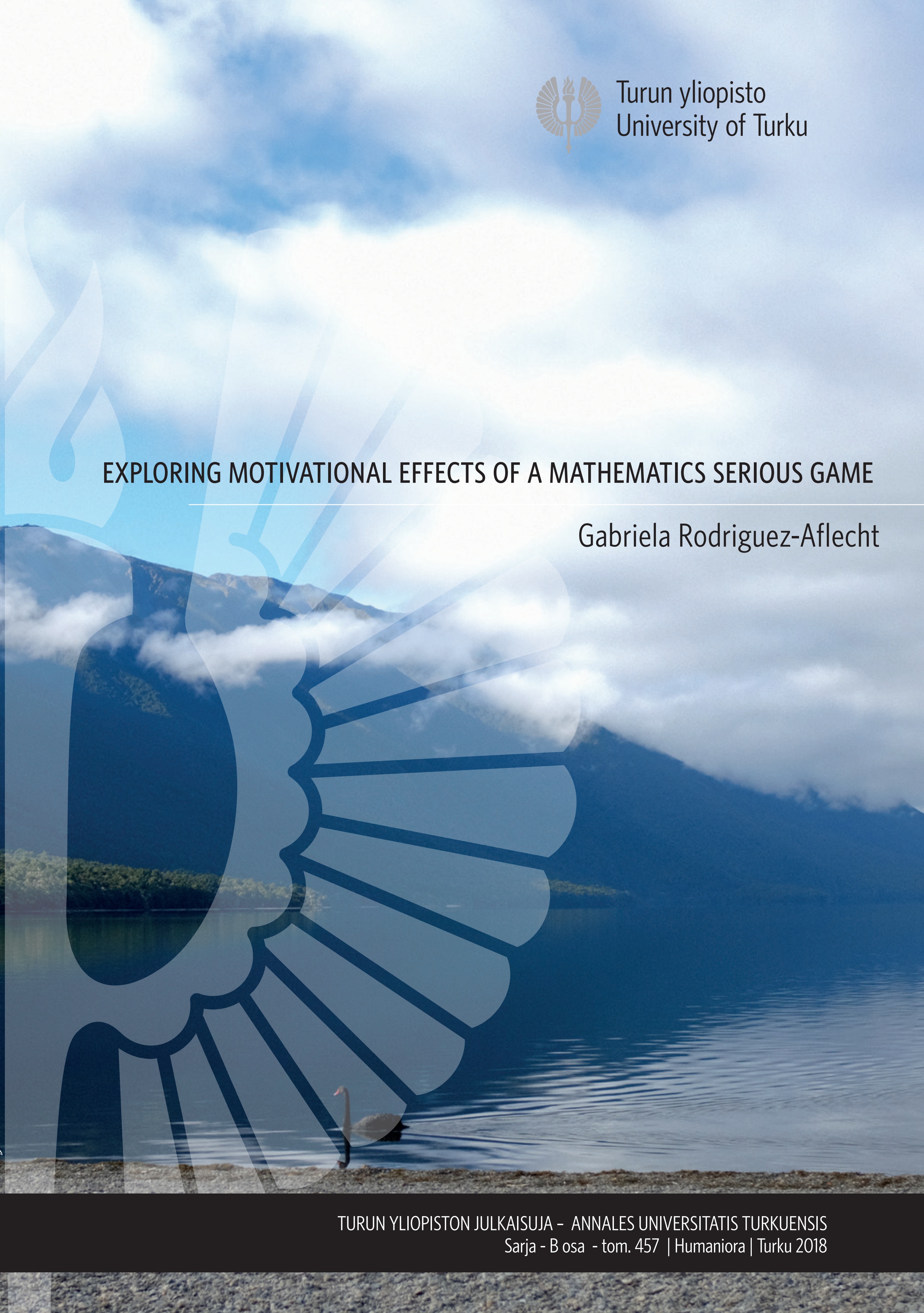

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Gabriela Rodriguez-Aflecht

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Dedicated to my father,
who paved the way,
and to Teijo,
who walks by my side.

TIIVISTELMÄ

TURUN YLIOPISTO

Kasvatustieteiden tiedekunta

Opettajankoulutuslaitos ja Oppimisen ja opetuksen tutkimuskeskus

Oppimisen, opetuksen ja oppimisympäristöjen tutkimuksen tohtoriohjelma

RODRÍGUEZ-AFLECHT, GABRIELA: MATEMATIIKAN OPPIMISPELIN MOTIVATIONAALISET VAIKUTUKSET

Väitöskirjassa tutkittiin matematiikkaan kohdistuvan Number Navigation Game –oppimispelin (NNG), vaikutusta suomalaisten ja meksikolaisten yläkouluoppilaiden motivaatioon. Tutkimuksen tavoitteena oli analysoida Number Navigation Game pelin motivaatiovaikutuksia expectancy–values -teorian näkökulmasta painottaen erityisesti oppilaiden tilannekohtaisen kiinnostuksen kehitystä pelaamisen aikana ja heidän henkilökohtaista kiinnostustaan matematiikkaan kohtaan. Lisäksi tutkittiin pelikokemuksen ja pelikontekstiin liittyvien tekijöiden, kuten pelaamisen vapaaehtoisuuden tai pakollisuuden, vaikutusta motivaatioon. Tutkimus on osa laajaa oppimispelien vaikutusta matematiikan oppimiseen selvittävää CUMA-tutkimusprojektia, joten tutkimuksessa otettiin huomioon myös Number Navigation Game -pelin vaikutus matematiikan oppimistuloksiin. Tutkimus koostuu kolmesta osatutkimuksesta, joihin osallistui alakoulun ylempien luokkien oppilaita.

Ensimmäinen osatutkimus toteutettiin Suomessa neljännellä, viidennellä ja kuudennella luokalla. Koeryhmä (*n* = 642) pelasi Number Navigation Game -peliä osana matematiikan tuntejaan kymmenviikkoisen jakson ajan, kun taas kontrolliryhmä (*n* = 526) jatkoi tavallista opetussuunnitelman mukaista ja oppikirjaan tukeutuvaa opiskelua. Aineisto kerättiin motivaatiota ja pelikokemusta kartoittavilla kyselyillä ja matemaattisilla testeillä ennen pelikokeilua ja sen jälkeen. Tulokset osoittivat, että pelillä oli positiivinen vaikutus oppimistuloksiin, mutta koeryhmän motivaatio laski hieman. Pelikokemukset olivat suurimmaksi osaksi negatiivisia, mikä on osoitus tarpeesta kehittää Number Navigation Game -pelin pelillisiä ominaisuuksia. Näissä kokemuksissa oli jonkin verran hajontaa sukupuolen mukaan, erityisesti liittyen oppilaiden mielipiteisiin kompetenssin ja haasteellisuuden kokemuksista, mutta kaiken kaikkiaan pelikokemukset eivät olleet yhteydessä oppimistuloksiin eikä motivaatioon.

Toinen osatutkimus keskittyi ensimmäisen osatutkimuksen kontrolliryhmän osallistujien osa-otokseen eli viidesluokkalaisiin (*n* = 212), jotka myöhemmin pelasivat Number Navigation Game -peliä kuusiviikkoisen jakson ajan. Oppilaiden henkilökohtaista kiinnostusta matematiikkaa kohtaan mitattiin ennen pelin pelaamista ja sen jälkeen. Lisäksi heidän tilannekohtaista kiinnostustaan peliä kohtaan mitattiin tehtävän aikana viidellä peilikerralla. Tulokset osoittivat, että aiempi henkilökohtainen kiinnostus matematiikkaa kohtaan ennustaa alkutilanteen tilannekohtaista kiinnostusta. Tilastollinen Growth mixture -analyysi paljasti kolmiluokkaisen tilannekohtaisen kiinnostuksen kehityskaaren mallin, joka osoitti, että oppilaiden tilannekohtainen kiinnostus kehittyi eri tavoin intervention aikana. Tulokset osoittivat, että peli pystyy herättämään ja pitämään yllä tilannekohtaisen kiinnostuksen suurimmalla osalla osallistujista, joskaan ei kaikilla. Joidenkin oppilaiden tilannekohtainen kiinnostus ei koskaan

herännyt peliä pelatessa. Niille oppilaille, joissa peli herätti kiinnostuksen, mutta ei pitänyt sitä yllä, pelillä oli negatiivinen vaikutus henkilökohtaiseen kiinnostukseen matematiikkaa kohtaan. Tulosten valossa vaikuttaa siltä, että peli on hyödyllinen oppilaille, jotka ovat jo kiinnostuneita matematiikasta

Kolmannessa tutkimuksessa meksikolaiset viidesluokkalaiset jaettiin kahteen pelaamisryhmään: vapaaehtoiseen ryhmään (*n* = 579) tai kouluryhmään (*n* = 482). Kouluryhmä pelasi NNG-peliä osana tavallisia matematiikan opintojaan. Vapaaehtoisessa ryhmässä oppilaat saivat kopion pelistä ja heille kerrottiin, että he voivat pelata peliä vapaa-ajallaan, jos niin tahtovat. Tarkoituksena oli selvittää pelikontekstin vaikutukset pelikokemuksiin, pelisuoriutumiseen sekä matematiikan oppimiseen ja motivaatioon. Lisäksi selvitettiin kuinka paljon oppilaat pelaisivat vapaaehtoisesti, ja kuinka he, jotka päättivät pelata, erosivat sukupuolen, koetta edeltävien matemaattisten taitojen ja motivaation osalta heistä, jotka eivät pelanneet. Tulokset osoittivat, että aiempi matemaattinen kiinnostus ja edistyneet matemaattiset taidot vaikuttavat oppilaiden halukkuuteen pelata vapaaehtoisesti, kun taas kiinnostus digitaalisia pelejä kohtaan ei vaikutanut halukkuuteen pelata. Vapaaehtoisesti pelaamatta jättäminen ei kuitenkaan vaikuta kiinnostukseen matematiikkaa kohtaan. Oppilaat, jotka pelasivat vapaaehtoisesti, kehittyivät vaativissa matemaattisissa taidoissa koulussa pelannutta ryhmää enemmän. Kouluryhmän oppilaat pelasivat pidempään, suorittivat enemmän pelinsisäisiä matemaattisia tehtäviä ja nauttivat kokemuksestaan enemmän kuin oppilaat vapaaehtoisryhmässä. Number Navigation Game -pelin pelaamisella on positiivinen vaikutus matemaattisiin taitoihin riippumatta pelikontekstista. Motivaatio pysyy suurimmaksi osaksi muuttumattomana pelikontekstista riippumatta.

Osatutkimusten tulokset tarjoavat lisätodisteita siitä, että motivaatio on suurimmaksi osaksi vakaata ja että oppimispelit eivät auta oppilaiden motivaation parantamisessa oppiainetta kohtaan. Pelin jatkokehittelyllä voidaan parantaa Number Navigation Game -peliin liittyviä pelikokemuksia. Toisaalta näyttää siltä, että pelikokemukset eivät vaikuta motivaatioon eivätkä oppimistuloksiin. Konteksti, jossa oppimispeliä pelataan tai vapauden määrä, joka oppilailla on pelatessa, ei näytä myöskään vaikuttavan motivaation vahvistumiseen. Toisaalta pelimekaniikka onnistuu parantamaan oppilaiden aritmetiikan taitoja. Se onnistuu myös herättämään ja pitämään yllä kiinnostuksen valtaosalla oppilaista. Tässä mielessä oppimispelit tarjoavat monia mahdollisuuksia opetuksen lisätyökaluina. On kuitenkin tärkeää, että pelit valitaan huolellisesti niiden todistettujen oppimisvaikutusten perusteella sen sijaan, että niiden avulla pyrittäisiin ratkaisemaan motivaatio-ongelmia.

ABSTRACT

UNIVERSITY OF TURKU

Faculty of Education

Department of Teacher Education and Centre for Research on Learning and Instruction

Doctoral Program on Learning, Teaching, and Learning Environments Research

RODRIGUEZ-AFLECHT, GABRIELA: EXPLORING MOTIVATIONAL EFFECTS OF A MATHEMATICS SERIOUS GAME

This dissertation examines the motivational effects of a mathematics serious game called the Number Navigation Game (NNG) amongst upper elementary school students in Finland and Mexico. The aims of the studies concern the NNG's impact on motivation as measured through the expectancy-value framework, with special emphasis on the development of students' situational interest during gameplay and individual interest toward mathematics. The role of factors such as game experience and the voluntary vs. compulsory nature of different play contexts is also explored. As this research was undertaken in the context of a larger project (CUMA) investigating the game's effectiveness in enhancing mathematical skills, some attention is also paid to the game's impact on mathematical learning outcomes. The results of three original empirical studies in which the game was implemented at the upper primary school level are reported.

Study I presents the results of a large-scale experiment carried out in Finland amongst fourth- to sixth-grade students. The students were randomly assigned by class to either an experimental or control group. The experimental group (n = 642) played the NNG as part of their regular mathematics class for a ten-week period, while the control group (n = 526) continued with traditional textbook-based learning. The students completed various mathematical tests and questionnaires on their motivation and game experiences both before and after the intervention. The results revealed the game had a positive effect on learning outcomes, but that there was a slight decrease in the motivation expectancy values of the experimental group. Game experiences were mostly negative, which indicates room for improvements in game design. There was some variation in these experiences by gender, specifically regarding students' feelings of competence and challenge, but in any case, game experiences did not play a role in either learning outcomes or motivation expectancy values.

Study II concentrated on a subsample of participants from the first study, namely n = 212 fifth-grade students who, although they served as a control group for Study I, later played the NNG for a six-week period. These students' individual interest toward mathematics was measured before and after playing the game, while their situational interest toward the game was measured on-task throughout five sessions. The results indicate that prior interest toward mathematics predicts initial situational interest. Growth curve mixture model analyses revealed a three-class model of situational interest trajectories, showing that the students' interest develops differently throughout the intervention. The results indicated that the game was able to trigger and maintain the interest of most (73.9%) although not all participants. Some students' interest was never triggered by the game (26.1%). In cases in which interest was triggered but not maintained by the game (15.9%), this had a negative impact on students' individual interest toward mathematics. At the moment it seems the game is beneficial to students who already have an interest toward the subject matter.

In Study III, fifth-grade students from Mexico were randomly sorted by class into one of two play context groups: the voluntary group (n = 579) or the school group (n = 482). The school group played the NNG as part of their regular mathematics lessons. Students in the volunteer group received a copy of the game and were instructed that they could play in their free time if they so desired. Pre- and post-tests and questionnaires were completed before and after the intervention. The aim was to find out the effects of play context on game experiences, game performance, learning outcomes, and motivation expectancy values, and to explore to what extent students would play voluntarily, and how those who chose to play differed from those who did not by gender, pre-test mathematical skills, and motivation expectancy values. The results revealed that students in the voluntary group who played had higher prior mathematics interest and advanced mathematical skills than students in the voluntary group who did not play; interest toward digital games did not play any role in terms of whether students in the voluntary group played or not. While some students in the voluntary group did not play the game, their interest toward mathematics did not decrease after the intervention. Voluntary play had a positive effect on advanced mathematical skills compared to students from the school group. As for game performance, students in the school group played for longer, completed more in-game mathematical tasks, and had more enjoyable game experiences than students in the volunteer group did. Playing the NNG had a positive effect on mathematical skills regardless of play context. Motivation expectancy values remained mostly unchanged regardless of play context.

The results from the three studies provide further evidence that motivation, as measured through the expectancy-value framework, is largely stable, and that serious games are not particularly successful in increasing student motivation toward a subject. Improvements in game design could result in improvements in experiences when playing the NNG, although it seems that game experiences do not play a role in either motivation or learning outcomes. The context in which a serious game is implemented, or the amount of freedom students have in playing does not seem to make a difference to motivational gains, either. The game is, however, able to trigger and maintain the situational interest of most students, although it seems that students who have a high prior interest toward mathematics are the ones who benefit. On the other hand, the game mechanism is successful at enhancing students' mathematical skills. In this sense, serious games offer many possibilities as additional tools for teaching, but it is important that games be carefully selected for their proven learning outcomes rather than because they are assumed to be motivating for all students.

CONTENTS

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Turku, Finland, May 2018

LIST OF EMPIRICAL STUDIES

This doctoral thesis is based on three studies, which were reported in three original publications. In all studies, the author of dissertation contributed with data collection, analysis, and interpretation. She also wrote the first draft of the manuscripts. In Study III, she contributed to the study conception and design as well as the implementation of the intervention. The studies are referred to in the text by their Roman numerals.

Study I

Rodríguez-Aflecht, G., Brezovszky, B., Pongsakdi, N., Jaakkola, T., Hannula-Sormunen, M.M., McMullen, J., & Lehtinen, E. (2015). Number Navigation Game (NNG): Experience and motivational effects. In J. Torbeyns, E. Lehtinen, & J. Elen (Eds.), *Describing and studying domain-specific serious games* (pp. 171-189). New York, NY: Springer.

Study II

Rodríguez-Aflecht, G., Jaakkola, T., Pongsakdi, N., Hannula-Sormunen, M., Brezovszky, B., & Lehtinen, E. (2018). The development of situational interest during a digital mathematics game. *Journal of Computer Assisted Learning*, 1-10. doi:10.1111/jcal.12239.

Study III

Rodríguez-Aflecht, G., Hannula-Sormunen, M.M., McMullen, J., Jaakola, T., & Lehtinen, E. (2017). Voluntary vs compulsory playing contexts: motivational, cognitive, and game experience effects. *Simulation & Gaming*, *48*(1), 36-55. doi:10.1177/1046878116673679.

1. INTRODUCTION

On a hot summer's day, some people will walk toward a swimming pool and hesitantly dip their toes into the water, gauging the temperature. Perhaps after some coaxing, they will start submerging themselves little by little, trying to postpone the shock of cold water for as long as possible. Others will eagerly jump into the pool. These two different approaches can also be seen in relation to the integration of digital technologies in the classroom, with "skeptics" and "techno-utopians" (Säljö, 2010, p. 54) or "pessimists" and "optimists" (Collins & Halverson, 2010) debating the role of these technologies in formal education. One of these much-debated technologies is digital games. There is a long history of using board, card, or dice games as classroom activities to foster student learning and motivation (Abt, 1971; Boocock & Coleman, 1966; Cohen & Bradley, 1978; McConkey & McEvoy, 1986; Ramani & Siegler, 2008). Digital games, in that sense, pose a natural progression rather than an entirely new phenomenon, and so digital games designed specifically with educational purposes in mind, or "serious games," have been, and continue to be developed.

The appeal of serious games is connected to the success of commercial digital games for entertainment. According to the Entertainment Software Association, in the United States alone, the video game industry took $36 billion in revenue in 2017, an increase of 18% from the previous year (Entertainment Software Association, 2018). The Play Barometer released by the University of Tampere indicates that in 2015, 60.1% of respondents (n = 995) in Finland played digital games, a figure that has risen from previous years; digital games are played for, on average, 4.17 hours (SD = 9.58) a week (Mäyrä, Karvinen, & Ermi, 2016). When looking specifically at respondents between the ages of 10 and 19, digital games are played even more frequently: 52.2% reported playing digital games on a daily basis and 81.6% reported playing at least once a week. Only 1.5% reported not playing digital games at all. It is clear that many children are motivated to play commercial digital games for entertainment; even when these games are long or challenging, children are actively engaged and put in effort and concentration, displaying what Garris, Ahlers, and Driskell term "persistent reengagement" (2002, p. 454). This persistent reengagement is an important reason why there has been a desire to "harness the motivational power of games" (Kirriemuir & McFarlane, 2004, p. 4) or to "harness the positive aspects of games for instructional purposes" (Garris et al., 2002, p. 459). Games are perceived to have the potential to make learning playful or the content more engaging.

Yet the idea of bringing digital games into the classroom is not without criticism. It has been claimed that digital games are addictive, violent, or misogynistic (for a discussion on these topics see Durkin & Barber, 2002; Ferguson, 2007; Fox & Tang, 2014; Przybylski, Weinstein, & Murayama, 2016), and, as such, they have no role in schools. Serious games have been called "chocolate-dipped broccoli," implying that learning on its own is unpleasant and needs to be sugar-coated (Bruckman, 1999, p. 75). By contrast, it has been claimed that "digital natives"—students who have grown up with digital technologies—have significantly different cognitive skills than previous generations do, and that "one of the few structures capable of meeting the Digital Natives' changing learning needs and requirements is the very video and computer games they so enjoy" (Prensky, 2001, p. 11). While the notion of digital natives has been much disputed (Bennet, Maton, & Kervin, 2008; Kirschner & van Merriënboer, 2013), many believe digital games present novel possibilities for learning (Gee, 2007; Oblinger, 2004; Squire, 2011). Conciliating the views of proponents and detractors, Ryan, Rigby, and Przybylski (2006) point out that digital games are so varied and complex that both positive and negative effects are possible.

Serious games have been developed for fields and subjects such as the military (Smith, 2010), business (Lainema, 2009), language (Meyer & Sørensen, 2008), medicine (Knight et al., 2010), science (Squire, 2011), and history (Korallo, Foreman, Boyd-Davis, Moar, & Coulson, 2012), to name but a few examples. At a general level, the majority of serious games focus on science, technology, engineering, and mathematics (STEM) subjects (Boyle et al., 2016). Looking specifically at the primary school level, most serious games are in the subject of mathematics (Hainey, Connolly, Boyle, Wilson, & Razak, 2016). Mathematics is also the school subject in which serious games are used the most (Egenfeldt-Nielsen, 2011). This focus on mathematics is not surprising as it is well documented that motivation toward mathematics decreases steadily throughout the school years (Fredricks & Eccles, 2002; Frenzel, Pekrun, Dicke, & Goetz, 2012; Hidi, Renninger, & Krapp, 2004; Krapp, 2002; Watt, 2004); this is also the case in Finland (Nurmi & Aunola, 2005; Tuohilampi & Hannula, 2013). In Western countries, mathematics education is often perceived as neither meaningful nor relevant (Brown, Brown, & Bibby, 2008). This helps to explain why there is an overall decrease in motivation toward mathematics. An online search for mathematics games will yield multiple results advertising games for all ages. Unfortunately, there is a risk that games will be implemented indiscriminately, prompted by unsubstantiated and unspecified beliefs about the motivational benefits of these games, and chosen perhaps for practical reasons (such as them being easy to install or become familiarized with, free, or flashy) rather than because they have proven learning outcomes.

Empirical research aiming to prove whether beneficial outcomes exist, and, if so, what these are, has risen in the last decades. In response to the growing number of publications on the topic of serious games, several meta-analyses have been carried out (Boyle et al., 2016; Calderón & Ruiz, 2015; Connolly, Boyle, MacArthur, Hainey, & Boyle, 2012; Hainey et al., 2016; Vogel et al., 2006; Wouters, van Nimwegen, van Oostendorp, & van der Spek, 2013) analyzing the literature published between 1990 and 2014. Despite the growing amount of scholarship on serious games, it has been pointed out that a comparison of the results is difficult due to methodological issues (All, Nuñez Castellar, & van Looy, 2016). Vogel and colleagues (2006) found that studies leave out important demographic details or do not describe the intervention or activities in sufficient detail. It has also been repeatedly pointed out that many studies lack an experimental design that includes a control group (Egenfeldt-Nielsen, 2007; Kebritchi, Hirumi, & Bai, 2010; Vogel et al., 2006). In cases where there is a control group, it is not always clear whether this group continues with traditional classroom teaching, engages in a different novel task, or plays a different serious game (All et al., 2016). Egenfeldt-Nielsen (2007) highlights the issue of a short exposure time and a lack of integration with previous research. Calderón and Ruiz (2015) also found that sample sizes are often small ($n < 40$). Additionally, All and colleagues (2016) mention further issues such as confounding elements that make it difficult to isolate the effects of games, the role of the teacher, and the implementation of pre- and post-tests on the same day. The issues listed above hinder understanding on the effectiveness of serious games.

Thus far, the focus of most studies has largely been on learning outcomes (Boyle et al., 2016; Calderón & Ruiz, 2015; Hainey et al., 2016; Wouters et al., 2013). Yet multiple national and international surveys have made it abundantly clear that the main reason teachers use serious games is because they believe in their motivational outcomes rather than because they believe these games have an impact on learning (Beavis et al., 2014; Egenfeldt-Nielsen, 2011; Hanghøj & Brund, 2011; Klemetti, Taimisto, & Karppinen, 2009; Wastiau, Kearney, & van de Berghe, 2009; Williamson, 2009). Some teachers believe serious games are particularly motivating for certain types of students such as male or demotivated students (Wastiau et al., 2009). In the Finnish educational context, 99% of surveyed teachers ($n = 291$) reported a belief that serious games can motivate student learning (Klemetti et al., 2009). The National Core Curriculum for Basic Education states, specifically in regard to mathematics in upper primary school, that "[l]earning games and play form an important and motivating working method" (Finnish National Board of Education, 2016, section 14.4.4).

Overall, serious games are perceived to be motivating, but there is little evidence to support this belief. This dissertation aims to add to the growing literature on this topic and explore the effectiveness of a mathematics serious game. While learning outcomes will be considered, the main focus will be on the game's effectiveness in increasing motivation, particularly one aspect of motivation: interest and its development. Mathematics, an area in which motivational decreases have been well documented, is the subject content of the game. Factors such as gender, game experience, and the context in which the game is played will be considered.

There are four sections in this doctoral dissertation. This first chapter introduces the theoretical background regarding serious games, game experience, motivation, and the design principles of the serious game used in the present work: the NNG. In Chapter 2, the overall aims are described in more detail. This is followed by Chapter 3, which presents the methods. Chapter 4 gives a summary of the three original empirical articles. Finally, the main findings, implications, and ideas for future research are presented in Chapter 5: General Discussion.

1.1. Serious games in education

Abt (1971) is often credited for coining the term "serious games," initially to describe card or board games intended to be educational. Nowadays, the term is largely used in relation to digital games that have been specifically designed to produce some educational outcomes. Other terms have been used, either synonymously or as overlapping terms, for instance, digital learning games, game-based learning, games for learning, applied games, educational games, edutainment (for a discussion on the terminology see Breuer & Bente, 2010; Crookall, 2010; Felicia & Egenfeldt-Nielsen, 2011; Hainey et al., 2016; and Michael & Chen, 2006). As an example, "game-based learning" may be used as a broadly encompassing term that also refers to board games or commercial digital games that, despite being originally developed for entertainment purposes, are also used for educational purposes (for instance, Bourgonjon et al., 2013). It has also been conceptualized the other way around, with game-based learning as a sub-genre of serious games (Hainey et al., 2016). In the meta-analysis of Boyle et al. (2016), both "game-based learning" and "serious games" were collapsed into one term for their review. In the articles presented in this dissertation, those two terms have also been used interchangeably, depending on the publication, to refer to the same concept: broadly speaking, "games that make use of computer technology and advanced video graphics and that are used for the purposes of learning and training" (Crookall, 2010, p. 905). Of course, the definition of "advanced" video graphics may also vary from one person to another. The definition by Michael and Chen (2006, p. 17), then, may be more appropriate, although it leaves out the digital aspect that is nowadays commonly implied by the term: "A serious game is a game in which education (in its various forms) is the primary goal, rather than entertainment."

It is not only the term that is controversial—serious games have, for various reasons, been the focus of much criticism. They have been described as simplistic, repetitive, and over-reliant on drilling mechanics (Egenfeldt-Nielsen, 2007; Kirriemuir & McFarlane, 2004). According to Squire (2011), unlike commercial games for entertainment, serious games are designed by non-players and are not made available for others to critique or build upon, which results in games that lack core features such as transgressive play, character progression, competition, interesting choices and consequences, and the chance to try out different social identities. At a more general level, it has been questioned whether serious games suffer from not being either educational enough or fun enough (van Eck, 2006). From the learning point of view, it has been stressed that many serious games fail to successfully integrate the learning content with game features. Egenfeldt-Nielsen (2007) argues that often, the learning is "subordinated" to the play experience (p. 265). Wouters and colleagues (2013) also question whether dynamics that are useful in the learning content—such as prompts for reflection—might disrupt engagement with the game. Habgood and Ainsworth (2011) call this imbalance a lack of intrinsic integration between a game's core game mechanics and its learning content. In other words, often players are rewarded with a mini-game after completing some learning activities, when ideally, learning should happen through the engaging features and mechanisms of the game. This is tied to a fundamental aspect of why games are seen as motivating, either due to the game features such as a challenge, curiosity, control, and fantasy (Malone & Lepper, 1987), or because they offer "an external representation of the learning content that is explored through the core mechanics of the gameplay" (Habgood & Ainsworth, 2011, p. 173).

Implementation is often problematic as well, as serious games are often integrated as stand-alone activities rather than as part of a larger process (Whitton, 2010), despite evidence that debriefing, feedback, and instructional support increase effectiveness (Hays, 2005). Teachers have reported having a lack of time and energy to become familiarized with new technologies (Klemetti et al., 2009) and they have expressed concern about insufficient resources (Klemetti et al., 2009; Shah & Foster, 2015), which affects their ability to implement digital games. Whitton (2010) also points out that there could be issues of accessibility for students with special needs. Some teachers may also be reluctant to use technologies they may perceive as a challenge to their own professional identity (de Freitas & Jarvis, 2007). Also, parents', teachers', and students' acceptance of serious games in the classroom cannot be taken for granted (Bourgonjon, Valcke, Soetaert, & Schellens, 2010; Bourgonjon, Valcke, Soetaert, de Wever, & Schellens, 2011; Bourgonjon et al., 2013; Hayes & Ohrnberger, 2013). More recently, attempts have been made to prepare future teachers to integrate serious games into their teaching (Shah & Foster, 2015), and to identify the different pedagogical, technological, collaborative, and creative competencies that teachers need to incorporate serious games in their teaching (Nousiainen, Kangas, Rikala, & Vesisenaho, 2018).

Despite the challenges in using serious games, proponents maintain that when properly used, they offer important learning affordances. For example, Gee (2007) claims that digital games have in-built "learning principles," or that they are designed in a way that teaches their players how to play as they play. Some of these learning principles are as follows: allowing multiple routes and solutions, encouraging dispersed and distributed knowledge, and having a situated or contextualized meaning. Players are able to explore content in a risk-free manner (Gee, 2007). Games require students to be active, are discovery-based, and use scaffolding (Gee, 2007; Oblinger, 2004). Assessments are embedded within the context and feedback is an essential part of their mechanism (Moreno & Mayer, 2005; Oblinger, 2004). Finally, they support types of learning that cannot be easily supported by conventional classroom practices and allow for extensive practice (Lehtinen et al., 2015).

1.2. Game experience framework

Here, game experience is considered from the perspective of gaming studies rather than from the educational psychology tradition. Finding ways to measure player experience has long been of particular interest to the computer games industry, as it informs product development; therefore, multiple and overlapping models and theories of game experience proliferate and a common taxonomy is missing (Caroux, Isbister, Le Bigot, & Vibert, 2015; IJsselsteijn, de Kort, Poels, Jurgelionis, & Bellotti, 2007; Nacke & Drachen, 2011; Poels, Hoogen, Ijsselsteijn, & de Kort, 2012). Specifically, in regard to serious games, it is important to understand player experiences as they are believed to mediate motivational and cognitive effects (Järvelä, Lehtinen, & Salonen, 2000; Lowyck, Lehtinen, & Elen, 2005; Nacke & Lindley, 2009; Oksanen, 2013).

In the studies conducted in this dissertation, the framework developed by Poels and colleagues (2010) was used. Although it was developed to measure player experience with commercial games, it has also been widely applied to serious games (de Grove, van Looy, & Courtois, 2010; Gajadhar, Nap, de Kort, & IJsselsteijn, 2008; IJsselsteijn et al., 2007; Nacke, Stellmach, & Lindley, 2011; Oksanen, 2013; Poels, IJsselsteijn, de Kort, & van Iersel, 2010). The framework consists of seven dimensions: competence, challenge, flow, sensory and imaginative immersion, negative affect, positive affect, and tension (IJsselsteijn et al., 2007). Additionally, the dimension of "positive value" was included, based on the argument that players must believe in the positive value of serious games in order to benefit from them (Whitton, 2010).

Competence refers to feelings of ability and is similar to the motivation construct of self-efficacy. Challenge refers to the perceived level of difficulty and should not be too high or too low. According to flow theory (Csikszentmihalyi, 1990), flow results from the balance between challenge and ability. In the framework used, however, flow is defined as a form of immersion resulting from a balance between how challenging the game is and how competent players feel they are at the game. A player's absorption in the game features such as graphics, the story, or sound effects is considered as a separate type of immersion: sensory and imaginative immersion. Finally, the last three dimensions of positive affect, negative affect, and tension refer to affective states that depend on how enjoyable players found the game.

1.3. Motivational constructs used in this study

Multiple conceptualizations of motivation exist. Often there is ambiguity and an overlap between motivation and its related constructs (see Murphy & Alexander, 2000, for a discussion on terminology within the field of motivation). Motivation has been described as a set of cognitive motives (such as beliefs, values, expectancies, intentions, or goals), which, together with emotions, influence behavior (Wegge, 2001). Self-determination theory (Deci & Ryan, 2000) focuses on whether choices are influenced by intrinsic or extrinsic motives. Activities foster intrinsic motivation by satisfying the human needs of competence, autonomy, and psychological relatedness. Another specific kind of motivation, achievement motivation, is related to "learning and development taking place in schools" (Murphy & Alexander, 2000, p. 7). Achievement motivation mediates the relationship between the school environment and school engagement (Wang & Eccles, 2013).

In the studies presented in this dissertation, motivation is explored in relation to mathematics as a subject to be learned within the context of serious games as a learning environment. Motivation is here looked at from the theoretical perspective of achievement motivation, and more specifically, Eccles and Wigfield's (2002) expectancy-value model. This model was applied because it covers many aspects of achievement motivation described in various theories of motivation. It is also widely used in studies on motivation in mathematics (for instance, Berger & Karabenick, 2011; Chouinard, Karsenti, & Roy, 2007). One of the aspects of the expectancy-value model is interest, but it has also been extensively studied independently of the model (e.g. Hidi & Renninger, 2006). Interest is a relevant aspect of motivation for studying game-based learning because it provides concepts for analyzing how motivation is triggered and maintained in specific situations and how it develops in the long term.

1.3.1. Expectancy-value model

According to the expectancy-value model, "expectancy," or how well a person believes they will perform a task, and "value," or a person's reasons for engaging in a task, will determine a person's motivation to perform the task (Wigfield, 1994; Wigfield & Cambria, 2010). The expectancy part of the model is similar to Bandura's (1997) efficacy expectation construct and is also related to Deci and Ryan's concept of competence (1985) or beliefs in one's own ability (Wigfield & Eccles, 2000, 2002). In Eccles and colleagues model, expectancy refers to a person's expectations for future success in a specific task, regardless of how others would comparatively succeed (Wigfield & Cambria, 2010).

"Value" refers to four distinct aspects: intrinsic value, attainment value, utility value, and cost. Intrinsic value or interest refers to how enjoyable a task is. According to Wigfield and Eccles (2000, p. 73), intrinsic value is similar to Deci and Ryan's (1985) construct of intrinsic motivation and is also related to Hidi and Renninger's (2006) concept of individual interest, which will be described in more detail in section 1.3.2. Attainment value refers to the importance given to performing well at a task in order to confirm or to be consistent with a person's self-image (Eccles, 2009). Utility value refers to how useful the task is to a person's goals or to them obtaining external rewards (Eccles, 2009). The distinction between attainment value and utility lies on the former's direct importance to personal and collective identity, and the constructs have been likened (Eccles, 2009; Wigfield & Cambria, 2010) to Ryan and Deci's (2000) constructs of identified regulation and integrated regulation. Finally, cost refers to the price a person believes they must pay in order to perform well on the task in terms of energy, time, or feelings of anxiety or fear (Eccles, 2009).

The expectancy-value model has been shown to predict students' future performance, persistence, and task choice (Eccles & Wigfield, 2002; Wigfield & Cambria, 2010). Expectancy values are already distinct in young children (Nurmi & Aunola, 2005; Wigfield & Eccles, 2000) and their development is influenced by psychological, sociocultural, and contextual factors such as the feedback a child receives from his or her parents, school, and peers (Wigfield & Cambria, 2010). Expectancy and values become increasingly positively related throughout the years (Wigfield et al., 1997), indicating that children grow to value tasks when they believe they are good at them (Bandura, 1997; Jacobs, Lanza, Osgood, Eccles, & Wigfield, 2002). Overall, though, there is a decrease in expectancy values across the school years, which has been attributed to increased competition in schools, and to children's improved ability to interpret feedback and assess themselves more realistically in different areas (Spinath & Spinath, 2005; Wigfield & Eccles, 2002; Wigfield, Tonks, & Klauda, 2009).

Originally, the model was developed to examine the impact of expectancy values on mathematics course choice taking into account the role of gender (Eccles, 1987). Later, gender differences in boys' and girls' motivation toward mathematics have been explored through the model (Frenzel, Pekrun, & Goetz, 2007; Greene, DeBacker, Ravindran, & Krows, 1999; Jacobs et al., 2002; Watt, 2004). Girls have been reported to doubt their competence in math (Jacobs et al., 2002), however, these gender differences in mathematics motivation decrease with time (Fredricks & Eccles, 2002). As well as exploring gender differences in achievement motivation toward mathematics, the model has been applied in numerous studies in this domain: for example, exploring the development of expectancy values over time (Fredricks & Eccles, 2002; Jacobs et al., 2002; Watt, 2004) and the impact of socioeconomic factors on expectancy values (Guo, Marsh, Parker, Morin, & Yeung, 2015). More concretely, the model's relation to mathematics learning strategies (Berger & Karabenick, 2011) and word problem solving (Gasco & Villarroel, 2014; Pongsakdi et al., 2017) has also been studied.

1.3.2. Interest

Most studies examining the effects of serious games on motivation have thus far focused specifically on interest (Moos & Marroquin, 2010). While interest is also a part of the expectancy-value model, it has been much examined in other contexts external from this framework. It is defined as the "psychological state of engaging or the predisposition to reengage with particular classes of objects, events, or ideas over time" (Hidi & Renninger, 2006, p. 112). It has been stressed that it is important to distinguish between two types of interest: situational and individual (Hidi & Renninger, 2006). The former refers to attention and affection of an unknown duration resulting from environmental stimuli, while the latter is an enduring predisposition to reengage particular content over time and its resulting psychological state (Hidi & Renninger, 2006; Renninger, Ewen, & Lasher, 2002). Simply put, the difference between the two is that situational interest is characterized by its transitory and context-specific nature, compared to individual interest, which is said to be more deeply ingrained (Murphy & Alexander, 2000).

The four-phase model of interest development describes four distinct and sequential phases of interest development: triggered situational interest, maintained situational interest, emerging individual interest, and well-developed individual interest (Hidi & Renninger, 2006). By triggering and maintaining situational interest, future engagement can lead to developing emerging and then well-developed individual interest (Renninger & Hidi, 2011). The length of each phase varies in the model, and each phase conveys different amounts of affect, knowledge, and value. Despite the sequential phase of the model, it has been argued that pre-existing levels of individual interest influence the way learners approach situations (Durik & Harackiewicz, 2007). Thus, pre-existing individual interest may also predict situational interest (Knogler, Harackiewicz, Gegenfurtner, & Lewalter, 2015; Krapp, 2002; Schiefele, 2009; Tapola, Veermans, & Niemivirta, 2013).

As it is believed that a) interest develops cumulatively and progressively from situational to individual interest and that b) individual interest supports learning (Alexander, Kulikowich, & Jetton, 1994; Hidi & Renninger, 2006; Murphy & Alexander, 2002), it seems important to develop activities that promote situational interest. Much attention has been given to ways in which to trigger and maintain students' situational interest. It has been argued that collaboration, the topic, and feedback may trigger situational interest (Siklander, Kangas, Ruhalahti, & Korva, 2017). There is also evidence that suggests interest can be promoted through the use of technology (Ainley, 2006; Chen et al., 2016; Mitchell, 1993). Linnenbrink-García et al. (2010) claim that situational interest depends on how material is presented, whereas the content of the material determines whether this situational interest is maintained or not. Rotgans and Schmidt (2014) argue that situational interest is triggered when individuals are confronted with a novel situation that makes them become aware of a knowledge deficit in themselves that they wish to counter; therefore, situational interest decreases as knowledge increases. Hidi and Renninger (2006), however, claim that situational interest may persist as long as the content remains meaningful to a person.

1.4. Design principles of the Number Navigation Game

The Number Navigation Game (NNG) is a PC strategy game expressly developed at the University of Turku with the objective of improving the mathematical skills of upper primary school students, specifically, adaptivity with regard to whole-number arithmetic (Lehtinen et al., 2015; McMullen et al., 2016). People with adaptive rather than routine expertise can more easily apply or transfer their skills or knowledge to different situations or problems (Hatano & Oura, 2003). A person who is adaptive with mathematics is able to solve problems using strategies that are appropriate to their context and the problem (Verschaffel, Luwel, Torbeyns, & van Dooren, 2009). In order to be able to do this, a strong foundation of adaptive number knowledge (ANK) including well-connected knowledge on numerical characteristics and relationships is needed (McMullen et al., 2016, 2017). ANK has, furthermore, been shown to relate to pre-algebra skills (McMullen et al., 2017). Arithmetic fluency, or the quick and accurate retrieval of basic number facts and combinations (Baroody, Bajwa, & Eiland, 2009; Canobi, 2009), is closely related to ANK (McMullen et al., 2016). Lehtinen and colleagues (2015) give a detailed description of the mathematical foundations of the game, and research focusing exclusively on the game's mathematical effectiveness is presented in Brezovszky and colleagues (2015, 2018).

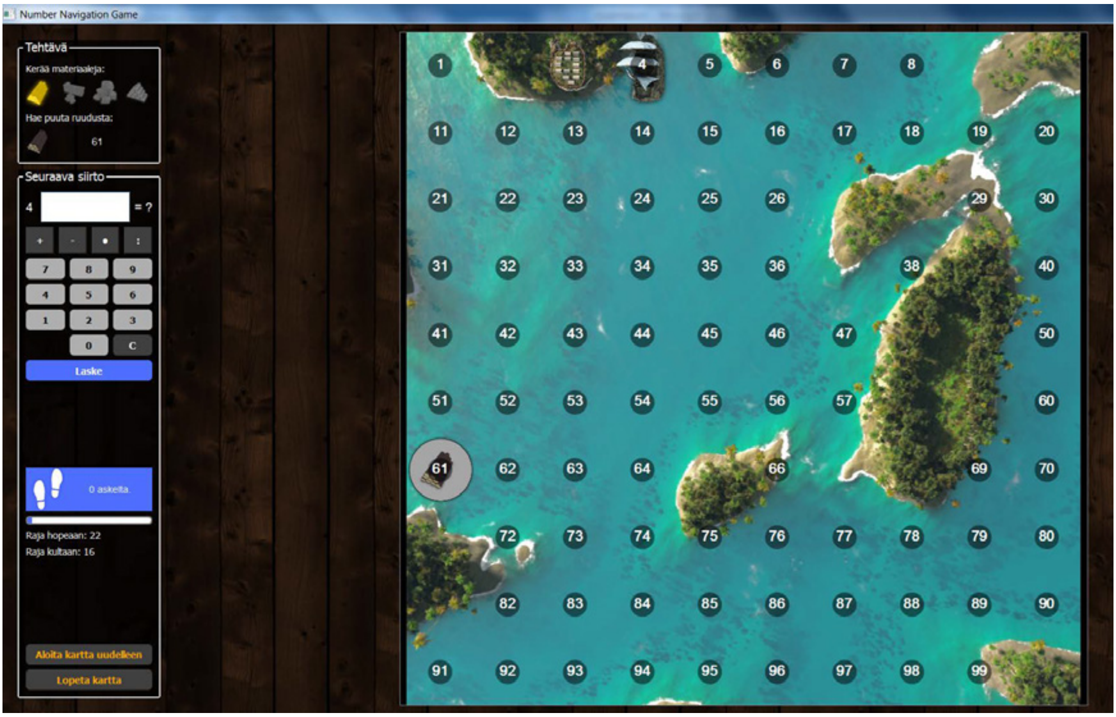


Figure 1. A screenshot of the Number Navigation Game.

Sixty-four tasks or "maps" are distributed over four levels. Each one of these levels is more challenging than the previous one. Within a level, maps can be played in any order. Maps correspond to an archipelago laid over a grid of numbers representing a hundred square. Distinct key number-based locations are marked on each map: a harbor, which is each map's fixed start/end point, and four different locations where "materials" will pop up sequentially. Players control a ship and must navigate, collecting materials dispersed throughout the archipelago in order to build settlements. Players move the ship from one numeric location to another by completing equations using a number pad. The solution to these equations determines the ship's next position. So, for instance, if a player is located at number 1, and wishes to reach material that has appeared at target number 10, the player could enter "(1) + 9" or "(1) x 10."

Figure 1 shows an example of a map from the first level of the NNG. The harbor is found at number 4 and the player needs to retrieve material that has appeared at target number 61. The number pad is found on the left-side menu bar and reads "4☐=?". By inputting +57 into the box and clicking "laske" or calculate, the equation now reads 4 + 57 = 61. The ship moves to number 61. Players have now reached the material and must return it to the harbor from their current location, "61☐=?", either by retracing their steps or by choosing a different route back.

The NNG has two scoring modes. The "step mode" requires players to retrieve materials using the least number of steps. In the previous example, supposing a player reverses the operations (61− 57 = 4) in order to return to the harbor, a total of two equations would have been needed to retrieve the material. The equations that are solved are equivalent to "steps." In the second scoring mode, players strive to use small-magnitude numbers (or "energy") to complete the equations. This encourages the usage of multiplication and division as well as the combination of different types of operations. In the example above in which the number entered into the number pad was 57, the material was reached using 57 energy points. In a map using the energy-scoring mode, a player needs to carefully analyze and compare different routes and options in order to minimize the energy used. For instance, if a harbor was placed at number 5 and the target number was 24, a player could complete "5☐=?" by adding 19 (5 + 19 = 24) or by multiplying by five and then subtracting one (5 × 5 = 25, 25 − 1 = 24); the first alternative took 19 energy points and the second one took six energy points altogether. The first alternative is preferable under the step mode, whereas the second alternative is preferable under the energy-scoring mode. Upon completing a map, players are awarded either a bronze, silver, or gold coin. The type of coin depends on a player's performance considering set criteria values: bronze coins are earned for simply completing a map, while gold coins are earned by completing a map using fewer steps or energy than specified.

The NNG has an "intrinsically integrated" design (Habgood & Ainsworth, 2011) in which the core gaming mechanism is directly connected to the educational content of the game. The versions of the game used in this dissertation had relatively few features that could be considered as extrinsically motivating elements: for instance, in-game rewards. It has been argued that games with intrinsic integration are more effective in achieving learning outcomes and also increase motivation (Habgood & Ainsworth, 2011). The game versions used in this dissertation made it possible to examine whether it is the gaming mechanism itself that would be motivating to students. Later game versions of the NNG, which were not used in these studies, include more externally motivating game features (Bui, Hannula-Sormunen, Rodríguez-Aflecht, & Lehtinen, 2018; Jaatinen, 2016).

1.5. Motivational effects of games

Research from multiple meta-analyses on the effectiveness of serious games concludes that they either have not been able to significantly increase motivation when compared to other methods, or that the results have been mixed and contradictory (Connolly et al., 2012; Wouters et al., 2013). Complicating these results is that often the term "motivation" is not very specific and may refer to a wide range of concepts. Connolly and colleagues (2012) report findings on both "affective and motivational outcomes," and include studies examining immersion, pleasure, fun, and positive and negative affect pleasure while playing. Wouters and colleagues (2013) indicate that they took a broad view of motivation, which included concepts such as interest and self-concept, but also enjoyment, engagement, attitude, and self-esteem. Boyle et al. (2016) and Hainey et al. (2016) do not examine motivational outcomes at all, and instead look at "affective outcomes," which include concepts such as flow, engagement, attention, satisfaction, and experience. At a general level, motivation is often looked at from the perspective of which game characteristics are motivating to students (Dondlinger, 2007; Garris et al., 2002; Habgood & Ainsworth, 2011). It also seems that many studies claiming that serious games are motivating actually mean that serious games were found to be more engaging compared to other forms of teaching and that students had positive game experiences (for instance, Papastergiou, 2009; Rosas et al., 2003; Wijers, Jonker, & Kerstens, 2008), rather than them being about the effectiveness of serious games in increasing motivation toward the subject matter.

Looking specifically at the motivational effects of mathematics serious games, and including games intended for various school levels, the results are mixed. Kebritchi and colleagues (2010) compared the motivation of a group playing a serious game of mathematics as part of their mathematics lessons and a control group that continued with their regular mathematics instruction. While no significant differences in post-test motivation were found, interviews with teachers and selected participants revealed that they felt the game to be motivating. Lopez-Morteo and López (2007) found that 70% ($n = 47$) of students answered positively to a question asking whether the use of a serious game motivated them to learn mathematics. There have only been a few studies of serious games in which expectancy-value theory has been utilized, two of which applied the model during the game design stage (Star, Chen, & Dede, 2015; Toprac, 2011). Toprac and colleagues looked at the motivational effectiveness of a science serious game called *Alien Rescue*, though they lacked a control group and only measured motivation at post-test—either by means of an interview of $n = 15$ seventh-grade students (Toprac, 2011) or via a questionnaire filled out by $n = 132$ sixth-grade students (Liu, Horton, Olmanson, & Toprac, 2011). Toprac's (2011) results indicated that the serious game increased the motivation expectancy values of interest and self-efficacy, while responses regarding attainment value, utility, and cost were either missing or neutral; however, the small number of participants in this study needs to be stressed, as well as some confusion amongst participants with the concepts of attainment value and cost. Liu and colleagues (2011) found that gender did not have an effect on motivation and that students enjoyed the play experience. Only one study was found in which motivation was looked at from the perspective of a game's impact on motivation expectancy values toward the subject matter: game-based activities were found not to have an impact on the motivation of $n = 16789$ fifth- to eighth-grade students' expectancy values. Self-efficacy remained stable and there were modest decreases in interest, utility, and attainment value, although the effect sizes were quite small. Individual differences such as gender and ethnicity were found not to play a role in motivation, although grade level had an impact (Star et al., 2015).

Wouters and colleagues (2013) discuss reasons why serious games have not been motivating. First, they speculate on whether the shortcomings of serious games in regard to motivational impact could be due to the way in which these games have been implemented in a formal and compulsory manner in which teachers decide what games will be played, with little student control or autonomy (Islas Sedano, Leendertz, Vinni, Sutinen, & Ellis, 2013; Wouters et al., 2013). Throughout the writing of this dissertation, no research was found exploring this issue, which might perhaps be due to the risk associated in implementing such a study and the challenges of data collection. Some studies focus on the effects on game experiences of playing in different contexts such as home/school (de Grove, Van Looy, Neys, & Jansz, 2011) or home/laboratory (Takatalo, Häkkinen, Kaistinen, & Nyman, 2010), but in both cases, play was compulsory regardless of the location. Second, serious games might not have been able to increase motivation due to issues of game design, which has already been discussed in section 1.1. Finally, the measurement methods might also be a problem, as motivation is often measured post-play through self-report measures that might not accurately convey affective states during gameplay (Wouters et al., 2013). While this is often due to methodological challenges (Chen et al., 2016; Ronimus, Kujala, Tolvanen, & Lyytinen, 2014), motivation or motivational aspects such as situational interest are rarely measured on-task (an exception being Tapola, Jaakkola, & Niemivirta, 2014).

2. AIMS

The previous chapter discussed the emergence of serious games and the assumption that they are able to motivate student learning and increase interest toward subjects such as mathematics, where motivation steadily decreases throughout the years. The results of the literature review are inconclusive. While the topic has been much researched, studies often have some methodological limitations or lack a strong theoretical framework for motivation. Motivation is often measured from the perspective of whether the game was an engaging activity, rather than whether it increased motivation toward the learning content. Many studies also focus on serious games in which the learning content and game mechanics are not integrated, rather than on intrinsic games such as the NNG. Further investigation is needed in order to enrichen our understanding of the motivational effectiveness of serious games, which would allow educational decision-makers to reconsider the criteria they use when selecting a serious game. Therefore, the present dissertation aims to:

a) analyze the effectiveness of a mathematics serious game, focusing on motivation toward mathematics as framed by the expectancy-value model yet also considering some learning outcomes;
b) describe game experiences and their relationship with the effectiveness of the serious game, considering the role of gender and grade level on these experiences;
c) explore the development of situational interest throughout an intervention with a mathematics serious game, identifying different trajectories of situational interest and the role of these trajectories on game performance and post-intervention individual interest;
d) investigate the occurrence of voluntary play and the role of background factors (such as gender and prior mathematics skills and motivation) on voluntary play; examine the effects of voluntary vs compulsory play on game performance, game experiences, and the effectiveness of the serious game

In order to achieve these aims, the present work consists of two empirical, large-scale, clustered, randomized experiments carried out amongst upper primary school students in two different educational contexts: Finland and Mexico. Study I was a large-scale, clustered, randomized intervention study that investigated the effects of a mathematics serious game called the NNG on the motivation of fourth-, fifth-, and sixth-graders in Finland in comparison to traditional textbook-based teaching methods. This study also looked at factors such as grade level, gender, and game experiences. Study II focused on a subgroup of participants from Study I (fifth-grade students) and examined the development of their interest while playing the game. Study III was a quasi-experimental intervention study that looked at the effects of the NNG on the motivation of fifth-graders in Mexico and focused on the role of play context such as whether students played compulsorily as part of their mathematics lessons or whether they played voluntarily at home.

3. METHODS

This section gives an overview of the design and procedure of the experimental studies. The studies were undertaken as part of a larger project, CUMA (PI Erno Lehtinen), examining the effectiveness of a mathematics serious game called the NNG. Study I took place in Finland and consisted of an intervention study with an experimental design, and it included both pre- and post-test measures. Study II drew from the participants of Study I and included on-task measures as well as a further post-test. Study III took place in Mexico and had a quasi-experimental design.

3.1. Instrument

The NNG software was contained on a memory stick. Based on informal feedback from Study I's participants, some changes were made to the design of the game, and so a new version was used for Study II. The changes mostly concerned the clarity and usability of the interface. For instance, the second version more clearly highlighted the game mode (steps or energy). Also in the first version of the game, progress was saved upon completing a task/map, so if a student ran out of time and did not complete the map, they needed to start all over the next time they played; the second version saved their progress more frequently, making it possible for students to continue playing a map where they had left off (a detailed description of the way in which the versions differ can be found in Lehtinen et al., 2015). Study III also used the second version of the game, which was, furthermore, translated from Finnish into Spanish.

3.2. Participants

Figure 2 shows a summary of the participants in Studies I and II. The participants in Study I were 1168 (*n* = 546 girls, *n* = 2 missing data) students from 61 classrooms spread across four cities in Finland. Schools were located in both urban and rural zones and participants were representative of the country's typical distribution of socioeconomic backgrounds. Participation was voluntary both for teachers and students. Informed consent was acquired in writing from the parents of all participating students. Students belonged to three different grade levels, fourth grade (*n* = 135; M_{age} = 10 years, 2½ months), fifth grade (*n* = 606; M_{age} = 11 years, 2½ months), or sixth grade (*n* = 427; M_{age} = 12 years, 3 months). Classes were randomly assigned into either Phase I (*n* = 642) or Phase II (*n* = 526). Phase I played the NNG for a ten-week period as part of their regular mathematics lessons, while Phase II continued with a traditional textbook-based mathematics curriculum. Afterwards, conditions were reversed, so even though originally Phase II served as a control group for Phase I, eventually they too played the NNG, albeit only for a six-week period.

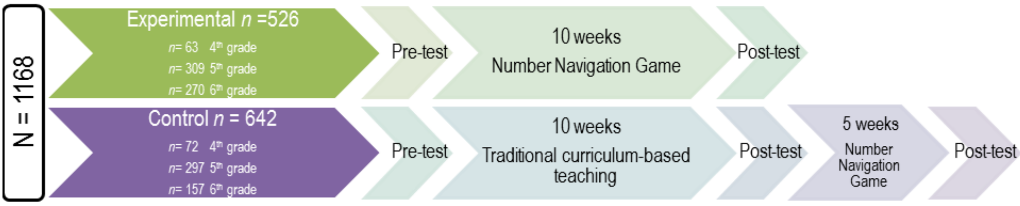
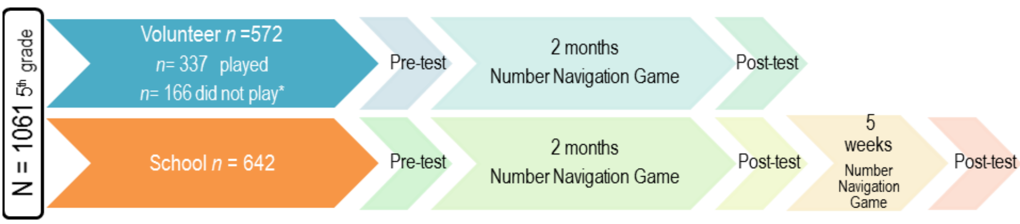


Figure 2. Design and Participants of Studies I and II.

Study II participants were drawn from Phase II, because the game version played in Phase II collected data for on-task measurements of situational interest. The participants consisted of 212 fifth-graders (n = 91 girls; M_{age} = 11 years, 2 months) who played the NNG individually and completed at least one map; participants came from 12 classrooms located in three cities in southern Finland. Fifth-graders were chosen as a sample because results from Study I made it clear that younger students enjoyed the game more than the older students did; fifth-grade students were chosen rather than fourth-grade students due to the number of participants required for the statistical analyses that needed to be carried out.

The participants of Study III were 1061 fifth-grade students (n = 508 girls; M_{age} = 10.13 years, SD = 0.41) from the state of Nuevo León in northeastern Mexico. The schools were located in both urban and rural zones and the participants had middle-class backgrounds. The students came from 53 classes and 39 different schools. Participation was voluntary both at the class level and the individual level, and all participants had written consent from their parents. The students were randomly assigned by class into either the volunteer group (n = 579; n = 278 girls; n = 32 classes) or the school group (n = 482; n = 230 girls; n = 21 classes). During a time period of almost two months (M = 61.38 days, SD = 5.90 days), the school group played the NNG as part of their regular mathematics classes, while the volunteer group received the game to play as much as they desired in their free time. Figure 3 shows a summary of participants in Study III.



*Students in this category had no log data and stated that they did not play.

Figure 3. Design and Participants of Study III.

The Finnish and Mexican educational contexts are so different that direct comparisons are not possible and were not intended. In 2015, Finland's mean PISA score in mathematics was 511 points, higher than the OECD average (490 points), while at 408 points, Mexico was significantly below average (OECD, 2018). Mexico's low performance in mathematics made it an ideal candidate for the implementation of the NNG.

3.3. Measures

The different measures used in the studies presented in this dissertation can be seen in Table I. The present section describes these measures in more detail.

Table 1. List of the different measures used in Studies I–III.

	Study I	Study II	Study III
Motivation			
interest (mathematics)	X	X	X
utility (mathematics)	X		
attainment value (mathematics)	X		
self-efficacy (mathematics)	X		X
situational interest		X	
interest (gaming)			X
self-efficacy (gaming)			X
Game Experience			
competence	X		X
challenge	X		
flow	X		
sensory and imaginative immersion	X		
negative affect	X		
positive affect	X		X
tension	X		
belief in the positive value of the game	X		X
Game Performance			
total playtime			X
tasks completed			X
tasks incomplete			X
total amount of gold coins		X	X
proportion of maps completed with top score			X
Learning Outcomes			
arithmetic fluency	X		X
adaptive number knowledge			X

3.3.1. Motivation

To measure the participants’ motivation toward mathematics, Berger and Karabenick’s (2011) 14-item questionnaire was used. The questionnaire is based on the expectancy-value theory of motivation, measuring interest, self-efficacy, attainment value, utility, and cost (Wigfield & Eccles, 2002). Participants respond to items using a 5-point Likert-scale ranging from 1 (*completely disagree*) to 5 (*completely agree*), with the mid-scale of 3 being neutral. Items were translated into Finnish (Studies I and II) and Spanish (Study III) and adapted to the ages of respondents. Additionally, for Study III, some items were adapted to separately measure motivation (interest and self-efficacy) toward gaming.

For Study II, individual interest was measured using the “interest” subscale of the motivation questionnaire. Situational interest was framed as liking or enjoying an activity and was measured on-task while students played the NNG. Every time a map was completed, the students were prompted to rate their level of agreement with the statement “I like this game” with options ranging from 1 (*completely disagree*) to 5 (*completely agree*). Only one item was used to avoid interrupting the students’ engagement, which is not without precedent (Ronimus et al., 2014). Responses were recorded in the game log data files, which were copied after the intervention.

3.3.2. Game experience

Poels and colleagues (2010) developed the game experience questionnaire (GEQ), deriving it from their 7-dimension framework of game experience. Items consist of a statement and a 1–5 scale for respondents to indicate to what extent the statement applies to them: 1 (*not at all*), 2 (*very little*), 3 (*a bit*), 4 (*quite a lot*), or 5 (*extremely*). For Study I, Finnish translations developed by Oksanen (2013) were used, while Spanish translations were developed specifically for Study III. Originally, the GEQ was used for adult participants. Consequently, the GEQ was shortened in consideration of the participants’ young ages by removing 15 of the 42 items. The remaining items were adapted to suit the NNG and to simplify the language for the young participants. As the benefit derived from game-based learning has been said to depend on the users’ belief in the positive value of these types of games (Whitton, 2010), three self-developed items measuring the students’ belief in the game’s positive value (“I have gotten better at math after playing”) were added.

3.3.3. Game performance

As students played the NNG, game log data files recorded variables related to their performance. These variables were posteriorly analyzed post-play and include: a) total playtime; b) the number of complete and incomplete maps; and c) the total amount of gold coins, which are earned upon completing a task with a top score. In addition to these variables, the proportion of tasks completed with the top score was calculated by dividing the total amount of gold coins by the total amount of maps completed.

3.3.4. Learning outcomes

In Studies I and III, the students' arithmetic fluency served as an indicator of their arithmetic skill development. It was measured through a timed paper-and-pencil test adapted from the Math Fluency sub-test of the Woodcock–Johnson Tests of Achievement (Woodcock, McGrew, & Mather, 2001). The students had three minutes to answer as many simple arithmetic problems as they could. The students' score of total correct answers (0–160) was used as a variable. For Study III, ANK was measured before and after the intervention using the ANK Task, a timed paper-and-pencil test developed specifically for this purpose (Brezvoszky et al., 2015; McMullen et al., 2016). The students had 1.5 minutes to create valid equations using four to five given numbers and the four basic arithmetic operations in such a way that the solution to their equations was equal to a target number. The ANK variable used in Study III was the sum score of a) the total number of mathematically correct solutions that followed the instructions and b) the total number of solutions that, in addition to being correct and following the instructions, used at least two different arithmetic operations.

3.4. Procedure

The data for Studies I and II were collected in spring 2014 at three measurement points: early February, mid-April, and mid-May. The participants were randomly sorted into groups by class, as described in section 3.2. Before the first measurement point, there was a session for all participating teachers in which the NNG, its learning aims, and its game mechanics were presented. The teachers had a lot of freedom during the implementation, and could decide how to space play sessions, how to support students, and whether students would play individually or in pairs. It was requested that the students would play the game for at least 10 hours in sessions lasting no less than 30 minutes each to allow the students to make significant in-game progress. Mathematics pre- and post-tests were administered during regular class periods by trained testers following standardized procedures. The tests had strict timing and a strict structure. Pre-questionnaires that included demographic items were imparted before the students were introduced to the game. Both the pre- and post-questionnaires were imparted by participating teachers during regular class time and they consisted of items measuring expectancy values. In addition, the post-questionnaires included the GEQ.

Study III took place in spring 2015 in Mexico. The data were collected at two measurement points: mid-January and mid-March. Participants were randomly assigned into groups by class (section 3.2.). The participating teachers received a printed guide that included information on the NNG's learning aims, game mechanics, and pedagogical information. The pedagogical information consisted of tips on how to introduce the game to students, provide support during game play, and how to debrief students. The teachers also received a link to an online Spanish-language tutorial video. They also received a document with information on the research project, the game's mechanics and objectives, and a FAQ section; the teachers were free to distribute this material amongst their students. As in Studies I and II in Finland, the initial measurements took place before the students were introduced to the game, and post-test measurements were taken after the intervention. Again, the tests were administered by trained testers following the same timed and standardized procedures as for the previous studies.

Ethical guidelines of the University of Turku were followed in all studies. Participation was voluntary at school, class, and student level. Students who chose not to participate in the data collection were still able to play the game as part of their class activities. Informed consent was acquired in writing from the parents or guardians of all participants. All students involved received access to the game.

3.5. Statistical analysis

Table 2 shows the different statistical analyses that were used in the studies described in this dissertation. With the exception of growth mixture modeling (GMM) and the multinomial logistic regression analyses, which were carried out on M*plus* 7.0 (Muthén & Muthén, 2012), all other analyses were carried out in SPSS (version 22).

Table 2. Statistical analyses used in Studies I–III.

Statistical Analysis	Study	Purpose
Principal component analysis	I	Explore the math motivation questionnaire and the GEQ
Factor analysis	I	Explore the math motivation questionnaire and the GEQ
Cronbach's alpha	I, II, III	Estimate reliability of measures
Composite reliability	III	Estimate reliability of measures
Split-half reliability	II	Test the homogeneity of situational interest ratings during the sessions

Variance components analysis	II, III	Determine the need for multilevel analyses due to nested data
Descriptive statistics	I, II, III	Describe different aspects of the data
Chi-square test	III	Find the association between gender and voluntary play
Independent sample *t*-test	I	Explore differences in game experiences (by gender)
One-way ANOVA	I	Explore differences in game experiences (by grade level)
ANCOVA	III	Compare pre-test mathematical skills and motivation of students who played and those who did not, while controlling for gender effects
		Compare game performance and game experiences of students in the volunteer group who played and those in the school group, while controlling for gender effects
		Compare post-test mathematical skills and motivation between volunteers who played, volunteers who did not play, and the school group, controlling for gender and using the corresponding values at pre-test as co-variates
Repeated measures ANOVA	I	Compare motivational effects by condition
	II	Compare individual interest by situational interest class membership
Growth mixture modeling	II	Model different growth trajectories of situational interest development
Linear regression model	I	Explore predictors of post-test expectancy values
Multinomial logistic regression	II	Predict the odds ratio of a student being assigned to one situational interest class rather than another one based on pre-test math interest

Principal component analyses and *factor analyses* were run (Study I) to determine the underlying factors of students' mathematics motivation and game experiences.

Cronbach's alpha was used to estimate the internal consistency and reliability of the items in the questionnaires (Studies I–III); in Study III, these were further complemented with analyses of composite reliability. Study II used *split-half reliabilities* to test the homogeneity of students' self-reported situational interest ratings during the play sessions.

Variance component analyses were run for Studies II and III. These were necessary due to the nested nature of the data, but intraclass correlation coefficients (ICCs) showed that multilevel analyses were unnecessary (Kline, 2011).

Descriptive statistics such as frequencies, means, standard deviations, and correlations were used to describe the data in all three studies.

Analyses of variance. In Study I, independent sample *t*-tests were run to examine differences in game experiences by gender, while one-way ANOVAs were used to explore these same differences but by grade level. In Study I, repeated measures ANOVAs were also used to look at differences in the motivation expectancy values and arithmetic fluency between the control and experimental group across two time points. For Study II, repeated measures ANOVAs exploring the differences in individual interest by situational interest membership and time were carried out. Finally, for Study III, a chi-square test of association was carried out to explore the association between gender and playing voluntarily at home. Multiple ANCOVAs were used in Study III to compare a) pre-test motivation and the mathematical skills of students in the volunteer group who played and did not play, b) game performance and experiences of students in the volunteer group who played and students in the school group, and c) post-test mathematical skills and motivation between students in the school group and students in the volunteer group who both played and did not play. In all cases, gender was controlled for, and in the ANCOVAs for post-test mathematical skills and motivation, the corresponding values at pre-test were also controlled for. In Studies I–III, post hoc comparisons were carried out when necessary to examine specific differences between the groups.

A *latent growth model*, that is, the growth mixture model analysis (GMM), was used in Study II to model different growth trajectories in students' situational interest development. This type of modeling flexibly groups participants and estimates the probability for an individual to belong to a class and each class's mean growth curves and growth factor variance (Kreuter & Muthén, 2008; Muthén, 2003; Muthén & Muthén, 2000). A maximum likelihood robust (MLR) estimator was employed. The number of classes was decided using the actual fit to the data and substantive theory, as well as statistical indicators such as log likelihood values, Akaike information criteria (AIC), Bayesian information criteria (BIC), entropy, class proportions, and average latent class posterior probabilities (Kreuter & Muthén, 2008).

Linear regression analyses were used in Studies I and II. In Study I, a linear regression model was used to predict post-test expectancy values using the corresponding values at pre-test and game experiences as predictors. In Study II, multinomial logistic regression analyses were carried out on M*plus* by first creating a pre-test math interest factor out of the three pre-test math interest items, then including this pre-test math interest factor as a predictor variable by using the auxiliary function R3STEP on the original GMM in M*plus* (Asparouhov & Muthén, 2014). The results showed the odds ratio of a student being assigned to one class rather than another one based on their pre-test math interest. The mean values of pre-test math interest for each of the classes were calculated using the auxiliary function BCH on M*plus* and were weighted by the accuracy of the classification or the posterior probabilities of being in a particular class.

4. OVERVIEW OF THE EMPIRICAL STUDIES

4.1. Study I

Rodríguez-Aflecht, G., Brezovszky, B., Pongsakdi, N., Jaakkola, T., Hannula-Sormunen, M. M., McMullen, J., & Lehtinen, E. (2015). Number Navigation Game (NNG): Experience and motivational effects. In J. Torbeyns, E. Lehtinen, & J. Elen (Eds.), *Describing and studying domain-specific serious games* (pp. 171–189). New York, NY: Springer.

This article reports on findings of a large-scale intervention study carried out with fourth- to sixth-grade students (N = 1168) in 61 classrooms spread across three schools in Finland. The students were randomly assigned by class to either the Phase I (n = 642) or Phase II (n = 526) groups. Classes belonging to Phase II served as a control group and they continued with their traditional textbook-based mathematics lessons during a ten-week period, while the experimental group, consisting of Phase I classes, played the NNG as an integral part of their mathematics lessons. The aims of this study were two-fold: First, to investigate the effects of the intervention with the NNG on both students' arithmetic fluency and motivation toward mathematics. Arithmetic fluency served as a proximal indicator of the NNG's mathematical impact. Motivation was measured using the expectancy-value model. The second aim was to measure students' game experiences in order to explore whether these were related to any changes in motivation or arithmetic fluency.

The results revealed that motivation remained largely stable. The motivational aspects of the attainment value and self-efficacy slightly decreased from pre- to post-test for all participants. Additionally, the experimental group showed small decreases in the motivational aspects of interest, utility, and attainment value compared to the control group. Arithmetic fluency significantly increased at post-test for both groups and there was a small positive intervention effect for students in the experimental group. The students' game experiences varied by gender and grade level and were not strong predictive variables for post-test arithmetic fluency. The game experience of competence was, however, a significant predictor of post-test motivational scores.

Slight decreases in motivation are in line with previous research (Berger & Karabenick, 2011; Wigfield & Cambria, 2010) and the intervention effects on expectancy values were quite small, supporting previous research that a game dynamic does not automatically increase interest toward a topic (Whitton, 2010). However, the slightly positive intervention effect on arithmetic fluency indicated that the game is effective in improving mathematical learning outcomes, regardless of game experiences.

4.2. Study II

Rodríguez-Aflecht, G., Jaakkola, T., Pongsakdi, N., Hannula-Sormunen, M., Brezovszky, B., & Lehtinen, E. (2018). The development of situational interest during a digital mathematics game. *Journal of Computer Assisted Learning*, *34*(3), 259–268. doi:10.1111/jcal.12239

This article reports on a subsample of participants from Study I, *n* = 212 fifth-graders belonging to Phase II who played the NNG during a six-week period. The interest items from Study I were used as measures of "individual interest." The measures of "situated interest" were captured on-task within and across five play sessions. The version of the NNG played in Phase II electronically recorded self-reported situational interest on game log data files as students progressed throughout the game. This made an analysis on the development of student interest possible. The aim of this study was to map the development of distinct trajectories in situational interest using GMM, and to explore its relationship with individual math interest. This is especially important considering game-based learning is presumed to be able to promote student interest.

The model fit results revealed a three-class model of situational interest. The situational interest of students in in the *High* class (*n* = 125 or 58% of participants) was triggered at the first session and was sustained throughout the intervention; conversely, students belonging to the *Low* class (*n* = 57 or 15.9%) did not have their situational interest triggered at any point. Students in the *Triggered not maintained* class (*n* = 30 or 26.1%) showed an initial high situational interest that steadily decreased. Class membership affected performance within the game, with students in the *High* class scoring significantly more gold coins than students in the *Triggered not maintained* class did. Pre-test individual interest influenced situational interest class membership, which, in turn, had an effect on post-test individual interest. Students in the *Triggered not maintained* class showed a marked decrease in individual math interest from pre- to post-test.

While the NNG successfully triggered situational interest in most students, the different classes—based on the development of situational interest—support the idea that game-based learning is not intrinsically motivating. Pre-existing individual math interest plays an important role in subsequent situational interest in a gaming situation. Triggering but not maintaining situational interest leads to a decrease in individual interest toward the subject. For this reason, with game-based learning, it is important to carefully select games with proven learning outcomes.

4.3. Study III

Rodríguez-Aflecht, G., Hannula-Sormunen, M. M., McMullen, J., Jaakola, T., & Lehtinen, E. (2017). Voluntary vs. compulsory playing contexts: Motivational, cognitive, and game experience effects. *Simulation & Gaming*, *48*(1), 36–55. doi:10.1177/1046878116673679

It has been argued that there is a lack of student control and autonomy when game-based learning is implemented in organized learning environments, which may be detrimental to student motivation (Islas Sedano et al., 2013). Study III thus investigated whether student game experiences, game performance, and cognitive and motivational outcomes differed by play context, with students either playing the NNG as part of their mathematics lessons or voluntarily in their free time. Additionally, another aim was to find out to what extent students played the NNG voluntarily when faced with the opportunity, and how students who chose to play differed from those who did not by gender and pre-test mathematical skills and motivation. The participants in this study (N = 1051) were fifth-grade students in Mexico and they were sorted by class into different play contexts: the voluntary group (*n* = 579) and the school group (*n* = 482).

The results revealed that students who played voluntarily (*n* = 337) had higher ANK compared to students from the volunteer group who did not play. ANK refers to one's ability to recognize and use pre-existing knowledge of numerical characteristics and relations (McMullen et al., 2016). Also, amongst the voluntary group, students who played had higher math interest at pre-test compared to students who did not play, but these two groups did not differ by gaming interest. This seems to suggest that interest toward the subject matter is more important than interest toward games when it comes to students' willingness to play voluntarily. However, the role of other factors such as the students' socioeconomic conditions and technological access needs to be explored in the future. Students in the volunteer group who did not play had lower post-test scores on gaming interest, gaming self-efficacy, and math self-efficacy, but their interest toward math did not change.

Regardless of the context, playing had an overall positive effect on mathematical skills. In addition, students from the volunteer group who chose to play had a significant increase in advanced mathematical skills or ANK when compared to students belonging to the school group. The students in the school group, on the other hand, played for longer, completed more mathematical tasks in the game, and reported more enjoyment from playing the game at post-test than students in the volunteer group who played did. As in Studies I and II, motivation remains largely stable, and it seems that giving more control to students in terms of their gaming context does not result in motivational improvements.

5. GENERAL DISCUSSION

The first aim of this dissertation was to analyze the effectiveness of a mathematical serious game called the NNG in enhancing mathematics motivation in terms of expectancy values. Some indicators of arithmetic development were also measured in order to explore the game's learning impact on mathematics. Game experiences and their impact on the effectiveness of the game were measured, and attention was paid to the importance of factors such as gender and grade level on game experiences. Another aim was to examine how student interest toward mathematics developed throughout the intervention, identifying trajectories of situational interest and the role of these trajectories on game performance and individual interest. Finally, the play context such as voluntary or compulsory play was examined in order to find out whether it has an effect on game performance, game experiences, and motivational and learning effectiveness. The factors influencing voluntary play were studied. To achieve these goals, two large-scale empirical experiments were carried out in Finland and Mexico. In this section, the main findings will be presented, as well as the implications of these results, limitations of the studies, and ideas for further research.

5.1. Main findings

The results, when looking at the general level for both Finland and Mexico, indicate that the serious game applied in this study was not able to increase student motivation toward mathematics when it was measured via the expectancy-value approach. The expectancy values of self-efficacy, interest, attainment value, and utility remained mostly stable. Amongst the participants in Study I, both at pre- and post-test, the expectancy values of interest, attainment value, and self-efficacy were rated in a mostly neutral way, while utility was rated more highly. Interest and self-efficacy amongst the participants in Study III were quite high at both measurement points. The game's motivational impact was not influenced by gender or grade level. The results fall in line with the growing number of high-quality empirical studies indicating that serious games are not able to produce more meaningful or long-term effects on student motivation when compared to other instructional methods (Star et al., 2015; Wouters et al., 2013). In fact, amongst Study I students, there was a very small decrease in the motivation expectancy values for the experimental group; nevertheless, overall decreases in expectancy values within and across academic years are well documented (Berger & Karabenick, 2011; Wigfield & Cambria, 2010). In all three studies, however, playing the game resulted in positive effects on students' learning outcomes, both in arithmetic fluency and ANK. In Study III, playing the NNG resulted in improved arithmetic fluency, regardless of whether students played at school or voluntarily at home. Furthermore, students who played voluntarily at home also showed an improvement in ANK when compared to students who played in schools. The positive effects of the NNG on basic and higher order mathematics learning have also been reported elsewhere (Brezovszky et al., 2015, 2018). The NNG's positive effects on learning, but not on motivation, are in line with the results of Wouters and colleagues' (2013) meta-analysis.

Overall, the Study I participants did not rate their game experiences (challenge, competence, flow, immersion, negative affect, positive affect, positive value, tension) very highly, with most students rating their experiences as neutral or below neutral. The most highly rated experiences were those of competence and negative affect, indicating that participants might have perceived either the game mechanics or the learning content as too simple. The lowest game experience was immersion, which suggests improvements in game design are needed. Nevertheless, these experiences did not seem to play a role in motivation either, with pre-test motivation being the strongest predictive marker for post-test motivation. Game experiences also varied by grade level: Sixth-grade students were less likely to report feelings of immersion compared to fifth-graders and saw less benefit in playing the game than fourth-graders did. Fourth-graders had lower scores for negative affect than both the fifth- and sixth-graders did. While this gives the impression that younger students had more positive game experiences than older students did, there were fewer participants in the fourth grade. Younger students might also have been less able to self-evaluate and reflect on their experiences. Study III focused on the game experiences of positive value, positive affect, and competence. Comparisons between the two countries are not possible because the samples were not nationally representative; however, the participants in Study III rated their experiences in a more positive way than the participants in Study I did.

As for the role of gender and grade level on game experiences, boys reported higher feelings of competence when they played, and girls reported higher feelings of challenge. It is unclear if this reflects gender differences in perceptions of mathematics or gaming skills, although it has been reported that boys have higher competence beliefs than girls do for math even when controlling for skill level (Wigfield & Eccles, 2002). Although competence was the one game experience that somewhat predicted post-test motivation expectancy values, it is possible that students interpreted questions related to competence as referring to their math competence (which would overlap with the math self-efficacy construct) instead of their gaming competence, as was intended by the measure. In any case, the pre-test expectancy values played a larger role in predicting post-test expectancy values than game experiences did and did not predict post-test arithmetic achievement. While this seems to indicate that experiences while playing the game do not really play a role in motivational or learning outcomes, it is possible that more enjoyable game experiences could have an effect.

Despite the findings regarding the stability of motivation, when looking more closely at one of its aspects, interest, it seems that attention must be paid to students' individual trajectories. When looking specifically at Finnish fifth-grade students, it becomes clear that the game is able to spark the interest of most—though not all—students, and in that sense, it is a successful new learning activity. High prior interest toward mathematics predicts situational interest during gameplay. This raises the question of whether prior interest toward the subject matter may arouse situational interest in an equal or larger measure than the game itself. In those cases in which situational interest is triggered but not maintained, there are negative repercussions on individual interest toward the subject matter, as the individual mathematics interest of these students shows a strong decrease even when compared to students whose interest was never triggered by the game at all. This suggests that unmet expectations about an activity may negatively influence individual interest and this is evidence of the relationship between situational and individual interest. At the moment it seems that the NNG benefits students who are already interested in the subject matter to begin with; this is in line with the finding that students' intensive and successful gameplay predict the positive learning outcomes of the NNG (Brezovszky et al., 2018). Speaking about adult learners, Whitton (2010) had argued that unlike children, a game mechanic would not automatically make something interesting to learners who had no interest in the subject itself. The results seem to indicate that adults may not be the only group of players who need to be interested in the subject matter in order to benefit from serious games, although more research with different types of serious games is needed, as this is only based on findings with the NNG.

Regarding the final aim, on the occurrence of voluntary play, the fact that over half of the students who received the game to play voluntarily at home were curious enough and willing to give it a chance and play at least once is further evidence of the game's ability to trigger student interest. The most prominent reason given for not playing the game was a lack of technological access at home. It could have been assumed that students who play digital games for entertainment would be more likely to play serious games voluntarily at home; the results indicate that it is instead interest toward the serious game's subject matter, here mathematics, which influences the students' decision to play or not. Students who were interested in mathematics and had higher advanced mathematical skills were more likely to play. Within the volunteer group, students who played had higher post-test advanced arithmetic skills compared to those who had the chance to play but did not. The students who chose not to play also had lower post-test scores on gaming interest, math self-efficacy, and gaming self-efficacy compared to students who played voluntarily. It is likely that these students' unwillingness or inability to play made them reconsider their views, although at least their mathematics interest did not change. While some gender differences were found, these were related to digital gaming rather than to learning outcomes or motivation. In Mexico, boys had higher post-test interest toward digital games and self-efficacy when playing digital games.

As to the differences by play context, playing the NNG at school resulted in higher feelings of the game experience of positive affect than when playing voluntarily at home. Perhaps the students playing at school were comparing the gaming activity to their regular mathematics class lessons, whereas the students playing at home compared the game to other leisure activities such as commercial games for entertainment? This could also explain why the game was played for longer in schools. The students in the school group had a higher number of incomplete tasks, but also a higher proportion of tasks completed with the top score. This could be due to the fixed playing times of the school group: Students might have been forced to interrupt their play mid-task when lessons ended. However, it must be emphasized that further information on the implementation of these games is needed. This would provide a better idea of how the game was introduced to the students, what kinds of support and scaffolding the teachers offered, how was it framed by related activities or content, etc. As mentioned at the start of this section, the play context had a positive effect on mathematical learning outcomes, with playing (either at school or voluntarily) resulting in higher mathematics skills than when not playing. There was no effect of condition on mathematics interest or self-efficacy, although students in the volunteer group who did not play had lower post-test interest and self-efficacy toward gaming.

5.2. Theoretical implications

The present studies have implications for the assumptions and beliefs on the effectiveness of serious games. Regarding motivation, there is a widely-held belief that serious games are able to motivate student learning (Beavis et al., 2014; Egenfeldt-Nielsen, 2011; Hanghøj & Brund, 2011; Klemetti et al., 2009; Wastiau et al., 2009; Williamson, 2009). This work provides further evidence that serious games are not able to significantly increase student motivation toward the learning content (Connolly et al., 2012; Wouters et al., 2013). While it has been argued that one reason serious games may have thus far proven unsuccessful at motivating students is that they are used in formal and structured school environments in which students have little control and autonomy (Islas Sedano et al., 2013; Wouters et al., 2013). Free and voluntary play did not account for a change in mathematics motivation expectancy values. Rather, voluntary play seems to be a symptom rather than a cause of increased mathematical interest. There are some encouraging and positive results, however: When carefully selected and implemented, serious games are able to produce learning outcomes. The NNG's success in enhancing arithmetic skills provides further evidence that serious games may present an effective and novel learning tool that allows students to practice content in ways that are not easy or even possible through traditional learning methods.

The results indicate that serious games might be successful in triggering situational interest, but efforts should be made to discover how to maintain this situational interest. This is especially important, as it seems that large and sudden drops in situational interest may have a negative impact on individual interest toward the learning content. This could be related to game design, which has been argued to be an important reason why serious games have failed to be motivating (Egenfeldt-Nielsen, 2007; Kirriemuir & McFarlane, 2004; Squire, 2011; van Eck, 2006). While game experiences did not seem to play a role in general motivation, including student individual interest, they might nevertheless influence situational interest. The students did not rate their game experiences very positively, so it remains to be seen whether improvements in game design and game features would have repercussions on motivation and situational interest.

5.3. Practical implications

The present study provides some practical implications for the implementation of serious games. First, teachers and decision-makers should have realistic expectations as to what benefits these games offer. The students' motivation expectancy values were largely stable and their self-reported game experience ratings were quite low. When looking at individual differences in student interest toward mathematics, it seems that when serious games are brought into the classroom, the students who most benefit are those who are already interested in the subject matter itself. Based on these results, games should indeed be integrated into current teaching practices, but these games should be chosen with great care based on their impact on learning outcomes rather than because they are perceived to be motivating activities or are able to increase motivation toward the learning content. Second, the students playing at school had higher positive affect and played the game for longer than students playing voluntarily at home did; furthermore, technological access at home cannot be guaranteed in many educational contexts. Therefore, it is recommended that serious games should primarily be used in schools, and that if they are made available to students for voluntary play, efforts should first be made to ensure all students have sufficient access. From a design perspective, it is important to continue developing the NNG. It is a challenge to design serious games, as we need to ensure that the first prototypes are effective at producing learning outcomes in order to warrant further development. A delicate balance is required, as game features need to be engaging yet not distract from the content.

5.4. Limitations and future studies

Some limitations may impact the conclusions that can be drawn from the studies presented in this dissertation. First, these studies focused specifically on the NNG. Generalizations cannot be made about all serious games based on these results. It would be important to explore the effectiveness of different types of serious games and find out whether the results achieved with the NNG could be due to either specific features of this game or to its particular type of mathematical content. Thus, a serious game with the aim of strengthening understanding of rational numbers is under development by the creators of the NNG. Also, the NNG continues to be developed. Since the studies in this dissertation were carried out, a new version of the game with new and improved features has been designed. Future studies could focus on the effect of these game features on the game's effectiveness in terms of both learning outcomes and mathematics motivation expectancy values.

Second, there are some methodological limitations. The questionnaires contributed data that are subjective and self-reported. While it has been used in other studies and was piloted before the interventions, some items in the GEQ were perhaps ambiguous for the students, as it is not clear whether they answered regarding, for instance, their feelings of competence with the game mechanics or with the subject content in mind. While it was very useful to have an on-task measure of situational interest, this was only one item (which is not without precedent, see Ronimus et al., 2014) and was always measured upon completion of a task, which means that particularly demotivated students or students who were struggling to progress within the game may be underrepresented. Although additional items would be disruptive to engagement, in the future, situational interest could be measured at set intervals that are not dependent on in-game progress. Also, some informal feedback from teachers reveals they perceived the implementation of the NNG as a successful activity that was positively able to engage students compared to their regular mathematics lessons. While these kinds of unofficial communications suffer from issues of subjectivity and self-selective bias, in the future, additional methods such as interviews and structured observations could enrichen our understanding of the students' experiences and motivation. Eye-tracking methods could yield important information as to the direction and duration of students' attention while playing. In addition, future studies with the NNG or serious games in general could include additional control groups. These groups could play a different serious game during the intervention period or engage in some other novel teaching activity, IT-based or not. However, the lack of these control groups is not seen as a limitation to the present studies; in light of motivation remaining largely stable, the novelty effect of the activity did not need to be considered in the interpretation of the results.

Finally, while the studies included in this dissertation take place in two different countries, there was no systematic data collection about the countries' differing teaching practices or their educational traditions with serious games. Future studies must especially pay closer attention to the effect of teachers. The roles teachers take when implementing serious games are varied yet crucial (Kangas, Koskinen, & Krokfors, 2017). The intention in the studies presented in this dissertation was to have as naturalistic a setting as possible. This was for practical reasons such as the teachers' self-reported lack of time and energy to become familiarized with new learning material (Klemetti et al., 2009), but also because it has been argued that reducing the role of the teacher helps to better analyze the effectiveness of serious games (All et al., 2016). However, this means that all participating volunteer teachers may have differed in the quantity and quality of debriefing, feedback, support activities, scaffolding interactions, or reflection they offered to students in relation to the game. Even in Study III in which teachers received pedagogical suggestions on how to support their students during gameplay, the extent to which teachers applied these suggestions is unknown. Similarly, the parents of students from the volunteer group were asked not to intervene in their child's willingness or lack of willingness to play the game, but some parents might nevertheless have offered different degrees of encouragement or pressure. A lack of control over the volunteer setting could also mean that the students did not play themselves or that they used a calculator, although their improved mathematical results indicate otherwise.

Despite these limitations, this dissertation offers some insight into the potential affordances of serious games and provides supporting evidence for their use in the classroom for learning outcomes. The present studies have some important strengths such as the large-scale nature of the data, the very different contexts and designs through which the data were measured, and the added value of having undertaken both person- and variable-oriented approaches. As described throughout this section, future studies could: a) focus on serious games with different mathematical content; b) compare different design versions of the NNG; c) incorporate more control groups; d) include additional data-collection methods or improve the existing ones (situational interest); and e) explore the role of teachers.

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