Revisiting the Intrinsic Integration Hypothesis

by

Graeme Nidd

A thesis submitted to the Faculty of Graduate and Postdoctoral Affairs in partial fulfillment of the requirements for the degree of

Master of Cognitive Science

Carleton University
Ottawa, Ontario

Abstract

The Intrinsic Integration Hypothesis proposes that educational games that use the core game mechanisms to teach the learning material are not only more fun to play, but also more effective at communicating the target knowledge. My thesis tests the Intrinsic Integration Hypothesis with two educational versions of Battleship that were designed for my experiment. This study examined the learning gains and motivation of 58 participants who interacted with either the intrinsic or extrinsic version for 35 minutes. The results contradicted previous findings in support of the Intrinsic Integration Hypothesis: participants reported that both games were similarly motivating as measured by questionnaire data, and participants who practised with the extrinsically-integrated version of the game learned more as measured by pretest to posttest gains. This work contributes empirical data to the debate concerning intrinsic integration, and it raises concerns about the need for transfer and increased cognitive load in these educational games.

Acknowledgements

I would like to thank my family, my friends, my supervisor, all of the participants, and you – the reader.

Table of Contents

List of Figures

List of Tables

List of Appendices

Chapter 1: Introduction

Educational games are structured forms of play that have been explicitly designed with educational purposes, or which have incidental educational value. Games are used in this way because they are theorized to be *intrinsically motivating* (Csíkszentmihályi, 1975; Ryan & Deci, 2000). In other words, the characteristic design of games can motivate students to engage with them, and thereby the educational content, without an external reward and/or punishment. This increased motivation can improve learning outcomes (Cordova & Lepper, 1996; Clark, Tanner-Smith, & Killingsworth, 2016). However, beneficial effects such as increased time-on-task do not always translate to learning gains (Landers & Landers, 2014). How to design games that foster both motivation and learning remains an open question. In particular, there is very little work investigating how to integrate learning materials with games. Should an educational game's learning material be integrated with the game's core mechanisms or incorporated into the game as a separate activity?

The present thesis addresses this question of effective game design by expanding upon Habgood and Ainsworth's (2011) examination of intrinsic versus extrinsic game design. Intrinsically-integrated games combine the learning material with the game's core mechanisms, so that the player must use the educational content to progress through the game. In contrast, extrinsically-integrated games have a distinct separation between the learning materials and the game itself, using the intrinsically motivating aspects of the game as 'sugar coating.' In other words, extrinsic integration rewards students for engaging with the learning material by giving them the opportunity to play the game once they finish a given learning activity. Habgood and Ainsworth (2011) hypothesized that games designed according to the principles of intrinsic integration would not only be more fun, but also more effective at helping students learn. The results of their experiment supported this hypothesis, as participants demonstrated higher posttest learning gains when given an intrinsically-integrated game and reported that it was more fun than the extrinsically-integrated version. This was the first study to examine the impact of extrinsic versus intrinsic game design, so more work is needed in this area.

My work addresses this gap by further investigating the design principles of intrinsic and extrinsic integration. Intrinsic integration has very little empirical data to support it as well as a number of potential disadvantages. Additionally, Habgood and Ainsworth's (2011) experiment suffered from some limitations that may have impacted the results. These limitations relate to the control of both the level of challenge during gameplay and the instructional sequences between the two game versions. Will the benefits of intrinsic integration found by Habgood and Ainsworth remain once these limitations are addressed? To answer this question, I created two versions of a game based on Battleship (an intrinsically-integrated and an extrinsically-integrated version) that was designed to teach the basics of complex numbers. To analyze learning from each version of the game, I conducted an experiment with undergraduate university students who played the game in pairs, and who were tested on their domain knowledge before and after playing the game.

Chapter 2: Related Work

2.1 Foundations

Games and the incorporation of their mechanisms into learning activities – typically referred to as gamified learning – are common, if not ubiquitous, pedagogical tools. When used as instructional activities, games can help students learn (Wouters, van Nimwegen, van Oostendorp, & van der Spek, 2013; Clark, Tanner-Smith, & Killingsworth, 2016). Why is that? One conjecture is that the intrinsically motivating gameplay encourages students to engage with the learning material (Malone & Lepper, 1987; Dickey, 2007). Intrinsic motivation is an internal reward mechanism: "an activity is generally said to be intrinsically motivated if there is no apparent external reward associated with the activity. In other words, the reward is said to be the activity itself" (Deci & Porac, 1978, p.150). This internal reward mechanism has been associated with higher interest and confidence as well as improved performance (Ryan & Deci, 2000; Sheldon, Ryan, Rawsthorne, & Ilardi 1997). Thus, games may be beneficial for learning because they are intrinsically motivating.

Several mechanisms have been suggested to explain why intrinsic motivation associated with games promotes learning, including mindset, persistence, attention, affect, and cognitive strategies. For instance, the fact that games are motivating may help students adopt beneficial beliefs about their intelligence, like believing their ability can be improved with practice, in turn leading them to invest more time and effort (Dweck, 1986; Lee, Heeter, Magerko, & Medler, 2012). Greater persistence, which is good for learning, has also been associated with intrinsic motivation (Vollmeyer & Rheinberg, 2000). As for emotion, there is established evidence that it impacts learning (Parkin, Lewinsohn, & Folkard, 1982). For instance, intrinsically motivating activities alleviate test anxiety and thereby mitigate the detrimental effect that it has on measures of learning (Pintrich, 2003; Zeidner, 1998). Intrinsic motivation can also improve learning by influencing the cognitive strategies students choose, such as more explorative behaviour (Martens, Gulikers, & Bastiaens, 2004). This range of potential mechanisms through which intrinsic motivation could benefit learning are not mutually exclusive, and may in fact be additive, increasing the overall effect that motivation has on learning.

In general, the ability to promote intrinsic motivation is clearly an important feature of educational games. Malone and Lepper (1987) made this observation and identified seven aspects that affect the motivational appeal of games. These motivating elements include: fantasy, control, cooperation, competition, recognition, curiosity, and challenge. Each of these elements has since been subject to extensive empirical work, both in the context of games and otherwise. Instructional environments involving fantasy, and hypothetical worlds more broadly, have been shown to increase children's deductive reasoning ability (Dias & Harris, 1988) as well as their production knowledge relating to new words (Weisberg et al., 2015). The perceived control over the game state is associated with greater enjoyment (Birk & Mandryk, 2013; Klimmt, Hartmann, & Frey, 2007). In addition to the established positive effect of cooperation on learning in general (Johnson, Johnson, & Stanne, 2000), cooperation has also been shown to increase a student's likelihood to engage in the learning activity as well as their opinion of the learning material itself (Ke & Grabowski, 2007; Plass et al., 2013). While competition can negatively impact affect, it has also been associated with higher learning gains (Plass et al., 2013). Recognition of students' time spent working on a task, in the form of a game-like ‘leaderboard,’ increased the time spent working on a project (Landers & Landers, 2014). Regarding curiosity and challenge it is often the suspense of a “close game” that captivates a game’s audience – players and spectators alike (Lomas & Koedinger, 2017). Malone and Lepper (1987) argued that the intrinsic motivation evoked by these seven game elements is necessary for student involvement when engagement with an instructional activity is not mandatory.

Malone and Lepper (1987) also make a distinction between ‘endogenous’ and ‘exogenous’ versions of each motivational element. Endogenous implies that the motivating element is an integral part of the game itself and exogenous implies that it is imposed upon the game. For example, the challenge associated with a game could arise from the game itself or from an external competition that has been agreed upon, such as getting a better score in a single-player game. In the former case, the challenge is derived from the activity itself, while in the latter it arises from an element which is outside of the game. This distinction applies to each of the motivating elements and it captures the fact that players bring additional elements to games, such as house rules, evolving strategies, and thriving communities.

More recent work has expanded upon Malone and Lepper’s (1987) seminal paper. Their seven motivational elements focus on the player experience and thereby include the exogenous elements that players bring to the game. For example, cooperation and competition highlight what the player is doing rather than the elements of the game that elicit this behaviour. These elements have been refined to use the structural aspects of the game itself as their point of reference, and include fantasy, rules/goals, sensory stimuli, challenge, mystery, and control (Garris, Ahlers, & Driskell, 2002). As an example of this revised focus, consider the change of the “curiosity” element to “mystery.” The latter can be identified by examining the game, whereas the former relies upon the user’s subjective reaction to the game. Evaluating the latter is more challenging since attempts to create a sense of mystery may or may not evoke curiosity in a given player. Garris et al. (2002) also depart from the earlier framework by acknowledging that intrinsic motivation is not necessary for student engagement when a learning activity is optional, as one’s decision to play an educational game can also stem from extrinsic motivation. For example, someone might play a game because their friend wants to. As a second example, extrinsic motivation in the form of compensation is often used in laboratory experiments. Nonetheless, the question still stands as to whether or not a game’s intrinsically motivating elements affects a player’s learning outcome.

Garris et al. (2002) formalized the various elements related to educational gameplay and the corresponding learning outcomes with an input-process-outcome model, which distinguishes short-term affective reactions from the long-term attitudes that constitute the affective outcome (Garris et al., 2002). This theoretical model (Figure

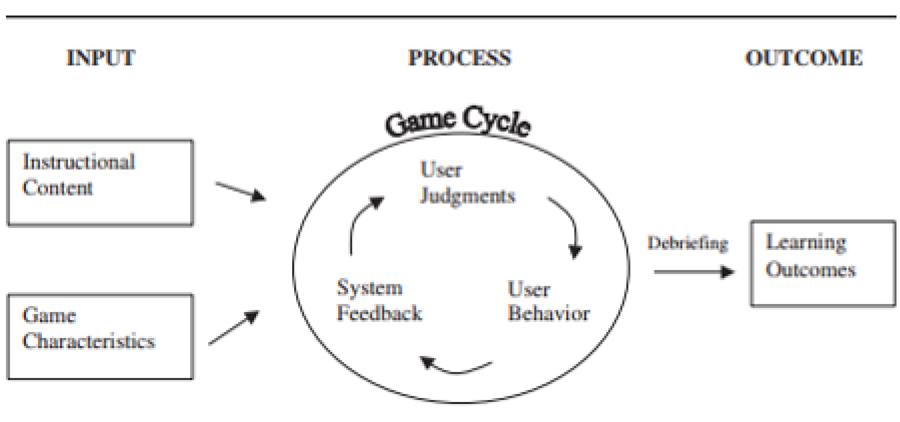


Figure 1. Input-Process-Outcome game model (Garris et al., 2002).

1) consists of three elements. First, the instructional material paired with the game's characteristics constitutes the input. Second, a process loop begins with the user's reaction to the input that subsequently triggers a certain behaviour, which then evokes feedback from the system. Third, the result of the game cycle is the learning outcome – the persistent effects that the game has on the player. Within this model, short-lived affective reactions termed "user judgments," such as interest, enjoyment, and confidence, lead to behaviours associated with increased motivation. Negative judgments, on the other hand, lead to behaviours associated with decreased motivation. These short-term elements of the game cycle will in turn influence the long-term effects that the game has on the player via the learning outcomes. Garris et al. (2002) divided the outcomes into four distinct sub-categories: declarative, procedural, strategic, and the aforementioned affective outcomes. All four are potentially important and distinct outcomes to measure when experimentally testing the impact of educational games.

2.2 Empirical Evidence Regarding Educational Games

This section summarizes related empirical work from two streams of game-related research, namely the media-comparison and value-added approaches (Mayer, 2011). Experiments from the media-comparison approach compare games to other instructional methods, and those from the value-added approach – including my experiment – compare design choices within games. Mayer (2011) made this distinction with regard to game-related research in order to stimulate and guide further empirical work, as he noted that game-related research could use more evidence for its claims. For instance, a review (Connolly, Boyle, MacArthur, Hainey, & Boyle, 2011) found that less than 2% of journal articles examining the effects of games on adolescent students reported empirical evidence about these effects (as another example see O'Neil, Wainess, & Baker, 2005). This trend has been attributed to the prominence of design-based methodologies, where researchers iteratively design educational games (Barab & Squire, 2004; Anderson & Shattuck, 2012). While these methodologies play an important role in research relating to educational games, it is likewise important to ensure that elements relating to game design do not eclipse the empirical aspects.

The Media-Comparison Approach. Research using the media-comparison approach aims to evaluate the efficacy of educational games by comparing this medium to other instructional methods. As an example of this, three recent meta-analyses (Sitzmann, 2011; Wouters et al., 2013; Clark, Tanner-Smith, & Killingsworth, 2016) all explicitly respond to researchers who argue that games are not better than more conventional instructional methods (such as Clark, Yates, Early, & Moulton, 2010). Each of the aforementioned meta-analyses found that educational games promote both learning and retention. Moreover, educational games were particularly effective when they supplemented other instructional methods and when participants had the chance to play the game multiple times (Wouters et al., 2013; Clark et al., 2016).

While the meta-analyses establish that games do foster learning, determining how the motivating elements of games can be most effectively leveraged, however, is not addressed by this empirical work. Indeed, the most recent meta-review highlighted that media-comparison studies tend to let the instructional medium overshadow the design of the game and the activity to which it is being compared (Clark et al., 2016). Determining how educational games ought to be designed is the focus of the value-added approach, under which my research is classified.

The Value-Added Approach. Research from the value-added approach identifies and tests design factors that influence learning from educational games. These experiments do so by measuring the effect of manipulating various design aspects of educational games. The effects of these design choices are measured by how much participants learn as well as other affective and motivational outcomes that benefit learning. For example, elements of the game could influence a student's attitude toward the instructional material, which could later cause them to spend more time engaging with that material. As an example of the value-added approach, a recent study examined the effect of a leaderboard that ranked students based upon how much time they spent in an on-line instructional environment (Landers & Landers, 2014). The results indicated that the presence of a leaderboard increased participants' time-on-task, a variable with an established effect on learning outcomes (Stallings, 1980). Landers and Landers concluded that there was a mediating process linking this specific game element to the learning outcome of the instructional environment.

Game elements have also been evaluated in terms of cognitive load, which refers to the amount of information that needs to be held in working memory. Since the human mind can only process so much information at once, effective pedagogical tools should limit the amount of extraneous cognitive load, or the unnecessary processing demands that are imposed upon the learner (Sweller, 1988; Mayer & Moreno, 2003). This mediating factor is often cited as a reason against the use of educational games, because irrelevant aspects of the medium – such as a score, the control scheme, and various visually stimulating aspects – could distract from the learning material (Schrader & Bastiaens, 2012; Kalyuga & Plass, 2009).

Another example of the value-added stream relates to studies examining the effects of cooperation and competition in educational games (Ke & Grabowski, 2007; Plass et al., 2013). Ke and Grabowski compared the effectiveness of games involving cooperative competition, individual competition, and a non-game control condition on math learning and attitudes among fifth-grade students. The results indicated that participants in both conditions that involved a game learned more than those in the non-game control group. Moreover, attitudes regarding math were significantly better in the cooperative game condition than in the other two conditions. Plass et al. examined the effects of endogenous cooperation and competition on learning outcomes. The difference between pretest and posttest results was only significantly higher in the competitive condition compared to the individual condition. Measures of in-game performance also indicated that the competitive condition increased performance, while the collaborative condition decreased it. However, affective outcomes were greatest in the cooperative condition, as measured by intention to play the game again and to recommend it to others.

An area within the value-added approach that has not received much attention is the effect of different approaches to integrating a game's motivating elements with the learning material. For example, a recent meta-analysis found only one experiment that completely separated the learning mechanisms from the mechanisms designed for engagement with the game (Clark et al., 2016). This experiment, conducted by Habgood and Ainsworth (2011), compared games with intrinsically and extrinsically integrated learning materials. With only this one experiment providing empirical data, the meta-analysis was unable to weigh in on the merits of intrinsic integration. My research aims to shed more light on this open question within the value-added stream.

2.3 Intrinsic Integration

Intrinsic integration is defined as the synthesis of an educational game's learning material with its core mechanisms. In other words, an intrinsically-integrated game uses one of the gameplay mechanisms as the primary way of helping players toward the intended learning outcome. This concept of intrinsic integration can be traced back to early research on educational games. Malone and Lepper (1987) first identified it with respect to fantasy, stressing that a game's fictional narratives should coincide with the instructional material and even serve as an analogy that will help the user process the new information. This idea was expanded from the realm of fantasy to game design more broadly by Kafai (1996), who anecdotally observed that his students tasked with designing educational games took two distinct approaches that he termed extrinsic and intrinsic integration. Those who took the extrinsic approach used the game as a form of 'sugar-coating:' players in the game were rewarded for answering questions relating to the learning material with the opportunity to continue playing the game. On the other hand, another group of students took what Kafai called the intrinsic approach by using the game's core mechanisms to help communicate the learning material. Players in these intrinsic games needed to use the learning material to progress through the game.

Habgood and Ainsworth (2011) hypothesized that games designed according to the principles of intrinsic integration would not only be more fun than their extrinsically-integrated counterparts, but that they would also be more effective educational tools.

These hypothetical benefits are reflected by Habgood, Ainsworth, and Benford's (2005) definition of intrinsically-integrated games as ones that:

> 1. deliver learning material through the parts of the game that are the most fun to play, riding on the back of the flow experience produced by the game, and not interrupting or diminishing its impact and;
> 2. embody the learning material within the structure of the gaming world and the player's interactions with it, providing an external representation of the learning content that is explored through the core mechanics of the gameplay. (Habgood et al., 2005, p. 46)

In this definition, the authors make two claims. First, they hypothesize that having separate mechanisms for gameplay and learning activities diminishes the benefits of intrinsic motivation by interrupting the state of mind referred to as flow. Second, they suggest that embodying the learning material within the gaming world is beneficial to learning as it encourages players to interact with the representations while they play. In contrast, extrinsic integration presents the learning material removed from the context of the game, typically in a format closer to that which is found in school. These two claims provide the rationale for the hypothesis that intrinsically-integrated games are more effective pedagogical tools than their extrinsically-integrated counterparts.

As noted above, the rationale behind the intrinsic integration hypothesis relies upon the construct of flow. This construct originates from Csíkszentmihályi's (1975) work in which he interviewed a series of individuals that devoted a great deal of time and effort to activities related to play, such as chess masters, professional rock climbers, and musicians. From the collected qualitative data, Csíkszentmihályi (1975) identified the core characteristics of flow, including: (a) concentrating on a limited stimulus field, (b) using skills to meet clear demands, (c) obtaining a sense of control, (d) removing oneself from quotidian concerns, and (e) forgetting one's separate identity. Flow is theorized to be the product of an ideal balance between the perceived skill of an individual and the perceived difficulty of the task (Figure 2). Thus, if an activity is perceived to be too difficult, then the player will not experience flow and instead be frustrated. Likewise, if the game is too easy, then the player will be bored or even apathetic. In general, mismatches between perceived skill and difficulty reduce the experience of flow. This means that an educational game that is perceived to be too easy or too hard will not be intrinsically motivating.

Habgood and Ainsworth (2011) propose that intrinsic integration delivers the learning material via the parts of the game that generate flow, while extrinsically integrated games interrupt flow and thus diminish the benefits afforded by educational

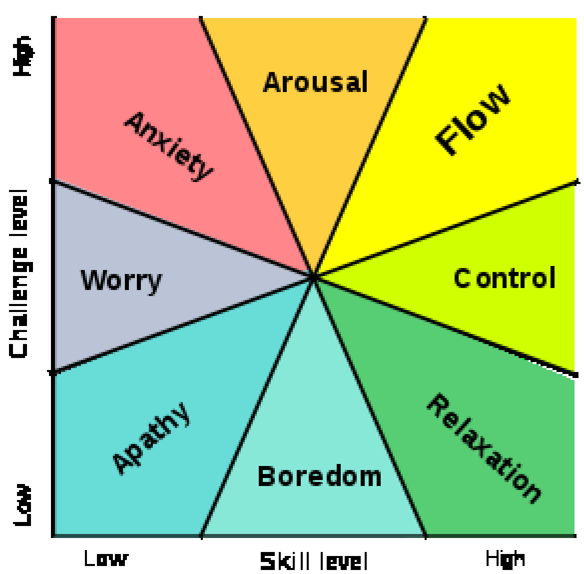


Figure 2. Relationship between perceived skill and perceived challenge (Csíkszentmihályi, 1997).

games. However, flow can be disrupted in at least two ways: (1) the player could be distracted from the game or (2) the balance between their perceived skill and the perceived challenge could be broken. For instance, a game could distract the player from the experience of flow with advertisements or learning material; or, a game could unexpectedly increase or lower the game's difficulty to interrupt flow. Habgood and Ainsworth (2011) argue that extrinsically-integrated games interrupt flow in the first way, by distracting the player from the game. However, extrinsic integration does not interrupt flow by disrupting the balance between perceived challenge and skill, as the game must motivate the player to make it through the unrelated content.

Potential Disadvantages of Intrinsic Integration. While intrinsic integration has potential benefits, it may also have disadvantages. One is related to transfer. Specifically, game designs following the principles of intrinsic integration present learning material that is assimilated into the game. The learning material is therefore in a context that is different from the one in which it will be later used and tested. In general, students find it difficult to apply knowledge learned in one context to a different one even when the fundamental concepts are the same (Nunes, Schliemann & Caraher, 1993; Kaminski, Sloutsky, & Heckler 2009). Intrinsic integration could create specialized knowledge that stays in the game rather than transferring to other contexts. Extrinsically-integrated games could therefore be advantageous as the format of the learning material is generally closer to the form that is found in the classroom, and this similar context could promote both recall and transfer (Tulving & Thompson, 1973; Gentner, 1989).

Intrinsic integration could also be disadvantageous because it conflates the learning material with the game's mechanisms, which could increase student's extraneous cognitive load. While this potential is of greater concern regarding action-oriented games as the pace is much quicker (Shaffer, 2004), there remains the possibility that combining the task of learning the game with that of learning the target knowledge could hinder student's ability to learn the domain principles. Through the lens of cognitive load, the game aspects add varying amounts of extraneous cognitive load to the information processing demands of the learning activity. This would impair the player's ability to process the lesson (Schrader & Bastiaens, 2012; Kalyuga & Plass, 2009). Habgood and Ainsworth (2011) describe this potential disadvantage associated with intrinsic integration as making the player simultaneously cope with two competing sets of demands – the educational and game-play elements. From this perspective, separating the learning material from the game's core mechanisms could be advantageous.

Empirical work related to intrinsic integration. To test their intrinsic integration hypothesis, Habgood and Ainsworth (2011) created an educational game called Zombie Division. In this game, players navigated their game character around a dungeon and used division to defeat computer-controlled opponents represented by skeletons. Each of these skeletons had a number displayed on them and defeating them involved choosing a value that divides this number into whole parts. Each divisor was represented by a weapon, so defeating an opponent carrying, for example, the number nine would require the player to attack it with the weapon associated with the number three. This game adhered to the principles of intrinsic integration as the learning activity, namely division, was the primary way in which players interacted with and progressed through the game. They also modified Zombie Division to create an extrinsically integrated version in which the learning material was removed from the game portion and isolated to quizzes in between game sessions (details below).

Habgood and Ainsworth (2011) tested the intrinsic integration hypothesis by comparing the learning outcomes and motivational appeal of the intrinsically- and extrinsically-integrated versions of Zombie Division. In a between-subjects design, students who played the intrinsically-integrated version improved significantly more from pretest to posttest performance than those who played the extrinsically-integrated version. The participants also indicated via the motivational questionnaires that they found the intrinsic version to be more engaging than its extrinsic counterpart. This was backed up by a second experiment wherein the students could choose between both the intrinsic and extrinsic versions of the game. These results suggest that students preferred and learned more from intrinsically-integrated games, supporting the intrinsic integration hypothesis.

However, the extrinsically-integrated version of Zombie Division had a limitation related to the design of the two versions of the game. Before describing this limitation, I provide some necessary details on the extrinsic versions design. Unlike the original intrinsic version, the math questions in the extrinsic version of the game were entirely constrained to quizzes located in between episodes of gameplay. Specifically, the sequence of events in the intrinsic version involved a domain question every time the player fought a skeleton in the game. In contrast, the extrinsic version of the game had players fight all the same skeletons, but the weapon the player needed to use was displayed instead of a number; and then, the player had to answer all the same domain questions that would have been paired with those skeletons. This difference between the intrinsic and extrinsic versions is not a necessary byproduct of extrinsically-integrated game design, because the extrinsic version could have likewise posed the player one of the test questions after they encountered each skeleton. This would still fall under extrinsically-integrated game design as long as the mechanism that players use to fight the skeletons was separated from the learning material. In general, extrinsic integration does not entail that the domain questions and periods of gameplay must be split into lengthy chunks. Thus, the varied sequence of events between the two versions of Zombie Division is a design choice that is unrelated to the issue of intrinsic and extrinsic integration.

A byproduct of removing the division questions from the extrinsic version's game portion was that defeating the zombies became much easier. This was because the extrinsic version of the game told the players which weapon would defeat each skeleton. This essentially gave them the answers to the game's only source of challenge. Since, the player no longer had to figure out which weapon would divide the enemies by the correct amount to defeat them, this design likely disrupted the balance between perceived challenge and skill. As discussed earlier, a mismatch between the perceived skill and perceived difficulty of a task can disrupt the experience of flow, leading to boredom rather than intrinsic motivation. This meant that the modification did not only distract from the experience of flow generated by the game; it removed this experience by disrupting the game's balance between the player's skill and the game's difficulty. This lack of flow was evident in the participants' reactions to the extrinsic game. For example, with regard to fighting the skeletons, participants noted that the extrinsic version was boring because "it just tells you what to use" and "it's not a challenge" (Habgood &

Ainsworth, 2011, p. 28). A lack of flow and intrinsic motivation undermines the theory behind extrinsically-integrated games, as the intrinsic motivation of the game is supposed to encourage students to complete the learning material. This lack of flow, resulting from the reduced challenge of the extrinsic version of Zombie Division, is a confounding factor and a limitation of Habgood and Ainsworth's study.

Chapter 3: The Present Study

My work tests the intrinsic integration hypothesis with an experiment designed to address the limitations of prior work by more tightly controlling the difference between the intrinsic and extrinsic versions of the educational game. The challenge of creating two versions of the same game that are as equivalent to each other as possible while respectively adhering to intrinsic and extrinsic integration is twofold. Firstly, the instructional sequences should be as similar as possible, which is to say that both versions of the game should be designed to maintain the same order of events. Secondly, the intrinsic and extrinsic version of the game should be equally challenging to avoid the confounding variable introduced by not controlling for the balance between perceived skill and challenge. To fulfill these criteria, I designed two variations of the game Battleship intended to help players practice the basics of the complex number system, my target domain. Specifically, the learning goals for both versions included: (1) being able to use the rectangular notation and (2) understanding that multiplication by the imaginary unit rotates a number's location around the origin.

The two-dimensional nature of complex numbers makes them particularly suited to Battleship, as the coordinates on the two-dimensional board can be substituted with complex numbers. To play Battleship each player secretly plots their ships onto a two-dimensional plane and then fires upon their opponent's ships that were likewise secretly placed. The first player to correctly guess every coordinate containing a ship wins the game. These coordinates map onto complex numbers as they can be understood as a two-dimensional number system: the real number line constitutes the horizontal dimension, and the imaginary number line constitutes the vertical dimension. The complex plane upon which these numbers are located is analogous to the Cartesian plane as well as the plane used for Battleship. This similarity between complex numbers and the board used in Battleship make this game suitable for studying intrinsic integration. As advocated by intrinsic integration, the structure of Battleship's microworld will embody the learning material to provide an external representation of complex numbers (Habgood & Ainsworth, 2011; Laski & Siegler, 2014). While this is also true of Cartesian geometry, complex numbers were chosen because they are difficult enough for the target population (undergraduate students).

To address the need for analogous instructional sequences across conditions, players were asked to identify a complex number in the extrinsic version of the game at the same point in the game that they would do so in the intrinsic version (details will be presented shortly). To address the need for equivalent levels of challenge, the core gameplay remained the same across conditions: players in both versions of the game still had to destroy their opponent's ships and doing so was similar in terms of challenge. Moreover, both versions included a human opponent to provide a potential source of challenge in addition to the domain questions. Specifically, competition between two players makes the game portion meaningful when the complexity imposed by the learning material is not integrated with the game's core mechanism.

I hypothesized that the beneficial effects of intrinsic integration on learning outcomes that were identified by Habgood and Ainsworth (2011) would be diminished in my study, given that both game versions have analogous instructional sequences and similar levels of challenge. These learning outcomes were measured by conceptual and procedural questions answered before and after the participants play the game, as well as a series of motivational and affective questionnaires.

3.1 Method

3.1.1 Participants

The participants (*N* = 66, 35 females) were undergraduate students at Carleton University recruited via Sona and posters displayed around campus. Since the game was played in pairs, each participant was instructed to bring a classmate or a friend with them, instead of being paired with a stranger. This was done to facilitate interaction during gameplay, as both participants already knew each other. Only students who were not enrolled in any math or engineering course were able to participate, as was stipulated in the study's eligibility requirements and then verified on the demographics questionnaire. Prior knowledge of Battleship was not screened for. Each participant was compensated with their choice of either 2% course credit or $20.

3.1.2 Materials

Complex-Numbers Lesson. To provide the domain background needed to play the educational game, participants were given a paper-based lesson developed for this research on the complex number system. The lesson consisted of two text pages with accompanying illustrations (see Appendix A). The lesson was framed with a fictional narrative to dissociate complex numbers from any negative preconceived attitudes, such as complex numbers being unnecessary because they are 'imaginary' or too difficult. The fictional narrative addressed these common attitudes by explaining the basic principle of complex numbers as if it was an alien number system before identifying them as imaginary and complex numbers. For instance, the analogy between the phase of a complex number and positive/negative numbers being on opposite sides of zero was used to explain the way in which complex numbers exist in more than just these two directions from zero. As another example, the similarity between the Cartesian plane and the complex plane was used to introduce this concept as well as the way in which complex numbers are plotted onto the complex plane. As a final example, the imaginary unit was introduced with its intuitive geometric understanding as a 90° rotation, and this was then used to explain its mathematical definition as the square root of minus one. This narrative was broken up into sections by boxes that repeated the important concepts and definitions that would be tested.

Test Materials. A pretest and posttest were used to measure participants' knowledge before and after they played the game (see Appendix B). Each test consisted of twenty questions. The first eight questions tested conceptual knowledge (e.g., "On the complex plane, a number with no real part is located on the <u>imaginary</u> number line."). The rest of the questions tested procedural knowledge: five asked participants to express numbers shown on a complex plane in the rectangular format, three asked participants to multiply a real or imaginary number by the imaginary unit and then plot it onto the complex plane (e.g., "5i × i"), and the final four asked participants to solve increasingly challenging multiplications that involved complex numbers. The questions were equivalent between the pretest and posttest, but the specific numbers were changed.

Game Materials and Rules. Two modified versions of Battleship that I designed were used to help participants practice using complex numbers. Both versions were played with pencil and paper materials and involved the basic premise of Battleship: each player would hide their ships behind a screen and then try to guess the location of their opponent's ships. The game consisted of the following components, which will be described in turn: the primary game page (the intrinsic version is in Figure 3, and the extrinsic version is in Figure 4), a paper screen to hide the location of their ships, and a response sheet for the complex numbers (Figure 5).

In both versions, the ships pictured at the bottom-left of the game page (Figures 3 and 4) were plotted onto a nine by nine plane located on the same page. The left plane ("Your Complex Plane" in Figure 3 and "Your Ships" in Figure 4) was used for their

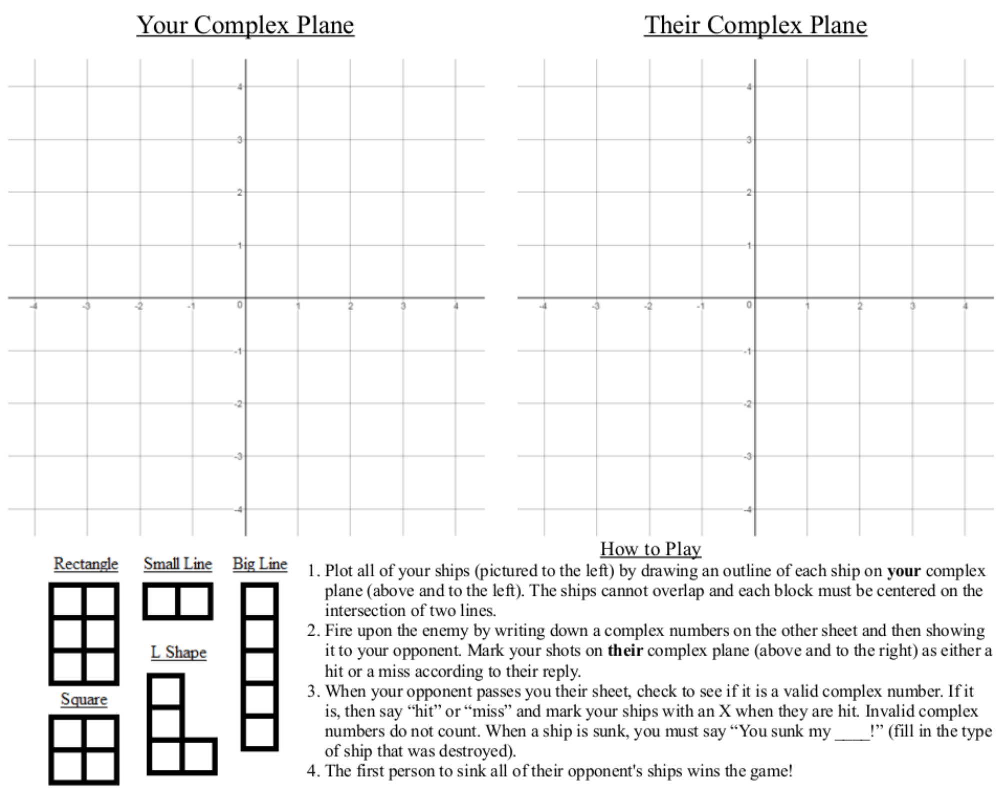


Figure 3. A blank game sheet from the intrinsic version. The ships (bottom left) were drawn onto the top-left plane according to the rules (bottom right), and shots were marked as a hit or a miss on the top-right plane.

ships and hidden behind the screen, while the right plane ("Their Complex Plane" and "Their Ships," respectively) was used later in the game and visible to both participants. The ships were represented by blocks to vary their shapes and thereby increase the difficulty of guessing their location. The ships were plotted according to the rules located on the same page: each block in the intrinsic version (Figure 3) was centred on the intersection of two lines, while each block occupied a square on the extrinsic version's chess-like board (Figure 4). The different planes were necessary to have the learning

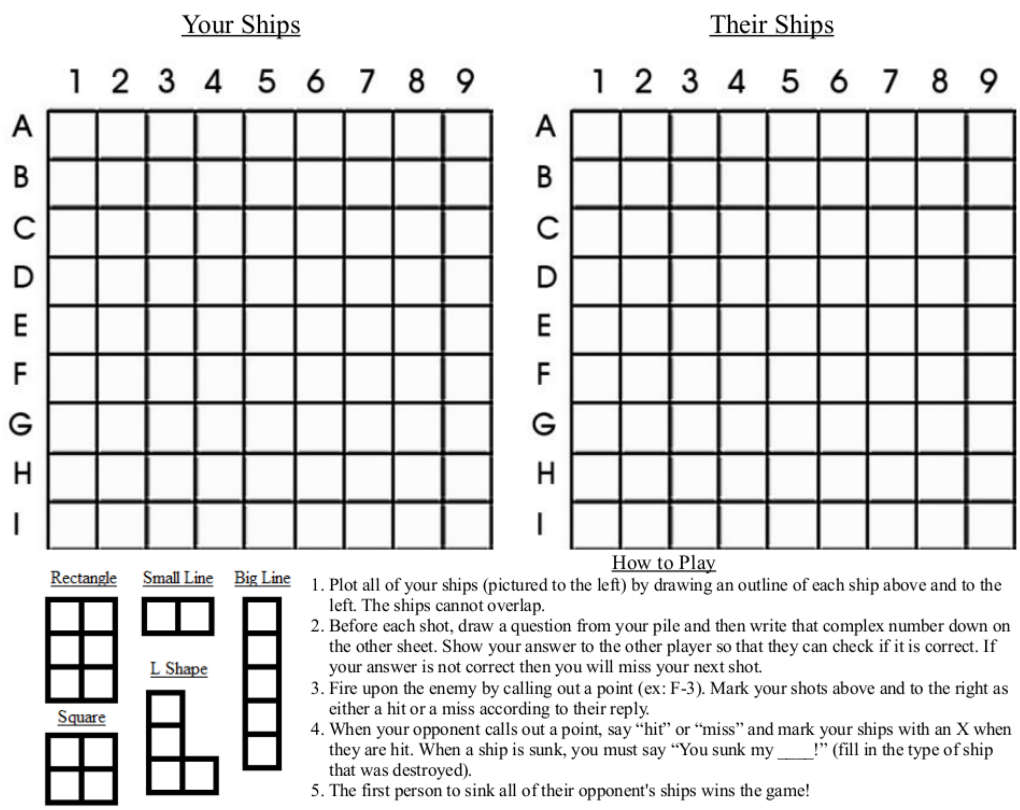
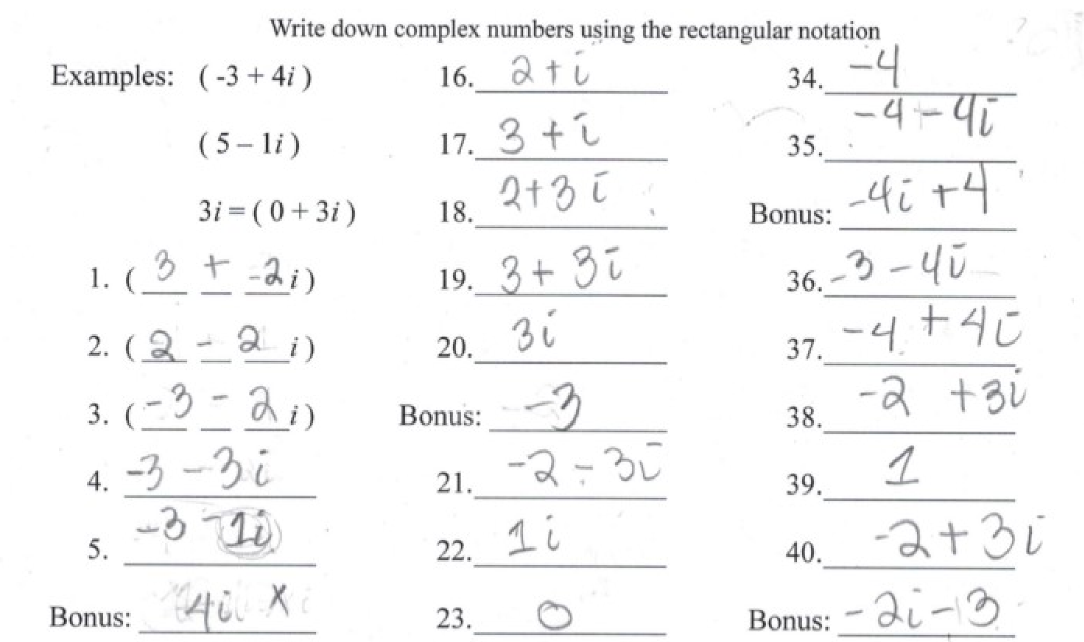


Figure 4. A blank game sheet from the extrinsic version. The ships (bottom left) were drawn onto the top-left plane according to the rules (bottom right), and shots were marked as a hit or a miss on the top-right plane.

material intrinsically integrated in one version and extrinsically integrated in the other. The extrinsic version's board and the coordinate system it used was based upon the standard Battleship game board. As an example of how the two planes related to each other, choosing to fire upon the coordinate A-1 in the extrinsic version would correspond to firing upon the coordinate indicated by the complex number (-4 + 4i) in the intrinsic version. The screen that was used to hide their ships also provided a recap of the complex numbers lesson to participants in both conditions (see Appendix C).

Participants took turns playing the game, and the turn sequence in both versions of the game was as similar as possible to each other. Each turn began with participants picking a coordinate on the complex plane: in the intrinsic version, the coordinate was chosen by the player as their shot for the turn; in the extrinsic version, the coordinate was randomly picked from a deck of cards. In both versions of the game, participants would



Write down complex numbers using the rectangular notation

Examples: (-3 + 4*i*)	16. 2 + i	34. -4
(5 – 1*i*)	17. 3 + i	35. -4 - 4i
3*i* = (0 + 3*i*)	18. 2+3 i	Bonus: -4i +4
1. (3 + -2 *i*)	19. 3+ 3i	36. -3 - 4i
2. (2 - 2 *i*)	20. 3i	37. -4 +4i
3. (-3 - 2 *i*)	Bonus: -3	38. -2 +3i
4. -3 - 3i	21. -2 - 3i	39. 1
5. -3 - 1i	22. 1i	40. -2+3i
Bonus: 4i X	23. 0	Bonus: - 2i - 3

Figure 5. An example of the response sheet on which participants wrote complex numbers. The same sheet was used in both game versions.

then translate this coordinate into a complex number in the rectangular form and write their answer onto the response sheet (Figure 5). This sheet was the same in both versions of the game and also provided three examples of complex numbers in the rectangular format as well as three scaffolded answers to help players understand the task (top-left of Figure 5). After both players wrote down a complex number, each version had them check each other's entries for correctness. The experimenter did not verify the answers and, if asked, referred participants to the examples provided by the game material. This meant that checking the answers had participant's in both conditions use their knowledge of complex numbers again. Correct answers were rewarded with a shot on the opponent's ships. In the intrinsic version, the shot for each turn was the complex number they had just written down. In the extrinsic version, this shot was chosen by the player after the complex number had been checked by their opponent. This was done to create a divide between the learning material and the game material, thereby making the game extrinsically integrated. Choosing a shot in the extrinsic condition entailed calling out a letter for the row and a number for the column (i.e. B-6). Once a shot was announced, the opponent would respond with either 'hit' or 'miss.' Finally, participants would mark their shot as either a hit or a miss on the right plane ("Their Complex Plane" in Figure 3, and "Their Ships" in Figure 4) and mark any of their ships that had been hit as such on the other plane. The process would then begin anew for the next pair of shots.

After every five shots participants in both game versions were asked to multiply the previous complex number by the imaginary unit, writing their answer on the response sheet (Figure 5). These bonus questions gave participants in both versions an opportunity to practice multiplying numbers by the imaginary unit and gave those who had already grasped the basic format some room for improvement. A player's answer was checked by the other player. A correct answer for this more challenging task rewarded the player with a bonus shot. In the intrinsic version, the bonus shot corresponded to the product of this multiplication. In the extrinsic version, participants chose and called out a number as they normally would.

Both versions of the game included a supplementary page with handwritten examples of the above tasks, which were always available to the participants (see Figure

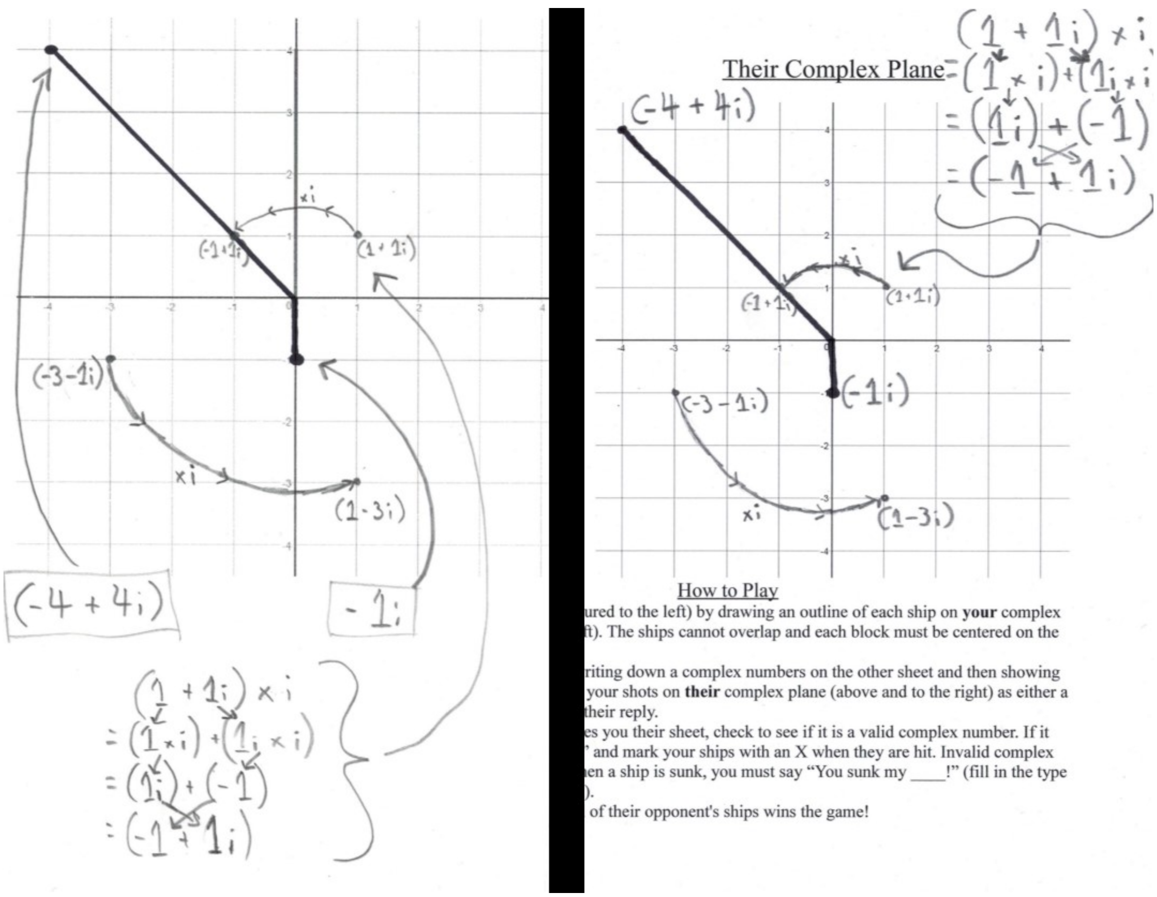


Figure 6. A visual comparison of the two hand-drawn example pages. The extrinsic version (left) was drawn on one of the cards that participants would pick up, and the intrinsic version (right) was drawn on the right side of the intrinsic game sheet.

6) and used during the game’s verbal description. These example pages only varied in the context of the complex plane upon which the information was conveyed. The extrinsic version of the example page was written on one of the questions they would draw in this version of the game (see hand-written text in Figure 6, right). The intrinsic version of the example page was written on one of the intrinsically-integrated game planes (see hand-written text in Figure 6, right). As the intrinsic version was drawn on an extra copy of the primary game sheet that was shown in Figure 3, the rules were incidentally included on this page.

Pilots. The aforementioned materials were refined via pilots to ensure that they communicated the subject material and avoided floor and ceiling effects. For instance, multiplication by the imaginary unit was added into the game because some pilot participants were able to quickly make the connection between the rectangular format and Cartesian coordinates. This made the educational content and the game too easy for them. The increased difficulty stemming from the multiplication questions that were added gave additional material for participants to learn, increasing the challenge levels and reducing ceiling effects. Additionally, the third section of the pretest and posttest were refined after pilots to exclude examples of the rectangular format. This was done because some participants, upon entering the third section, would go back to the second section and correct their mistakes after seeing the correct format in section three. Additionally, several test questions that turned out to be trivial were removed and more were added that focused on the more difficult conceptual and procedural knowledge, again to avoid ceiling effects on the posttest.

The game itself was also refined after the pilots, as the game board was originally two spaces larger both horizontally and vertically. However, this extra number of spaces led to long periods where no ships would be hit by one or both players. This was particularly problematic as the added learning material already made the process of taking a shot longer than it is in the regular version of Battleship. The board was therefore reduced to the current nine by nine size to increase the frequency of the rewarding hits on the opponent's ships.

Motivational and Affective Questionnaires. An online survey was used to collect motivational and affective data, in addition to basic demographics (see Appendix D). The motivational and affective survey used a Likert scale and included: (1) the Intrinsic Motivation Inventory (Deci & Ryan, 2003) based on four sub-constructs, including interest, competency, choice, and pressure; some custom questions measuring participants' willingness to re-engage with the instructional material were mixed in with the previous four sub-constructs (e.g., "I would use the game to teach complex numbers"); (2) the implicit theory of intelligence scale (Dweck, 1999) to measure participants' general mindset (e.g., "You have a certain amount of intelligence, and you can't really do much to change it"); (3) a modified version of the previous questions to measure game-specific mindset (e.g., "You have a certain amount of gaming ability, and you can't really do much to change it"); (4) the Attitudes Toward Math Inventory (Lim & Chapman, 2013), which measured their pre-existing attitudes towards math based on four sub-constructs, including enjoyment, motivation, self-confidence, and value (e.g., "I am willing to take more than the required amount of mathematics"). These instruments were chosen because they have been shown to be reliable in prior work.

3.1.3 Design

This study used a two-factor (2 by 2) mixed design. The first factor, ‘condition,’ was a between-groups variable with two levels (intrinsic and extrinsic). The second factor, ‘time,’ was a within-groups variable with two levels (pre and post). Participants were assigned to a given condition in a round robin fashion.

3.1.4 Procedure

Each session was conducted individually by the thesis author, with one session involving a pair of participants. Each dyad spent approximately 90 minutes in the study, with the exact duration varying based upon the amount of time participants spent on the instructional material as well as the pretest and posttest. The study included three main phases, including the pre-game, game, and post-game phases. The procedure for the two conditions was the same unless stated otherwise.

Pre-Game Phase. Participants began the experimental session seated back-to-back in an experimental room to avoid unwanted interaction. After signing the consent forms, each session began with the participants reading the two-page lesson on complex numbers. This took an average of four minutes and 11 seconds (all participants finished in under ten minutes). Once both participants had finished reading the instructional material, it was collected and then the pretest was distributed. This took an average of eight minutes and 22 seconds (all participants finished in under 18 minutes). Participants were not permitted to speak to each other during this phase of the study. Once both participants had finished the pretest, they were asked to move to the game table positioned in the centre of the room where they sat across from each other.

Game Phase. Participants were provided with all the game materials and instructions on how to how to play the game, as follows. As described in the materials sections, the game rules as well as a recap of the instructional material were always in front of them during this phase. Participants were instructed to read the rules even if they were familiar with Battleship. After both participants had finished reading the rules, a brief description and sample turn was read from the experimental script to ensure the instructions were consistent across participants (see Appendix E for both the intrinsic and extrinsic versions of this script). This description of the example page brought the participants' attention to two examples of the rectangular format and two examples of multiplication that were available to both players on the supplementary example page, regardless of condition. The examples of multiplying a complex number by the imaginary unit were described both as a visual rotation and as a mathematical equation. Participants were then instructed to plot their ships.

After ensuring that both participants had plotted their ships according to the game rules described in the materials section, the timer and audio recording was started before participants began to play the game for thirty-five minutes. Any questions relating to complex numbers were answered by referring the participants to the examples that were provided as well as the recap of the lesson on each of their screens. When the time was up, participants were given the choice to play for another five minutes if they wanted. This was done as an additional measure of motivation.

Post-Game Phase. Directly after the game phase, participants were moved back to their initial seats where they were seated back-to-back and the posttest was completed. This took an average of six minutes and 15 seconds (all participants finished in under 18 minutes). Once finished, participants were instructed to set aside the test and sit quietly until both had finished. Both participants were then instructed to fill in the online questionnaire consisting of demographics, the Intrinsic Motivation Inventory along with intention to reengage questions, the implicit theory of intelligence scale with general and domain-specific questions mixed together, and finally the Attitudes Toward Math Inventory, respectively. Once both participants were finished they were given their compensation and walked to the exit.

Chapter 4: Results

Of the 66 participants who completed the study, eight were excluded from the analysis. Five participants were at ceiling as they each scored above 90% on the pretest (2.5 *SD*s above the mean). The other three participants were excluded from the analysis because their performance decreased from the pretest to the posttest, suggesting that they rushed the posttest and/or did not pay attention to the instructional material. Another explanation for these participants scores is that the game diminished their understanding, but there was no evidence of this as the rest of the participant's scores did not decrease from pretest to posttest. Thus, the analyses are based on the remaining 58 participants.

The analyses, which were conducted with the statistical software *R*, used inferential statistics that assume independence between participants. Since participants worked together during the game, there was a potential concern that their learning-related data might be dependent. To check for this, a correlation between pretest to posttest difference scores of both individuals in a pair was conducted. The correlation between the learning outcomes of paired participants was not significant and corresponded to a very small effect, $r(31) = .05$, $p = 0.78$, indicating that the independence assumption was not violated. Thus, I proceeded with the analyses and now present the results. These results are organized according to the conditional effect on (1) learning outcomes and (2) motivation. Additionally, (3) an exploratory analysis was conducted to examine relationships between the various constructs of interest.

4.1 Are Intrinsically-integrated Games Better for Learning?

To ensure equivalence between the two conditions on a priori knowledge, participants' pretest scores were compared. The scores were distributed fairly evenly between the two conditions, as shown in Figure 7. The pretest mean score was similar in the extrinsic condition, $M = 4.93$, $SD = 2.85$, and the intrinsic condition, $M = 4.83$, $SD = 3.71$, with no significant difference between the two conditions as indicated by an independent samples t-test, $t(54.05) = 0.11$, $p = .91$. Both the extrinsic and intrinsic pretest data were slightly positively skewed (skewness of 0.90 and 0.60 respectively). While the intrinsic condition happened to have slightly more participants from both the upper and lower end of the distribution (kurtosis of -0.05 and -0.61), a Levene's test indicated that this did not violate the homogeneity of variance assumption, $F = 1.88$, $p = .18$.

As is standard, learning was measured by the difference between a participant's performance on the pretest, completed after they read the instructional material but before they played the educational game, and their performance on the posttest. The descriptive statistics are shown in Table 1. The higher mean difference in the extrinsic condition

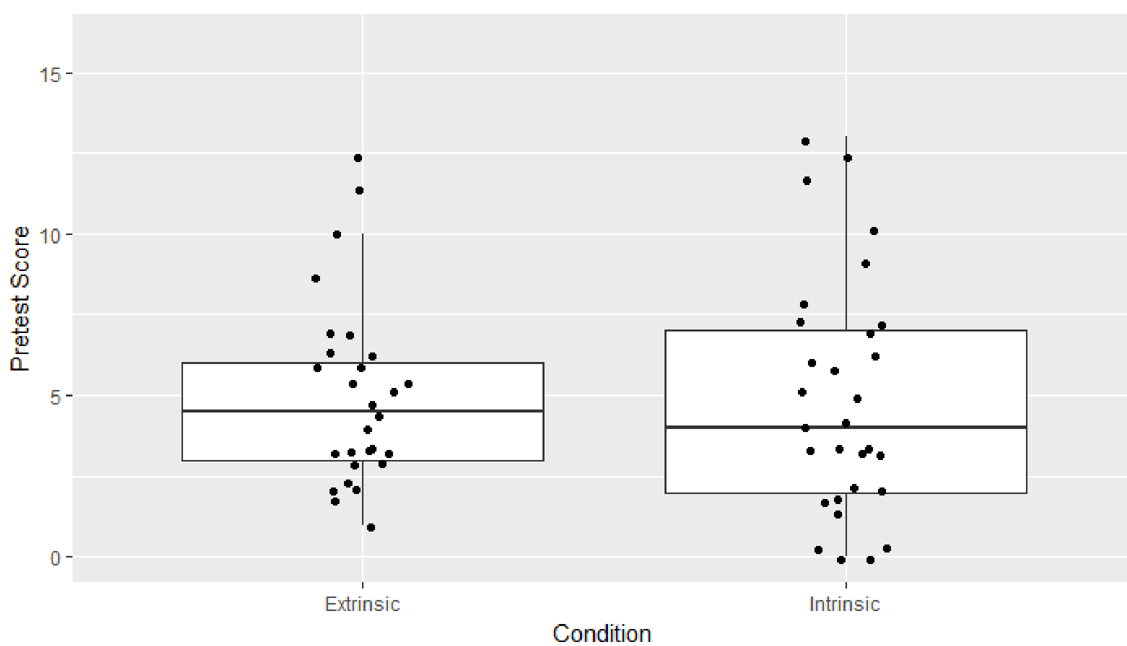


Figure 7. Boxplot of the pretest scores (out of 20) split by condition.

Table 1

Descriptive statistics for the test scores among both conditions

	Extrinsic		Intrinsic	
	M	*SD*	*M*	*SD*
Pretest (out of 20)	4.93	2.85	4.83	3.71
Posttest (out of 20)	10.39	3.79	8.73	4.38
Pretest to Posttest Difference	5.46	2.43	3.90	2.64

suggests that participants who played the extrinsic version of the game may have learned more.

To analyze the impact that the extrinsically and intrinsically-integrated versions of the game had on learning, a two-way mixed ANOVA was conducted with test scores as

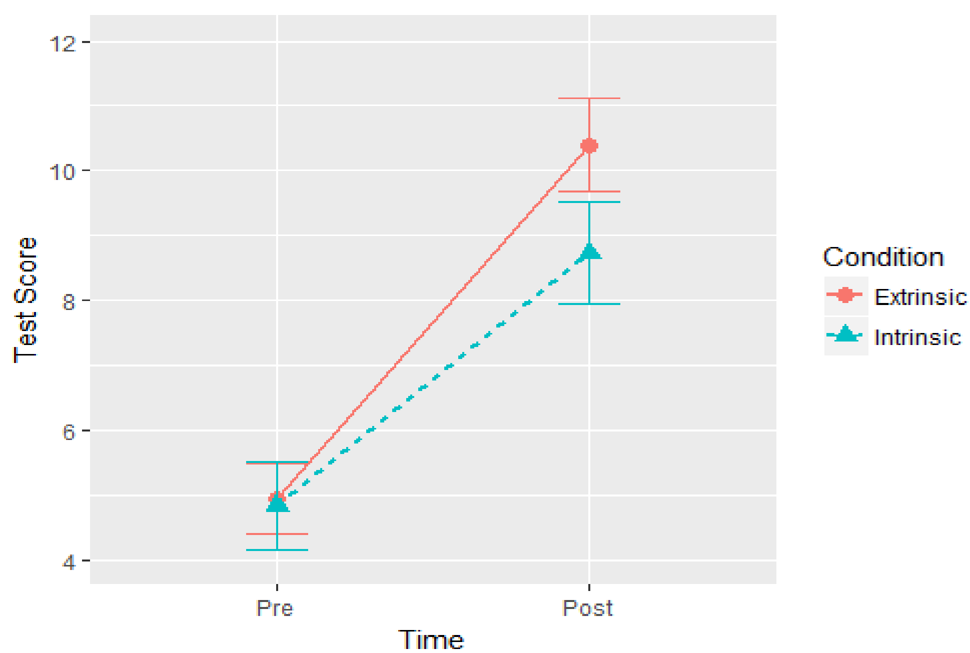


Figure 8. Mean pretest and posttest scores (out of 20) for each condition. Graph shows interaction between time and condition, with the error bars showing the 95% confidence intervals.

the dependent variables, condition (extrinsic vs. intrinsic) as the between-subjects independent variable, and time (pre and post practising with the respective game) as the within-subjects independent variable.

In general, collapsed across condition, participants improved from the pretest to posttest as indicated by the significant main effect of time on participants' test scores, $F(1, 56) = 194.62$, $p < .001$, $\eta_p^2 = .78$. While this demonstrates that the instructional material was beneficial for learning, of primary interest is the time by condition interaction, which was significant, $F(1, 56) = 5.49$, $p = .02$, $\eta_p^2 = .09$. As shown in Figure 8 this interaction indicates that while participants in both conditions benefited from the educational game, those who played the extrinsic version of the game learned significantly more than those who played the intrinsically-integrated game.

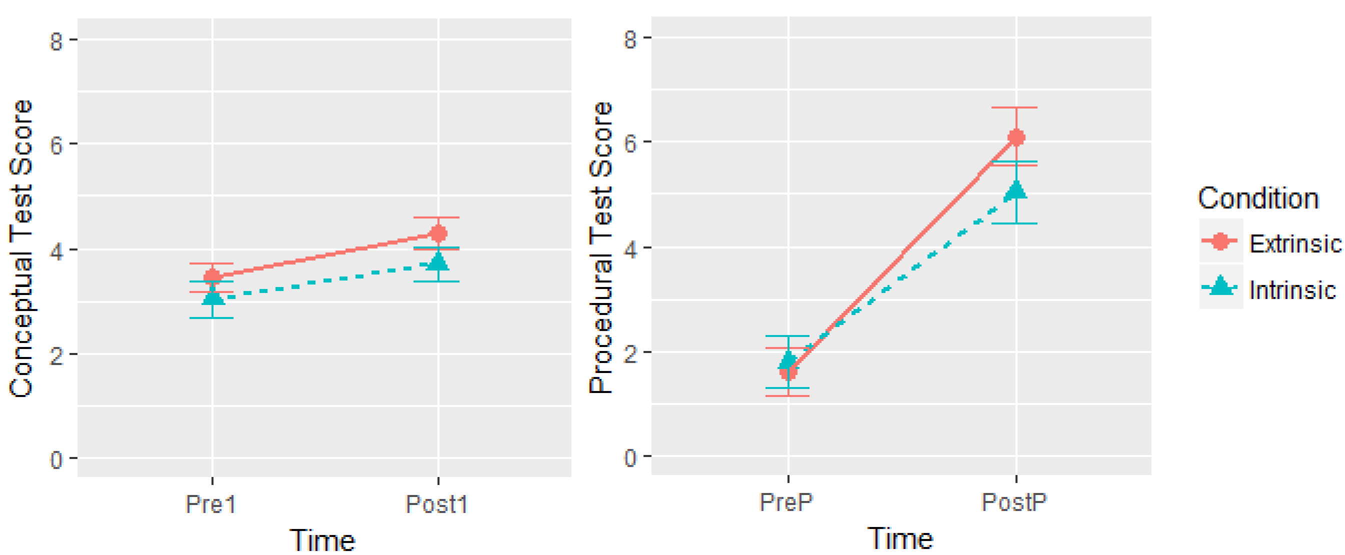


Figure 9. Mean pretest and posttest scores for each condition on the conceptual questions (left) and the procedural questions (right). The conceptual section was out of eight, and the procedural section was out of 12.

To determine if the type of question had an effect, the above analysis was repeated with participants' scores on the conceptual and the procedural questions of the pretest and posttest (Figure 9). Mirroring the findings above, collapsing across conditions participants improved significantly from pretest to posttest on both types of questions, as indicated by the significant main effect of time for the conceptual questions, $F(1, 56) = 17.62$, $p < .001$, $\eta_p^2 = .24$, and the procedural questions, $F(1, 56) = 124.92$, $p < .001$, $\eta_p^2 = .69$. While the effect of condition on learning was not significant for either type of question, there was a trend for higher learning in the extrinsic condition for the procedural questions, $F(1, 56) = 3.39$, $p = .07$, $\eta_p^2 = .06$; for the conceptual questions there was no evidence of a conditional effect as suggested by the lack of significance and small effect size, $F(1, 56) = 0.27$, $p = .60$, $\eta_p^2 = .005$. This suggests that the overall effect that the extrinsic game had on participant's learning outcomes may have been driven by gains in procedural knowledge.

4.2 Are Intrinsically-integrated Games More Motivating?

The effect of game version on participants' motivation was measured by the

Table 2

Means and standard deviations for the five motivation subscales among each condition

	Extrinsic		Intrinsic	
Subscale	*M*	*SD*	*M*	*SD*
Interest	5.00	1.64	5.01	1.48
Competency	4.27	1.41	4.62	1.44
Choice	5.03	1.42	5.13	1.40
Pressure	2.66	1.37	2.99	1.22
Re-engagement	4.17	1.27	3.95	1.44

Note. The maximum score for each subscale is 7.

Intrinsic Motivation Inventory (Deci & Ryan, 2003) as well as the additional sub-construct measuring re-engagement. Like the Intrinsic Motivation Inventory, this additional measure was derived by averaging a participant's answers to a custom set of questions that asked them to report their willingness to re-engage with the instructional material on a 7-point Likert scale. Descriptive statistics for this data are in Table 2. As shown, there was little difference between the two conditions in terms of the motivational variables.

This was confirmed by a series of independent-samples t-tests comparing the five measures of participants motivation in the two conditions. As shown in Table 3, none of the analyses were significant. While this analysis did not control for familywise error rate (i.e. via a Bonferroni correction), doing so would not have changed the results as none of the findings were significant to begin with.

A chi-squared test of independence was performed to examine the relationship between the game version and participants' decision to continue playing for an additional five minutes. Like the other measures of motivation, the difference between the two conditions was not significant, $X^2(1, N = 29) = 0.016$, $p = .90$. In summary, there was no

Table 3

T-test results for each subscale of the motivational questionnaire

Subscale	*df*	*t*	*p*	*d*
Interest	54.35	-0.03	.98	.01
Competency	55.89	-0.94	.35	.25
Choice	55.57	-0.28	.78	.07
Pressure	54.20	-0.96	.34	.25
Re-engagement	55.82	0.61	.54	.16

evidence that the version of the game, intrinsic versus extrinsic, impacted any measures of participants' motivation; however, these measures may not have been sensitive enough.

4.3 Does Gamified Learning Benefit Everyone Equally?

To analyze relationships between participants' psychological attributes (mindset and attitudes toward math) and the educational game's outcome, an exploratory analysis was conducted. While this analysis involved multiple comparisons and doing so inflates the chances of type one error, the focus was on effect sizes rather than significance. Furthermore, the choice of comparisons was based on prior work (e.g. Habgood & Ainsworth, 2011; Lee et al., 2012). As described earlier, the implicit theories (i.e. mindsets) of participants were measured by four sets of questions that measured the entity and incremental beliefs of both general intelligence (general mindset) and gaming ability (game-specific mindset). An entity mindset treats intelligence and ability as fixed traits, whereas an incremental mindset treats them as malleable traits that can be improved. While some researchers collapse the entity and incremental sub-constructs into one bipolar construct (Blackwell, Trzesniewski, & Dweck, 2007), this practice is questionable because the sub-constructs may not be unipolar (Tempelaar, Rienties, Giesbers, & Gijselaers, 2015). To check for this in the present data, a correlation was conducted between each pair of constructs. As expected both the general mindset and game-specific mindset pairs were negatively correlated. However, these correlations were not perfect: the correlation was strong for participants' general mindset, $r(56) = -.64$, $p < .001$, and moderate for participants' game mindset, $r(56) = -.31$, $p = .02$. Thus, to avoid missing any nuance in the analyses, each sub-construct was treated independently as a unipolar scale in the following analysis. Participants' attitudes toward math were measured by a set of questions taken from and scored according to the Attitudes Toward Math Inventory (Lim & Chapman, 2013). Both instruments were scored according to the corresponding scoring manuals, which called for the aggregation of the individual questions and thus treats the individual Likert responses as interval data; thus, Pearson correlations are reported rather than Spearman correlations.

The results related to relationships between math attitudes and learning outcomes are in the top of Table 4, and those between mindset and learning outcomes are in the bottom of Table 4. As above, the learning outcome was operationalized by the difference

Table 4

Correlations between learning outcomes and psychological attributes ($N = 58$)

Construct		Difference from pre to post	Conceptual Dif.	Procedural Dif.
ATMI	Enjoyment	.229	.144	.163
	Motivation	.215	.209	.123
	Self-confidence	.07	.052	.044
	Value	.248	.108	.211
Mindset	General Entity	-.127	.029	-.138
	General Incremental	-.001	.022	.025
	Game Entity	-.228	.086	-.275*
	Game Incremental	.165	.034	.198

Note. * $p < .05$.

between pretest and posttest scores. This analysis collapses across the two conditions as there was no apparent difference between the results for each condition as verified with a visual inspection of the scatterplots displaying the relationships in question. The results show that the largest effect size was also the only one to reach significance: participants' entity beliefs about gaming ability were negatively correlated with their improvement on the procedural questions (see Figure 10). This indicates that

participants who believed that one cannot improve gaming ability learned less procedural knowledge from pretest to posttest. While the rest of the correlations between these measures and the overall learning outcomes were not significant, three of them trended

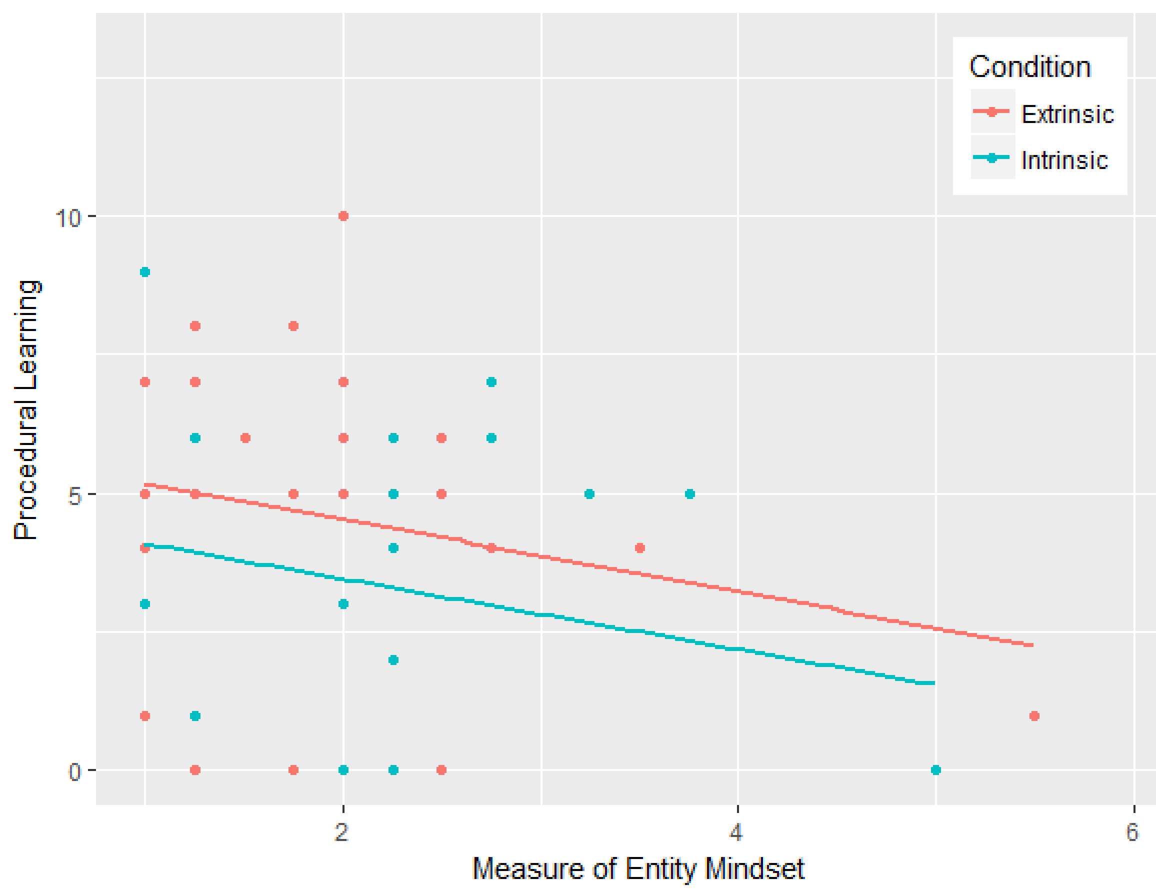


Figure 10. Relationship between procedural learning and entity mindset.

towards significance: (1) enjoyment and learning outcomes, $p = .083$, indicating participants who reported that they enjoy math may have learned more from the game; (2) value and learning outcomes, $p = .060$, indicating that participants who reported that they value math may have learned more from the game; (3) entity beliefs with regard to gaming ability and learning outcomes, $p = .085$, indicating that participants who believed it is not possible to improve gaming ability may have learned less from the game.

The results related to the relationships between math attitudes and motivation are in the top of Table 5, and those between mindset and motivation are in the bottom of Table 5. The custom questions regarding re-engagement yielded the strongest correlations with the participants' attitudes toward math and their incremental mindsets.

Table 5

Correlations between motivational variables and psychological attributes ($N = 58$)

Construct		Re-engage.	Interest	Competency	Choice	Pressure
ATMI	Enjoyment	0.499**	0.259*	0.292*	0.1	-0.252
	Motivation	0.458**	0.186	0.296*	0.028	-0.303*
	Self-confidence	0.285*	0.279*	0.357**	0.171	-0.422**
	Value	0.385**	0.086	0.25	0.037	-0.023
Mindset	General Entity	-0.03	0.182	0.099	0	0.248
	General Incremental	0.431**	0.119	0.12	-0.105	-0.301*
	Game Entity	0.213	0.176	-0.03	0.011	0.288*
	Game Incremental	0.393**	0.268*	0.263*	-0.174	-0.312*

Note. ** $p < .01$, * $p < .05$.

This indicates that participants' attitudes toward math – particularly their enjoyment of it and motivation to engage with it – were positively correlated with their willingness to re-engage with the instructional material. This willingness was also positively correlated with the beliefs that one can improve one's basic intelligence and one's gaming ability. Participants' sense of choice was not correlated with any of the motivational outcomes, likely due to the experimental context (i.e. the experiment required that they play the game). The pressure felt by the participants was predictably correlated negatively with their self-confidence concerning math and their self-motivation to engage with it. Participants who reported less confidence regarding math and less of an inclination to do math felt more pressured by the instructional material. Pressure was also negatively correlated with both measures of incremental mindset, and positively correlated with the measure of game-specific entity mindset. This indicates the belief that intelligence and gaming ability are malleable was related to less pressure from the instructional material.

Participants' interest in the educational game – the primary measure of the games impact on motivation – and their sense of competency while playing it was positively correlated with their attitudes toward math. This indicates that individuals who reported that they liked math tended to also report that they were motivated by the instructional material, which was not surprising considering the game involved math. Participants' interest in the game and perceived competence with it was also positively correlated with game-specific incremental mindset, suggesting that the more they believed they could improve their gaming ability, the more motivated they were by the game.

Chapter 5: Discussion

The results did not support the intrinsic integration hypothesis, as participants who played the intrinsic version of the game were not more motivated and did not learn more than those who played the extrinsic version. On the contrary, those who played the extrinsic version of the game learned more. This section will begin by discussing some features of my experiment that could qualify its findings, before turning to the implication that these findings have on the following issues: the potential disadvantages of intrinsic integration, the design of educational games, and whether or not there is an optimal audience for this type of instructional environment.

5.1 The Educational Game

Generally speaking, the educational game designed for this experiment was a success. In addition to the demonstrable learning from the game collapsed across condition, participants had fun playing the game. This was evinced by the measures: participants reported that they were interested in the instructional material as indicated by high scores on the motivational questionnaire, and a third of them chose to stay longer than they needed to. Anecdotally, these measures are further supported by the verbal reactions of participants. One person remarked that the experiment was "really fun actually. If math was like this, I'd enjoy it a lot more." Another exclaimed upon receiving the post-test, "Battleship actually helped with this!" When the same participant – who was vocally anxious about math – forgot to take their shot upon the opponent's ships and immediately drew another complex number question, they joked: "Sorry, I just love math." Additionally, some participants asked if they could keep their game sheets to finish the game at home, and one participant even asked if they could buy the extrinsic version as they thought it was an improvement on the original Battleship. These measures and anecdotal reactions indicate that the educational game was intrinsically motivating for participants.

There were, however, a few aspects that I would refine in future iterations of this work. One relates to feedback. In the current version, participants had to check each other's answers, and some participants were unsure as to whether or not they were correctly using complex numbers. This uncertainty was summed up by a participant, when they remarked, "I think this is right, but we could both be doing it wrong." While the participants were generally able to figure out the correct usage from the examples that were provided in the game materials, as evinced by the learning gains, it would be interesting to investigate if providing explicit feedback would further increase learning gains. Whether or not this outside support in the form of explicit feedback should be added depends upon whether or not the educational game is intended to function without the support of another person, such as a teacher.

The medium imposed some restrictions. The lack of appealing graphic design sets my educational game apart from those that are available on the market as well as those used in previous experiments that involved video games (e.g. Zombie Division). This limitation could be addressed with a digital version of the educational game. Such an implementation would have the added benefits of guiding the users through the steps of the game, verifying that their responses are correct by providing the aforementioned feedback, and facilitating the process of plotting their ships. The latter is particularly true of the intrinsic version as some participants playing this version of the game took more time to plot their ships onto the board, as centring the ships on the points where the lines intersect was less intuitive than the non-intrinsic alternative. This preference is also a cultural factor as many Eastern games, such as Go and Xiangqi, place pieces on the intersections of their game board's lines. While this mistake was corrected before the game started (recall that the experimenter verified that the ships were plotted correctly in both versions), a digital implementation in which both versions of the game involved dragging and dropping the ships onto the game board would facilitate this stage of the game. A digital version also facilitates the integration of helpful resources. For instance, a video representing the relationship between multiplying a number by the imaginary unit and a 90° rotation may have helped participants grasp this aspect of the lesson.

5.2 Why Did Extrinsic Integration Outperform Intrinsic Integration?

The difference between the present results and those from Habgood and Ainsworth's (2011) experiment are likely due to the greater control of the instructional sequence and challenge across the two versions of my educational game. These results favouring the extrinsically-integrated version substantiate the potential disadvantages of intrinsic integration. To recap, the first of these disadvantages is the need for transfer. In other words, presenting the learning material within the context of the game, as is required by intrinsic integration, could make it more difficult for the player to recognize the mathematical content independently of the game and learning it as such. Second, intrinsic integration could increase the extraneous cognitive load of the learning activity, due to the overlapping demands of playing the game and learning the material, which could in turn negatively affect the learning process. These two explanations for the results of my experiment will be discussed before addressing ways in which future research may be able to shed more light on these issues.

Transfer was a potential issue with the intrinsic version of my game as the complex numbers in this version corresponded to the coordinates of players' ships. This means that the complex numbers in the intrinsic version represented two things: they were concrete representations of a location on the game board, and they were the abstract representations that would later be tested. By having participants play and interact with these representations, intrinsic integration potentially made it more difficult for them to see the complex numbers they were using as being important in themselves (Brown, McNeil, & Glenberg, 2009; Uttal, O'Doherty, Newland, Hand, & DeLoache, 2009). This could also be framed as a benefit of extrinsic integration. Specifically, the extrinsic version could have made it easier for participants to focus on and learn the mathematical principles by separating the abstract target knowledge from the more concrete interactions between the player and the game state (Uttal et al., 2009).

The intrinsically-integrated game may have increased participants' extraneous cognitive load, as players utilized the target knowledge in between picking the location of their shot and resolving it. In other words, the intrinsic version had players pick a shot, practice the learning material, and then resolve the shot; whereas, the extrinsic version separated these tasks. These competing demands imposed by the intrinsic game and the domain questions may have diminished players' learning by increasing the load on their working memory (Clark, Nguyen, Sweller, & Baddeley, 2006). Similarly, the extrinsic version could have made working memory available for the mental processing that is required for learning. While the previous explanation involving transfer emphasizes the role of context, this explanation emphasizes the effect that intrinsic integration could have on the cognitive processes involved in learning. These two explanations for the results are not mutually exclusive.

Determining whether or not these two factors, cognitive load and transfer, diminish the learning from intrinsically-integrated games requires further research. To identify if cognitive load is increased by the intrinsic version of the game, load could be measured in both version via a questionnaire such as Paas (1992). Alternatively, a computer version of the games could measure reaction time as an index of cognitive load. To identify if lack of transfer is the issue, participants could fill out an additional questionnaire that presents the questions in a context similar to the game. This would determine if their knowledge of complex numbers was better in the context of the game than in the standard posttest. As an anecdotal example of why this measure could be useful, a number of participants from my experiment reverted to their incorrect pretest answers after having correctly used the procedural knowledge during the game. Further understanding the ways in which intrinsic integration could have impeded learning would allow educational game designers to avoid these potential pitfalls of integrating the game's learning material in this way.

5.3 Implications for Educational Game Design

The results of my experiment support the claim that extrinsic integration is a more effective design for educational games. However, the conflicting results between the present experiment and Habgood and Ainsworth's (2011) earlier work also raise the possibility that extrinsic and intrinsic games could have different sets of best practices. For instance, the less disruptive version of extrinsic integration employed by my educational game could have outperformed the lengthy quiz approach used by Zombie

Division; or, perhaps the benefits of intrinsic integration identified by Habgood and Ainsworth are limited to single-player games, unlike the educational game used by my experiment. Design choices such as these that could potentially interact with the type of integration are discussed below. These possibilities make further empirical studies necessary to fully understand the effects of both extrinsically-integrated and intrinsically-integrated game design.

Of particular interest is the interaction between the type of integration and features of collaborative games, like cooperation and competition. Not only do these game elements have an established effect on learning as well as motivation (Ke & Grabowski, 2007; Plass et al., 2013), but the addition of competition may also gamify the non-game elements. For instance, participants answering the non-game domain questions in the extrinsic version of Battleship were still competing against their opponent to get the right answer. This aspect of the extrinsic game is comparable to a trivia game, as a correct answer was required for them to take a shot in the game of Battleship. Indeed, an educational game could consist of just this competitive quiz aspect (as in Ke & Grabowski). In Zombie Division, completing the domain questions in the extrinsic version was likewise necessary to play the game as participants needed to repeat the quiz if they did not get a passing score; however, this requirement could seem like more of a prerequisite in a single-player game, whereas it could seem like an element of the game when another player is involved. The effect of the presence of a human opponent could be examined by testing a single-player version of the educational game used in this experiment. A digital version of the game could easily accomplish this with a computer-controlled opponent, as this opponent would not be competing with the player on the domain questions. This extension would allow for a more detailed understanding of intrinsic integration.

Another possibility is that the efficacy of intrinsic and extrinsic integration could depend upon the specific learning material in question, as well as the type of game. The abstract mathematical knowledge that has been the subject of experiments regarding intrinsic integration could be a domain that favours the more abstract presentation that is afforded by extrinsic integration. While my educational version of Battleship and Zombie Division both focused on mathematical knowledge, many educational games use physics as the target knowledge and simulations thereof as the primary game mechanism. This popular form of educational games relies upon intrinsic integration and has been associated with increased learning in comparison to numerous other instructional methods (Sitzmann, 2011; Squire, Barnett, Grant, & Higginbotham, 2004). Simulation games are not amenable to extrinsic game design as the scientific simulations are integral parts of the game itself, in the same way that, for example, real physics is an integral part of billiards. This type of educational game is just one example of a pairing between a game and its learning material that could favour intrinsic integration. Furthermore, one could argue that simulation games are more intrinsically integrated than the games used in my own experiment as well as in Habgood and Ainsworth's (2011), as the integration of the mathematical learning materials is relatively artificial. Therefore, exclusively using abstract mathematical knowledge to test the difference between intrinsic and extrinsic integration could limit the conclusions that can be drawn from the resulting data.

5.4 The Audience for Educational Games

The correlations between the measures of learning outcomes in my study and the participants' attitudes toward intelligence, gaming ability, and mathematics indicate that certain groups may benefit from educational games more than others. In particular, the negative correlation between participant's game-specific entity mindset and their procedural learning outcome indicate that those who believed that gaming ability could not be improved benefited less from the educational game. The effects of mindset on learning have been shown extensively in academic domains (Blackwell et al., 2007), but my study shows that participants' beliefs of game-playing ability affect the learning outcomes of educational games. This provides evidence that individuals who are averse to gaming could benefit less from educational games. However, an entity mindset regarding gaming ability may not necessarily indicate an aversion to games. Thus, more demographic data concerning participant's gaming habits and their broader attitudes toward the hobby of gaming are required to explicitly test the relationship between personal preferences regarding games and learning outcomes.

The relationship between participants' implicit theories regarding gaming ability and their implicit theories regarding general intelligence was moderate, supporting the practice of measuring both general and domain-specific mindset (Lee et al., 2012). Moreover, a comparison of general mindset's and gaming-specific mindset's relationships with how much participants learned indicates that the domain-specific measure was more informative. This is evinced by the stronger associations between mindset regarding gaming ability and the various measures of the game's outcome, as compared to the associations with general mindset. These findings suggest that an individual's implicit theories regarding gaming ability may have a greater effect upon their learning from and experience with an educational game than their mindset regarding general intelligence. However, as my analyses were only correlational and did not control for these factors, this possibility requires research with controlled experiments. More generally, my results support the consideration of psychological attributes when designing and applying educational games.

Another possibility is that embedding a game-specific mindset intervention into the game could make it a more enjoyable and effective pedagogical tool, particularly for students who start out with an entity mindset. In my study, participants with a lower game-specific entity mindset had higher procedural learning outcomes, and participants with a higher game-specific growth mindset reported increased interest in the instructional material and a higher sense of competency with it. Educational game designs that include mindset interventions could thereby increase learning as well as how intrinsically motivating they are. More broadly, similar mindset interventions that address students' subjective view of themselves and their abilities have successfully increased learning (Paunesku et al., 2015; Yeager et al., 2016). Thus, it would be interesting to see how these interventions apply to educational games. In general, using aspects of a game's design to address psychological attributes that negatively impact the experience, such as game-specific mindset, could mitigate their impact upon learning and motivation.

General Implications

My thesis tested the effect of intrinsic and extrinsic integration with two versions of an original educational board game. This work has contributed empirical data to the debate concerning intrinsic integration, and in the process raised new questions. In particular, the results of my experiment contradict previous findings that supported the Intrinsic Integration Hypothesis. While this difference may be due to the greater control of the instructional sequence and challenge across the two conditions of my experiment, the contradictory results signal that this topic needs more investigation. There are many open questions regarding intrinsic integration’s interaction with other game elements, learning domains, and psychological attributes.

References

Anderson, T., & Shattuck, J. (2012). Design-based research: A decade of progress in education research?. *Educational Researcher*, *41*(1), 16-25.

Andri Signorell et al. (2018). DescTools: Tools for descriptive statistics.

Azad, K. (2007). A visual, intuitive guide to imaginary numbers. *Better Explained.* Retrieved from https://betterexplained.com

Barab, S., & Squire, K. (2004). Design-based research: Putting a stake in the ground. *The Journal of the Learning Sciences*, *13*(1), 1-14.

Birk, M., & Mandryk, R. L. (2013, April). Control your game-self: effects of controller type on enjoyment, motivation, and personality in game. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 685-694). ACM.

Blackwell, L. S., Trzesniewski, K. H., & Dweck, C. S. (2007). Implicit theories of intelligence predict achievement across an adolescent transition: A longitudinal study and an intervention. *Child Development*, 78(1), 246-263.

Bowman, R. F. (1982). A "Pac-Man" theory of motivation: Tactical implications for classroom instruction. *Educational Technology, 22*(9), 14-16.

Brown, M. C., McNeil, N. M., & Glenberg, A. M. (2009). Using concreteness in education: Real problems, potential solutions. *Child Development Perspectives*, 3(3), 160-164.

Clark, D. B., Tanner-Smith, E. E., & Killingsworth, S. S. (2016). Digital games, design, and learning: A systematic review and meta-analysis. *Review of Educational Research*, *86*(1), 79-122.

Clark, R. C., Nguyen, F., Sweller, J., & Baddeley, M. (2006). Efficiency in learning: Evidence-based guidelines to manage cognitive load. *Performance Improvement*, 45(9), 46-47.

Clark, R. E., Yates, K., Early, S., Moulton, K., Silber, K. H., & Foshay, R. (2010). An analysis of the failure of electronic media and discovery-based learning: Evidence for the performance benefits of guided training methods. *Handbook of Training and Improving Workplace Performance*, *1*, 263-297.

Connolly, T. M., Boyle, E. A., MacArthur, E., Hainey, T., & Boyle, J. M. (2012). A systematic literature review of empirical evidence on computer games and serious games. *Computers & Education*, *59*(2), 661-686.

Cordova, D. I., & Lepper, M. R. (1996). Intrinsic motivation and the process of learning: Beneficial effects of contextualization, personalization, and choice. *Journal of Educational Psychology*, *88*(4), 715-730.

Crawford, C. (1982). *The Art of Computer Game Design*. Berkeley, California: Osborne/McGraw-Hill.

Csikszentmihalyi, M. (1997). *Finding Flow: The Psychology of Engagement with Everyday Life*. Basic Books.

Csikszentmihalyi, M. (1975). Play and intrinsic rewards. *Journal of Humanistic Psychology, 15*(3), 41-63.

Deci, E. L. (1975). *Intrinsic Motivation*. New York: Plenum Publishing.

Deci, E. L., & Porac, J. (1978). Cognitive evaluation theory and the study of human motivation. In M. Lepper and D. Greene (Eds.), *The Hidden Costs of Reward: New Perspectives on the Psychology of Human Motivation* (pp. 149-176). New

Jersey: Lawrence Arlbaum Associates.

Deci, E. L., & Ryan, R. M. (2003). Intrinsic motivation inventory. *Self-Determination Theory*, 267.

Dias, M. G., & Harris, P. L. (1988). The effect of make-believe play on deductive reasoning. *British Journal of Developmental Psychology*, *6*(3), 207-221.

Dickey, M. D. (2007). Game design and learning: A conjectural analysis of how massively multiple online role-playing games (MMORPGs) foster intrinsic motivation. *Educational Technology Research and Development*, 55(3), 253-273.

Dweck, C. S. (1986). Motivational processes affecting learning. *American Psychologist*, *41*(10), 1040-1048.

Dweck, C. S. (1999). Self-theories: Their role in motivation, personality, and development. Philadelphia: Psychology Press.

Garris, R., Ahlers, R., & Driskell, J. E. (2002). Games, motivation, and learning: A research and practice model. *Simulation & Gaming*, *33*(4), 441-467.

Gentner, D. (1989). The mechanisms of analogical learning. In S. Vosniadou & A. Ortony (Eds.), *Similarity, Analogy, and Thought* (pp. 199–241). New York: Cambridge University Press.

Habgood, M. J., & Ainsworth, S. E. (2011). Motivating children to learn effectively: Exploring the value of intrinsic integration in educational games. *The Journal of the Learning Sciences*, *20*(2), 169-206.

Habgood, M. J., Ainsworth, S. E., & Benford, S. (2005). Endogenous fantasy and learning in digital games. *Simulation & Gaming*, *36*(4), 483-498.

John Fox and Sanford Weisberg (2011). An {R} Companion to Applied Regression, Second Edition. Thousand Oaks CA: Sage.

Johnson, D. W., Johnson, R. T., & Stanne, M. B. (2000). Cooperative learning methods: A meta-analysis.

Kafai, Y. B. (1996). Learning design by making games: Children's development of strategies in the creation of a complex computational artifact. In Y. B. Kafai & M. Resnick (Eds.), *Constructionism in Practice: Designing, Thinking and Learning in a Digital World* (pp. 71-96). Mahwah, NJ: Lawrence Erlbaum Associates.

Kalyuga, S., & Plass, J. L. (2009). Evaluating and Managing Cognitive Load in Games. In R. Ferdig (Ed.), *Handbook of Research on Effective Electronic Gaming in Education* (pp. 719-737). Hershey, PA: IGI Global.

Kaminski, J. A., Sloutsky, V. M., & Heckler, A. F. (2008). The advantage of abstract examples in learning math. *Science*, 320(5875), 454-455.

Ke, F., & Grabowski, B. (2007). Gameplaying for maths learning: cooperative or not?. *British Journal of Educational Technology*, *38*(2), 249-259.

Klimmt, C., Hartmann, T., & Frey, A. (2007). Effectance and control as determinants of video game enjoyment. *Cyberpsychology & Behavior*, 10(6), 845-848.

Landers, R. N., & Landers, A. K. (2014). An empirical test of the theory of gamified learning: The effect of leaderboards on time-on-task and academic performance. *Simulation & Gaming*, *45*(6), 769-785.

Laski, E. V., & Siegler, R. S. (2014). Learning from number board games: You learn what you encode. *Developmental Psychology, 50*(3), 853-864.

Lee, Y. H., Heeter, C., Magerko, B., & Medler, B. (2012). Gaming mindsets: Implicit theories in serious game learning. *Cyberpsychology, Behavior, and Social*

Networking, *15*(4), 190-194.

Lim, S. Y., & Chapman, E. (2013). Development of a short form of the attitudes toward mathematics inventory. *Educational Studies in Mathematics*, 82(1), 145-164.

Lomas, J. D., Koedinger, K., Patel, N., Shodhan, S., Poonwala, N., & Forlizzi, J. L. (2017). Is Difficulty Overrated?: The Effects of Choice, Novelty and Suspense on Intrinsic Motivation in Educational Games. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (pp. 1028-1039). ACM.

Malone, T. W. (1981). Toward a theory of intrinsically motivating instruction. *Cognitive Science*, *5*(4), 333-369.

Malone, T. W., & Lepper, M. R. (1987). Making learning fun: A taxonomy of intrinsic motivations for learning. *Aptitude, Learning, and Instruction*, *3*(1987), 223-253.

Martens, R., Gulikers, J., & Bastiaens, T. (2004). The impact of intrinsic motivation on e-learning in authentic computer tasks. *Journal of Computer Assisted Learning*, *20*(5), 368-376.

Mayer, R. E. (2011). Multimedia learning and games. In S. Tobias & J. D. Fletcher (Eds.), *Computer Games and Instruction* (pp. 281-305). Charlotte, NC: IAP Information Age Publishing.

Mayer, R. E., & Moreno, R. (2003). Nine ways to reduce cognitive load in multimedia learning. *Educational Psychologist*, *38*(1), 43-52.

Navarro, D. J. (2015). Learning statistics with R: A tutorial for psychology students and other beginners. Adelaide, Australia: University of Adelaide.

Nunes, T., Schliemann, A.-L., & Caraher, D. (1993). *Street Mathematics and School Mathematics*. New York: Cambridge University Press.

O'Neil, H. F., Wainess, R., & Baker, E. L. (2005). Classification of learning outcomes: Evidence from the computer games literature. *The Curriculum Journal*, *16*(4), 455-474.

Parkin, A. J., Lewinsohn, J., & Folkard, S. (1982). The influence of emotion on immediate and delayed retention: Levinger & Clark reconsidered. *British Journal of Psychology*, *73*(3), 389-393.

Paas, F. (1992). Training strategies for attaining transfer of problem-solving skill in statistics: A cognitive load approach. *Journal of Educational Psychology*, 84, 429-434.

Paunesku, D., Walton, G. M., Romero, C., Smith, E. N., Yeager, D. S., & Dweck, C. S. (2015). Mind-set interventions are a scalable treatment for academic underachievement. *Psychological Science*, 26(6), 784-793.

Pintrich, P. R. (2003). A motivational science perspective on the role of student motivation in learning and teaching contexts. *Journal of Educational Psychology*, *95*(4), 667-686.

Plass, J. L., O'keefe, P. A., Homer, B. D., Case, J., Hayward, E. O., Stein, M., & Perlin, K. (2013). The impact of individual, competitive, and collaborative mathematics game play on learning, performance, and motivation. *Journal of Educational Psychology*, *105*(4), 1050-1066.

R Core Team (2013). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Ryan, R. M., & Deci, E. L. (2000). Intrinsic and extrinsic motivations: Classic definitions and new directions. *Contemporary Educational Psychology*, *25*(1), 54-67.

Schrader, C., & Bastiaens, T. J. (2012). The influence of virtual presence: Effects on experienced cognitive load and learning outcomes in educational computer games. *Computers in Human Behavior*, *28*(2), 648-658.

Shaffer, D. W. (2004). Pedagogical praxis: The professions as models for postindustrial education. *Teachers College Record*, 106(7), 1401-1421.

Sheldon, K. M., Ryan, R. M., Rawsthorne, L. J., & Ilardi, B. (1997). Trait self and true self: Cross-role variation in the Big-Five personality traits and its relations with psychological authenticity and subjective well-being. *Journal of Personality and Social Psychology*, 73(6), 1380.

Sitzmann, T. (2011). A meta-analytic examination of the instructional effectiveness of computer-based simulation games. *Personnel Psychology*, *64*(2), 489-528.

Squire, K., Barnett, M., Grant, J. M., & Higginbotham, T. (2004, June). Electromagnetism supercharged!: learning physics with digital simulation games. In *Proceedings of the 6th International Conference on Learning Sciences* (pp. 513-520). International Society of the Learning Sciences.

Stallings, J. (1980). Allocated academic learning time revisited, or beyond time on task. *Educational Researcher*, *9*(11), 11-16.

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science*, *12*(2), 257-285.

Tempelaar, D., Rienties, B., Giesbers, B., & Gijselaers, W. (2015). The pivotal role of effort beliefs in mediating implicit theories of intelligence and achievement goals and academic motivations. *Social Psychology of Education*, 18(1), 101-120.

Tulving, E., & Thomson, D. M. (1973). Encoding specificity and retrieval processes in episodic memory. *Psychological Review*, 80(5), 352-373.

Uttal, D. H., O'Doherty, K., Newland, R., Hand, L. L., & DeLoache, J. (2009). Dual representation and the linking of concrete and symbolic representations. *Child Development Perspectives*, 3(3), 156-159.

Vollmeyer, R., & Rheinberg, F. (2000). Does motivation affect performance via persistence?. *Learning and Instruction*, *10*(4), 293-309.

Weisberg, D. S., Ilgaz, H., Hirsh-Pasek, K., Golinkoff, R., Nicolopoulou, A., & Dickinson, D. K. (2015). Shovels and swords: How realistic and fantastical themes affect children's word learning. *Cognitive Development*, *35*, 1-14.

Wickham, H. (2016). ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag New York.

Wickham, H. (2007). Reshaping Data with the reshape Package. *Journal of Statistical Software*, 21(12), 1-20.

Wouters, P., van Nimwegen, C., van Oostendorp, H., & van der Spek, E. D. (2013). A meta-analysis of the cognitive and motivational effects of serious games. *Journal of Educational Psychology, 105*(2), 249-265.

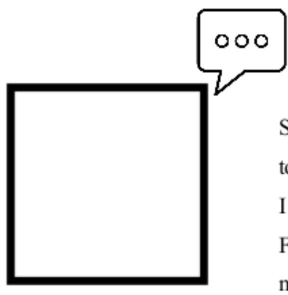
Yeager, D. S., Romero, C., Paunesku, D., Hulleman, C. S., Schneider, B., Hinojosa, C., ... & Trott, J. (2016). Using design thinking to improve psychological interventions: The case of the growth mindset during the transition to high school. *Journal of Educational Psychology*, 108(3), 374.

Zeidner, M. (1998). *Test Anxiety: The State of the Art*. New York: Plenum Press.

Appendices

Appendix A Complex Number Lesson

Instructional Material



Hey you! Yeah, the three-dimensional one. My name is A Square and I'm from Flatland – a two-dimensional world connected to your three-dimensional one. I'm glad I got your attention because I could really use your help with a game that we play here in Flatland, but first you'll need to understand the two-dimensional numbers that us Flatlanders use.

One way of understanding numbers is with **the number line** (Fig. 1). On it, we can place all of the positive numbers to the **right** of zero in ascending order. Indeed, this order means that a number's size is related to how far it is from zero – also known as its magnitude. The number one is just to the right of zero, while one hundred is a hundred times further to the right! Likewise, all the negative numbers can be placed to the **left** of zero in descending order. The bigger the negative number's magnitude, the further it is to the left of zero. For example, 3 and -3 have the same magnitude, but they are in different directions.

Fig 1.

Definition: *Real Number Line*: Horizontal line upon which we can place all the positive and negative numbers. – Positive numbers are to the right of zero – Negative numbers are to the left of zero

Here in Flatland we call these numbers to the left and right of zero the horizontal numbers, but I believe your people call them the *real numbers*. Now, calling a single dimension real is an affront to me personally and to the people of Flatland as a whole! As you can clearly see by looking at my square self, we possess **up** and **down**, in addition to **left** and **right**. This is reflected by the numbers that we use here in Flatland, as they can also be placed on a **second number line** that is vertical (Fig. 2). On it we place what your people call the *imaginary numbers.* The magnitude of a positive imaginary number is how far **up** from zero it is on the imaginary number line. The magnitude of a negative imaginary number is how far **down** it is. So $3i$ and $-3i$, as well as 3 and -3, all have the same magnitude, but they are located in different directions from zero.

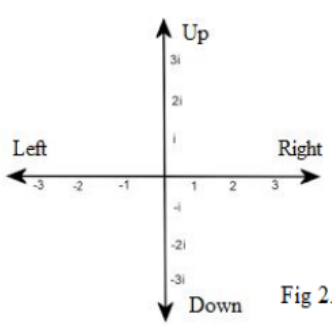


Fig 2.

The imaginary unit (i) indicates that a number is located on the imaginary number line. Specifically, i indicates that a number is above zero when it is positive and below zero when it is negative. This function of i can be understood geometrically as a rotation: multiplying 1 by i moves the product onto the vertical number line by performing a **90° rotation around zero**. Multiplying any number by i two times would therefore be the same thing as multiplying it by -1 (i^2 = -1). Repeating this process results in the cycle that is pictured in Fig. 3.

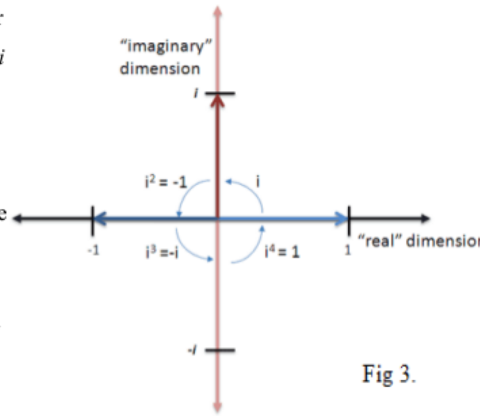


Fig 3.

Definitions:
Imaginary number line: Vertical line upon which we can place all the positive and negative imaginary numbers. – Positive imaginary numbers are above zero on this line – Negative imaginary numbers are below zero on this line *The imaginary unit* (i): indicates that a number is on the imaginary number line. (i^2 = -1) – Multiplying a number by i performs a 90° rotation counter-clockwise around zero

These two number lines create the **complex plane**, and you might have noticed that it resembles a Cartesian Plane. This is a good comparison, as our numbers – **complex numbers** – can be located anywhere in this two-dimensional space (Fig 4.). To represent these numbers we use **the rectangular notation ($x + yi$)**. This notation breaks a complex number into two components – the distance from zero along the horizontal real number line and the distance from zero along the vertical imaginary number line. This is similar to the Cartesian coordinates of x and y, we just use i to indicate which number is the imaginary component and then sum each component in order to create a single number. For example, the distance between zero and the point at x = 3 and y = 4 on a Cartesian plane, could be represented as the number (3 + 4i). The magnitude of (3 + 4i) is the length of the line in Fig. 4, which happens to be 5. So 5, 5i, and (3 + 4i) all have the same magnitude, but are located in different directions from zero.

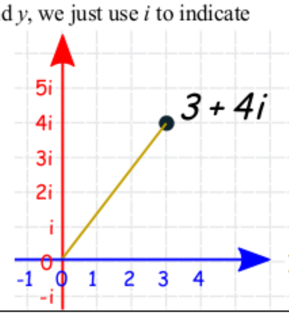


Fig 4.

Definition:
Complex plane: Similar to a Cartesian plane, the complex plane is composed of two number lines that cross at zero. The real number line takes the place of the x-axis, and the imaginary number line takes the place of the y-axis. Every point on the complex plane represents a complex number.

Appendix B Pretest and Posttest

Pre-Test

a) Complex numbers can be understood geometrically as having ___________ dimensions.

b) In the complex plane, the x axis is replaced by the ___________ number line.

c) The imaginary unit can be mathematically defined as (i^2 = ___________).

d) On the complex plane, a number with no real part is located on the ___________ number line.

e) Multiplying a number by the imaginary unit can be understood geometrically as ___________.

f) On the complex plane, a number with a positive real part is located to the ___________ of the imaginary number line.

g) In the complex plane, the y axis is replaced by the ___________ number line.

h) On the complex plane, a number with a negative imaginary part is located ___________ the real number line.

2. Express the numbers on the complex plane to the right in rectangular format:

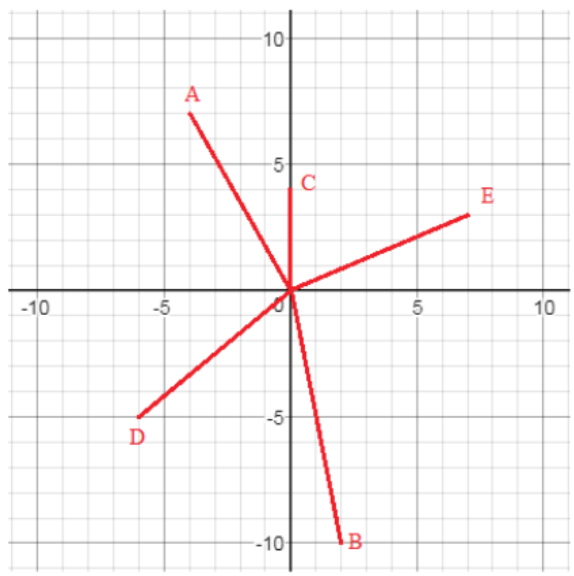
A. ___________

B. ___________

C. ___________

D. ___________

E. ___________



3. Add the following numbers to the complex plane on the right:

F. $-7 \times i^2$

G. $10 \times i^3$

H. $5i \times i$

4. Multiply the following complex numbers (simplify your answer as much as possible):

a) $(5 + 0i) \times i$

b) $(1 + 1i) \times i$

c) $(15 - 3i) \times -2i$

c) $(3 + 2i) \times (2 + 3i)$

Post-Test

a) Complex numbers can be understood geometrically as having ___________ dimensions.

b) In the complex plane, the x axis is replaced by the ___________ number line.

c) The imaginary unit can be mathematically defined as (i^2 = ___________).

d) On the complex plane, a number with no real part is located on the ___________ number line.

e) Multiplying a number by the imaginary unit can be understood geometrically as ___________.

f) On the complex plane, a number with a positive real part is located to the ___________ of the imaginary number line.

g) In the complex plane, the y axis is replaced by the ___________ number line.

h) On the complex plane, a number with a negative imaginary part is located ___________ the real number line.

2. Express the numbers on the complex plane to the right in rectangular format:

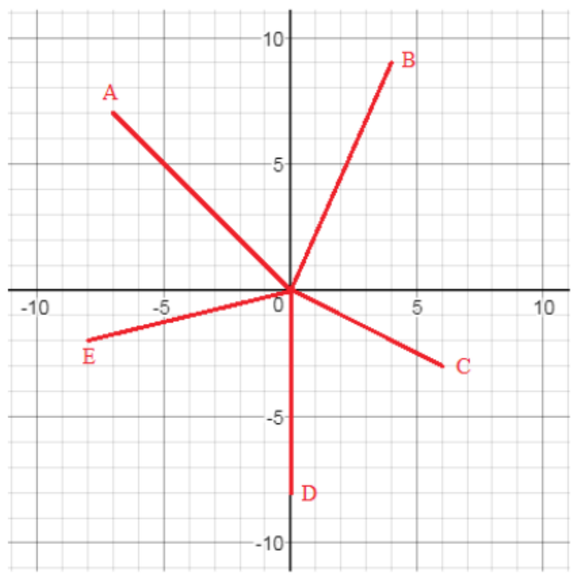
A. ___________

B. ___________

C. ___________

D. ___________

E. ___________



3. Add the following numbers to the complex plane on the right:

F. $5 \times i^2$

G. $3 \times i^3$

H. $2i \times i$

4. Multiply the following complex numbers (simplify your answer as much as possible):

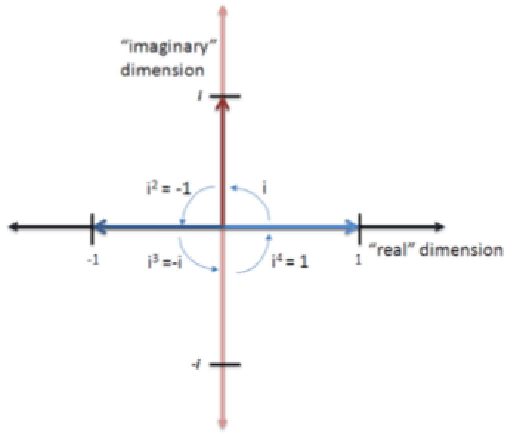
a) $(2 + 0i) \times i$

b) $(-1 + 1i) \times i$

c) $(11 - 4i) \times 2i$

c) $(4 + 2i) \times (1 + 1i)$

Appendix C Game Screen



Recap:
Complex numbers are two-dimensional numbers that can be represented with the rectangular notation ($x + yi$), which sums the number's real and imaginary components. Every point on the complex plane represents a complex number:

- positive real components (+) mean that the number is that far to the right of the vertical axis.
- negative real components (–) mean that the number is that far to the left of the vertical axis.
- complex numbers without a real component are located on the vertical axis.
- positive imaginary components (+i) mean that the number is that far above the horizontal axis.
- negative imaginary components (–i) mean that the number is that far below the horizontal axis.
- complex numbers without an imaginary component are located on the horizontal axis.

Note. This material was printed onto the two game screens behind which participants hid their ships in both versions of the game. The top depicts the rotation that occurs when multiplying by the imaginary unit (Azad, 2007). The bottom provides a recap of the complex numbers lesson.

Appendix D Online Questionnaires

D.1 Demographic questionnaire

1. What is your Gender?
2. What is your age?
3. What is your native language?
4. What is your major (or preferred area of study if you don’t have a major)?
5. What year of University are you in?
6. What was the last grade (or equivalent course level) in which you took a math course in high school?

D.2 Motivational Questionnaire

1. While I was playing the game, I was thinking about how much I enjoyed it.
2. I did not feel at all nervous about playing the game.
3. I am very interested by complex numbers.
4. I felt that it was my choice to play the game.
5. I think I am pretty good at this game.
6. I found the game very interesting.
7. I felt tense while playing the game.
8. I would be willing to learn more about complex numbers.
9. I think I did pretty well at this game, compared to other students.
10. Playing the game was fun.
11. I felt relaxed while playing the game.
12. I enjoyed playing the game very much.

13. I didn’t really have a choice about playing the game.
14. I am satisfied with my performance at this game.
15. I would be willing to play the game again.
16. I was anxious while playing the game.
17. I thought the game was very boring.
18. I felt like I was doing what I wanted to do while I was playing the game.
19. I would use the game to teach someone about complex numbers.
20. I felt pretty skilled at this game.
21. I will most likely tell a friend about complex numbers.
22. I thought the game was very interesting.
23. I felt pressured while playing the game.
24. I felt like I had to play the game.
25. I would describe the game as very enjoyable.
26. I will most likely seek out more information about complex numbers.
27. I played the game because I had no choice.
28. After playing the game for a while, I felt pretty competent.

D.3 Mindset Questionnaire

1. You can always substantially change your basic intelligence.
2. You can change even your basic gaming ability level considerably.
3. You can learn new things, but you can’t really change your basic intelligence.
4. No matter how much gaming abilities you have, you can always change it quite a bit.
5. Your intelligence is something about you that you can’t change very much.

6. To be honest, you can’t really change how intelligent you are.
7. You can learn new things, but you can’t really change your basic gaming abilities.
8. No matter who you are, you can significantly change your intelligence level.
9. You can always substantially change your basic gaming abilities.
10. To be honest, you can’t really change how good at games you are.
11. No matter who you are, you can significantly change your gaming ability level.
12. You have a certain amount of gaming abilities, and you can’t do much to change it.
13. You can change even your basic intelligence level considerably.
14. Your gaming abilities is something about you that you can’t change very much.
15. You have a certain amount of intelligence, and you can’t do much to change it.
16. No matter how much intelligence you have, you can always change it quite a bit.

D.4 ATMI Questionnaire

1. Mathematics is a very worthwhile and necessary subject.
2. Mathematics is one of the most important subjects for people to study.
3. I am happier in a mathematics class than in any other class.
4. I am willing to take more than the required amount of mathematics.
5. I am always confused in my mathematics class.
6. It makes me nervous to even think about having to do a mathematics problem.
7. Mathematics lessons would be very helpful no matter what I decide to study in the future.
8. I have usually enjoyed studying mathematics in school.
9. The challenge of mathematics appeals to me.

10. I am confident that I could learn advanced mathematics.

11. I plan to take as much mathematics as I can during my education.

12. I like to solve new problems in mathematics.

13. A strong mathematics background could help me in my professional life.

14. I am always under a terrible strain in a mathematics class.

15. I really like mathematics.

16. Mathematics is a very interesting subject.

17. Mathematics is important in everyday life.

18. I feel a sense of insecurity when attempting mathematics.

19. Studying mathematics makes me feel nervous.

Appendix E Script

The next part of the study involves a modified version of the game battleship. You will play the game for thirty-five minutes. The rules of the game are in front of you. Please read them even if you are familiar with battleship, and let me know once you are done so I can show you a sample turn.

Experimental Condition

The ships should be plotted onto the game board like this. [point]

Keep their location hidden from your opponent with the screen. [point]

Both players write down a complex number at the same time. This number represents the coordinates of where you want to fire on the other player's ships. So let's say one of you wanted to fire on the space in the top left [point], then you would write down this complex number [point]. If the other player wanted to fire on the space directly below the center [point], then you would write down this complex number [point]. If you don't remember how to write down a complex number then you can refer to the recap of the instructional material on each of your screens [point]. Once these numbers are written down, each player passes their shot to each other and checks if their opponent hit one of their ships.

If your ship is hit mark it like so. [point]

If your shot was a miss, mark it on their complex plane like so. [point]

If your shot was a hit, mark it on their complex plane like so. [point]

Then you will pass back the page with the other player's complex number on it and repeat the process of writing down a number and passing it to the other player.

Additionally, each of you will get the opportunity to fire a bonus shot every five shots. To do so, you will need to correctly multiply the previous shot by the imaginary unit. You can do this visually with a 90 degree rotation around zero [point] or mathematically – like so [point]. You will then pass it to the other player so they can check if it is correct and tell you if it is a hit or a miss as normal.

I cannot answer any questions relating to complex numbers. However, you can refer to the recap on each of your screens, and you can also ask each other questions about complex numbers using the complex plane on the example page as a point of reference. You can also use this to confirm that the other player is marking your shots correctly.

I will let you know when this part of the study is complete thirty-five minutes after you plot your ships.

Control Condition

The ships should be plotted onto the game board like this. [point]

Keep their location hidden from your opponent with the screen. [point]

Before each shot, both players draw a question and write down a complex number at the same time. So let's say one of you were to draw a complex number that is in the top left [point], then you would write down this complex number [point]. If the other player were to draw a complex number directly below the center [point], then you would write down this complex number [point]. If you don't remember how to write down a complex number then you can refer to the recap of the instructional material on each of your screens [point]. Once these numbers are written down, each player passes their sheet to each other and checks if their opponent identified the complex number correctly.

Then you will call out a shot if you answered correctly.

If your ship is hit mark it like so. [point]

If your shot was a miss, mark it on their side like so. [point]

If your shot was a hit, mark it on their side like so. [point]

Then you will repeat the process of drawing a question, answering it, and firing on the other player's ships.

Additionally, each of you will get the opportunity to fire a bonus shot every five shots. To do so, you will need to correctly multiply the previous number by the imaginary unit. You can do this visually with a 90 degree rotation around zero [point] or mathematically – like so [point]. You will then pass it to the other player so they can check if it is correct. Once again, a correct answer means you get to call out a shot.

I cannot answer any questions relating to complex numbers. However, you can refer to the recap on each of your screens, and you can also ask each other questions about complex numbers using the complex plane on the example page as a point of reference.

I will let you know when this part of the study is complete thirty-five minutes after you plot your ships.