, and developers. Providing support for educators to help unpack complex concepts or narratives outside gameplay may increase students' self-efficacy in science and improve their strategies during game play. Identifying the strategies that best support student approaches to learning can help designers and developers select mechanics that are most useful for teaching complex content.

CONCLUSION

In this paper, we explored how games can support STEM learning, and the role of SEL such as STEM self-efficacy, identity, and curiosity in enhancing learning. We conducted a study of *Assassins of the Sea*, a deck-building card game about killer marine snails, where participants conduct research on their snail's peptides to create in-game cures and compete against other players. We looked at 178 participants in two schools across three grades (6th, 7th and 8th grade), and found that on the whole, STEM knowledge of marine snails, and other relevant learning from the game, significantly increased between the pre- and post-game assessments. A portion of the players (N = 109) were also assessed qualitatively on their scientific self-efficacy, STEM identity and interest in being a scientist. We found that the responses varied, but a higher proportion of females had an interest in being a scientist, and those whose scores changed more substantially from pre- to post- also demonstrated a higher interest in being a scientist. A future study should include a control condition and questions about self-efficacy both pre- and post-game to further parse out the effect of the game on these measures.

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APPENDIX I.: *ANALYSIS OF ASSASSINS OF THE SEA, USING THE CHECKLIST CREATED BY DUNLAP AND RIVERS (2018).*

Component	*Y or N*
Designed for a teen audience	Y
Integrates evidence-based SEL content accurately	N
Is a complex system comprised of interesting, meaningful choices (complexity)	Y
Players are active, influential agents within the game space (autonomy & agency)	Y
Players start with basic mechanics or knowledge which scale in difficulty and complexity in response to actions	Y
Skills are practiced and revisited across multiple contexts (iteration)	Y
Social and emotional content is embedded within gameplay via mechanics, narrative, cut scenes, etc. (integration)	Y
Challenges faced can provide opportunities for social and emotional growth experiences within and around the game (identity)	Y
Provides opportunities to connect and learn from more experienced players (mastery)	Y
Supports and encourages sharing of personal accomplishments, performances (supported sharing)	Y
Facilitates social interaction and meaningful relationships (connection)	Y
Provides an environment where the process of learning from mistakes is valued and supported by the group (productive failure)	Y
Feedback is timely, consistent, constructive, and accurate (constructive feedback)	Y