Chasing Newton

Designing and implementing an intrinsically integrated game on Newtonian mechanics

ANNE VAN DER LINDEN

Chasing Newton

Designing and implementing an intrinsically integrated game on Newtonian mechanics

Anne van der Linden

Chasing Newton - Designing and implementing an intrinsically integrated game on Newtonian mechanics; Anne van der Linden – Utrecht: Freudenthal Institute, Faculty of Science, Utrecht University / FI Scientific Library (formerly published as CD-β Scientific Library), no. 121, 2024.

Dissertation Utrecht University. With references. Met een samenvatting in het Nederlands.

ISBN:	978-90-70786-60-1
Keywords:	Educational games; Intrinsic integration; Physics education; Newtonian mechanics; Secondary education
Cover design:	Anne van der Linden
Printed by:	Canon

Chasing Newton

Designing and implementing an intrinsically integrated game on Newtonian mechanics

Newton achterna

Het ontwerpen en implementeren van een intrinsiek geïntegreerde game over Newtoniaanse mechanica

(met een samenvatting in het Nederlands)

Proefschrift

ter verkrijging van de graad van doctor aan de
Universiteit Utrecht
op gezag van de
rector magnificus, prof.dr. H.R.B.M. Kummeling,
ingevolge het besluit van het college voor promoties
in het openbaar te verdedigen op

dinsdag 18 juni 2024 des middags te 12.15 uur

door

Anne van der Linden

geboren op 22 mei 1992
te Soest

Promotor:
Prof. dr. W.R. van Joolingen

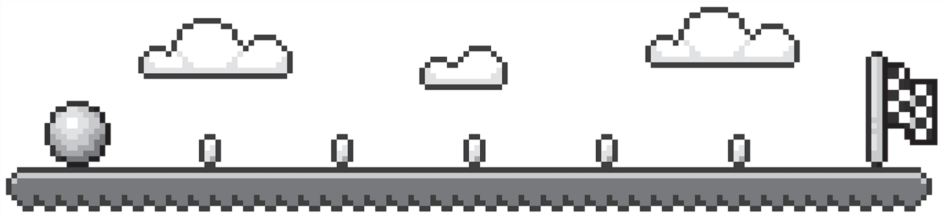
Copromotor:
Dr. ir. R.F.G. Meulenbroeks

Beoordelingscommissie:
Dr. L.M. Doorman
Prof. dr. L. Kester
Dr. A.T. Lehtinen
Prof. dr. J.T. van der Veen
Prof. dr. R.C. Veltkamp

Dit proefschrift werd (mede) mogelijk gemaakt met financiële steun van het Ministerie van Onderwijs, Cultuur en Wetenschap (OCW/PromoDoc/1065001).

Table of contents

Chapter 1 General introduction



1. Introduction

When I was growing up in the 1990's, gaming was a quite popular pastime, in my environment anyway. For example, I fondly remember playing Kirby and Pokémon on my very first gaming platform, the *Game Boy Color*.

Such commercial games make excellent use of the scientific concept of *flow* (as defined by Csíkszentmihályi (1990)) allowing players to be fully immersed in the game, forgetting where they are and what time it is. Players, such as myself, can engage in gaming for some time fully immersed in the task at hand. The idea of using this concept in education is quite natural since students' engagement on formal learning activities in school often leaves much to be desired.

Indeed, apart from playing classic products of the gaming industry, I also remember playing some educational games and enjoying the experience. For instance, I used to play RedCat, a race game to learn calculations, quite a lot and I even used to stay at school after class in grade five to play a point-and-click adventure about unmasking the phantom of the opera.

Since then, the gaming industry has developed; consoles became more powerful and game graphics enhanced. The way people could interact with games also expanded; motion control (for example the Nintendo Wii), augmented reality (AR) games (such as Pokémon GO) and virtual reality (VR) games (for instance the Oculus) were developed. Parallel to that, research focussing on serious games (played for purposes other than primarily entertainment) and educational games (played in a formal education setting) has also increased in the past decades, showing potential benefits for increasing motivation and learning (Bellotti et al., 2013; Clark et al., 2016). I thought, how great would it be to add to this field of research, developing guidelines on how to design and implement an educational game, since it combines my interests of gaming and teaching physics.

2. Digital game based learning

Besides these evident and tantalizing advantages of gaming in terms of motivation and engagement, other benefits of digital game based learning (DGBL) can be imagined, such as adaptivity to student's specific needs, creating a safe environment to practice and make mistakes and offering different approaches for learning (Plass et al., 2015; Greipl et al., 2020). A large review suggests that DGBL on average ($\bar{g} = 0.33$) shows promising results in terms of intrapersonal learning and cognitive learning outcomes, (Clark et al., 2016). However, when studying individual educational games, large variations, especially in learning outcomes exist. For instance, Clark and colleagues (2016) classified educational games into different categories. Effect sizes within the same category of contextualization score, for example, can vary between -0.5 and 2.3. This raises the questions: what is it that makes an educational game foster learning and why are some games better at this than others? However, various studies show that these questions are not easily answered (Clark et al., 2016; Denham, 2016; Ke, 2016; Lameras et al., 2017; Ávila-Pesántez et al., 2017; Czauderna & Guardiola, 2019; Zeng et al., 2020), there seems to be no clear, single path to designing an effective educational game. This thesis aims to add to the body of knowledge on the characteristics of educational games that make them effective, knowing that no easy fix exists. This requires the design of a theoretical guiding frame as well as the study of a carefully developed game design in practice (Greipl et al., 2020; Tsai & Tsai, 2020).

3. Intrinsic integration

In the last decades, a concept called intrinsic integration emerged used in the theoretical background of educational games. Intrinsic integration is defined as the integration of subject matter (learning) with gameplay (Kafai, 1996). Although literature on this topic, unfortunately, is not consistent in its use of terminology, some consensus can be found in the idea that the learning effects of DGBL can be increased by ensuring that learning and gameplay are integrated during the design prosses of an educational game (Habgood & Ainsworth, 2011; Denham, 2016; Ke, 2016; Vandercruysse & Elen, 2017). Turning these insights into a practical game can, however, be a quite challenging task (Vandercruysse & Elen, 2017; Czauderna & Guardiola, 2019; Walkington, 2021), since the alignment between subject matter and gameplay is not a natural one. The easiest way to develop an educational game is by not integrating learning and gameplay; using an existing game and adding some learning elements into it. For instance, having players solving some equations before proceeding to the next level. This however disrupts the state of flow, which is exactly what we want to use to keep the players engaged. Habgood and Ainsworth (2011) provided evidence for this statement by studying the effects of different versions of the same educational game (Zombie Division). An intrinsic version (defeating skeletons by dividing them into whole parts) and an extrinsic version (defeating skeletons by selecting the appropriate weapon and providing an end-of-level mathematical quiz) were compared. The results show that with fixed time limits, students learned more from the intrinsic version and with no time limits, students also played the intrinsic version seven times longer.

For this thesis we wanted to further expand on the idea of intrinsic integration. There is evidence supporting an intrinsic approach for designing educational games, however the design of such a game is quite a challenge. For this thesis we accepted this challenge and wanted to take it one step further by finding some directives for designing an intrinsically integrated game, so that it is hopefully less of a challenge for other aspiring developers. Therefore, the aim of our research project was to develop some guidelines on how to design and implement an intrinsically integrated game.

In any digital game, the player tries to reach a *game goal* by interacting through *game mechanics*, such as walking, jumping over obstacles, trading with other players, or collecting coins. Analogously, in a learning activity, students are stimulated to reach a *learning goal* by using the *pedagogical approach* (chosen by the teacher or educational developer). Based on this apparent analogy, we proposed a guiding frame based on aligning the game goal, learning goal, pedagogical approach, and game mechanics, as is shown in Figure 1 (as it basically is the foundation of our design process, this figure will be present in several subsequent chapters). The alignment between the game goal and learning goal is in line with the intrinsic integration theory (Kafai, 1996). We hypothesize that the alignment of a pedagogical approach and game mechanics are essential in optimizing the alignment of the game goal and learning goal.

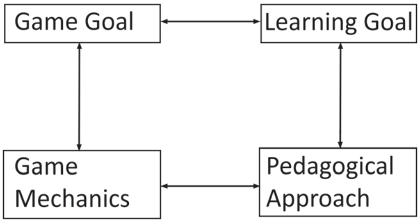


Figure 1. Guiding frame on alignment between the game goal, learning goal, pedagogical approach and game mechanics.

4. Newton's Race

In order to do so, we wanted to start with formulating design criteria for designing a digital educational game. Starting with a -at the time- relatively recent, large meta-analysis by Clark and colleagues (2016), we had to conclude that it was impossible to make general claims about which game design elements (e.g., narrative, game rewards, and player collaboration) are effective and which are not. For instance, in some cases digital educational games with a lot of narrative have been shown to yield positive learning effects, whereas and in other cases they do not. There appear to be too many variables and differences in the body of literature to make general claims about design criteria. Most studies present a game and report learning outcomes and motivational effects of that game as a whole. Subsequently you can look at all those studies, such as for example Clark and colleagues (2016) did, and report on different design elements that were in the games. This however does not mean that using such a game element will be guaranteed to lead to an education game that fosters learning.

We therefore opted for a case-based approach to examine the design process of a game and the associated lesson plan in depth. As is the case for any educational activity, the educational game design process starts with a learning goal in mind, from which design choices follow. In our case we started with a learning goal about Newtonian mechanics, a key part of every secondary school physics curriculum. Newtonian mechanics is the part of physics that says something about the relationship between forces and motion of objects. Based on their day-to-day experiences with ubiquitous moving objects, such as bikes, cars, balls, etc., students enter the classroom with many preconceptions formed during those experiences. In order for students to alter these preconceptions and accept scientific explanations, those preconceptions need to be addressed specifically (Vosniadou, 1994; Duit & Treagust, 2003; Schumacher et al., 2016). In order to achieve this, what better way is there than to let students actually experience the consequences of their own preconceptions? Unfortunately (or fortunately, depending on your point of view), when conducting an experiment, the experiment always follows the rules of physics. Resulting in the need of a digital environment, such as a game, where this pedagogical approach is aligned with its game mechanics. Thus, the idea of Newton's Race was born: a game where players can adjust the forces working on a ball, resulting in different types of movement. But here's the kick: a player should only be able to finish a trajectory (the game goal) if the ball makes a realistic movement (the learning goal), thus ensuring intrinsic integration.

5. Transfer

By using an educational game as a standalone intervention, players can reach a learning goal within the specific game context, by reaching the game goal. However, one of the goals of science education is, that students gradually become able to apply the learned conceptual knowledge outside of the initial (in this case: game) context. In other words, students should be able to transfer their conceptual knowledge from the game context to other scenarios. In the case of Newton's Race, the game context is a rolling ball on a trajectory. In transfer, students should also be able to apply the newly aquired knowledge to other situations, such as moving a box or riding a bike. In order to foster transfer, additional learning activities are usually required (Wouters et al., 2013).

Generally, students' ability to transfer knowledge from one situation to another depends on their understanding of the underlying principles and concepts. A possible way to achieve transfer is by abstraction and finding connections (Perkins & Salomon, 1994). Transfer is then fostered when students are able to construct a general abstract representation and apply this representation to other situations (Rebello et al., 2007).

For Newton's Race, this means that in-game learning about forces and motion need to be taken to a more abstract level and connections with other scenarios (i.e., not presented in the game itself) need to be made explicit. This led to embedding Newton's Race into other educational activities.

The above considerations led to the overarching research question of this dissertation:

> *How can a digital intrinsically integrated game be designed and implemented in a lesson fostering conceptual knowledge and transfer regarding Newtonian mechanics?*

6. Research outline

The research question consists of two parts; first an intrinsically integrated game needs to be designed and tested, before it can be implemented in a lesson. Chapters 2 and 3 focus on game design and learning from Newton's Race as a standalone intervention. Chapters 4 and 5 focus on how to implement Newton's Race in a lesson.

In **Chapter 2** we describe the above guiding frame (Fig 1.) based on the principles of intrinsic integration. We used that frame for the first version of Newton's Race that was subsequently piloted. We present the step by step design process of Newton's Race in search of overarching design guidelines. This chapter therefore answers the following research question:

RQ 1: How can an educational game be designed where learning is integrated with the game mechanics?

A part of the results of Chapter 2 showed some issues regarding design elements in the game. For the next study we addressed those issues and improved Newton's Race. The pilot provided some general information on motivation and learning outcomes. However, to gain insight on how players interacted with and learned from the game, some recording of gameplay was needed. In **Chapter 3** we used a mixed-methods approach to examine how players played Newton's Race and how that results in possible learning and transfer effects. Newton's Race was played by 223 children in a Dutch science museum to answer the following research questions:

RQ2.1: To what extent does participants' conceptual understanding of Newtonian mechanics change as a consequence of playing the game?

RQ2.2: To what extent does the acquired knowledge transfer to different situations that are not closely related to the game?

RQ2.3: To what extent does the participants' gameplay demonstrate evidence of intrinsic integration?

From the results of Chapter 3, a further improved version of Newton's Race was made and we concluded that it was time to implement Newton's Race in a lesson to further strengthen comprehension and transfer. A lesson was designed based on the findings Chapter 2, Chapter 3 and several other studies (Perkins & Salomon, 1994; Rebello et al., 2007; Long & Aleven, 2014; Wouters et al., 2013; Choi et al., 2017; Tokarieva et al., 2018). This lesson was evaluated in small groups of students. In **Chapter 4** we present the results of this study. Using a mixed-methods approach, the following research question is answered:

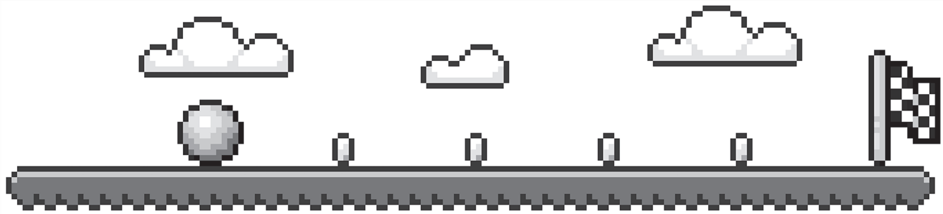
RQ3: What is the impact on learning outcomes in terms of conceptual understanding and transfer of embedding an educational game in a lesson?

Results of Chapter 4 provides insight on learning during a lesson in small groups of students. This, however, is not a realistic classroom situation, where many students are present. To study a realistic classroom situations, the lesson plan needed to be altered. Using the results of Chapter 4, we explored two different ways of embedding Newton's Race in larger groups. In **Chapter 5** we present and evaluate these lesson plans in an actual classroom situation.

RQ4: How do different means of embedding an intrinsically integrated game in a realistic classroom situation affect students' conceptual development and transfer?

In **Chapter 6** we discuss the overall conclusions and implications of this research project.

Chapter 2 Designing an intrinsically integrated educational game on Newtonian mechanics



This chapter is based on:

Van der Linden, A., Van Joolingen, W. R., & Meulenbroeks, R. F. G. (2019). Designing an intrinsically integrated educational game on Newtonian mechanics. *International Conference on Games and Learning Alliance*, *11385*, 123–133. https://doi.org/10.1007/978-3-030-11548-7_12

Abstract

In the current paper we present the design process of an intrinsically integrated educational game on Newtonian mechanics. The design is based on a guiding frame in line with the intrinsic integration theory, which states that in a game, learning goal and game goal should be aligned. This also results in an alignment between a pedagogical approach and game mechanics. Our findings suggest three guidelines within this guiding frame. First, the guiding frame works in a specific order starting with forming a learning goal and ending with the game goal. Also, to optimize the alignment between the learning goal and the game goal, it should only be possible for players to reach the game goal when the desired learning goal is reached. Finally, during the iterations of the design process the focus is on aligning the pedagogical approach with the game mechanics. This proved to be an essential but difficult step.

Keywords

Educational game, Intrinsic integration, Newtonian mechanics

1. Introduction

When we look at a person who is gaming, we see a person fully immersed to master the game. Mastering the game means learning how to play the game. This learning occurs whilst the player, fully immersed in the gaming experience, loses the sense of time and surroundings, resulting in a state of flow (Csíkszentmihályi, 1990). This learning in a state of total immersion is in sharp contrast with the commonly observed lack of engagement in formal education. So, could it be possible to use this immersed learning that occurs whilst playing a game in formal education?

In the past decades, research focusing on using educational games has increased (Clark et al., 2016). Research focusing on motivational effects show that educational games sometimes show an increase in intrinsic motivation of students as compared to participating in other instructional activities. However, a meta-analysis (Wouters et al., 2013) shows that educational games in general do not yield positive motivational effects on students. Research focusing on cognitive effects of educational games, on the other hand, show promising results in general (Ke, 2008; Clark et al., 2016). However, the results of individual educational games remain inconsistent. This leads to the question why some educational games yield learning effects and others do not. Of course there could be many factors contributing to the absence or presence of a learning effect. In this paper we investigate the influence of the game design itself.

Several studies have been devoted to gain insight on the design process and different design elements of an educational game (Clark et al., 2016; Denham, 2016; Ke, 2016; Lameras et al., 2017). Although this research has led to some interesting insights, much of how to design a good educational game remains unclear.

In the present study we aim to elucidate some design principles by describing the design process of an educational game on Newtonian mechanics. In our analysis of the step by step design process, we search for overarching design guidelines that can be transferred to the design process of other educational games.

The next section presents the theoretical substantiation of the designed educational game, which leads to the research question. Subsequently, the research question will be addressed in a case study that will describe the design process of the game.

2. Theoretical substantiation

2.1 Educational game goals

Every game has a game goal, for instance, freeing a princess, collecting stars or simply surviving. To reach the game goal, players interact with the game through game mechanics and game attributes. Sicart (2008) defines game mechanics as ‘methods invoked by agents, designed for interaction with the game state’. Examples of game mechanics are jumping, trading and climbing. Game mechanics thus describe an interaction between the player and the game. Game attributes are visualizations of game properties, such as stamina. For instance, a player is only able to climb a wall with enough stamina. In this case the player needs a visualization of their stamina, in a meter for instance, in order to make a decision to continue climbing. Game attributes and game mechanics are strongly connected and essential in reaching the game goal.

In an educational activity, students need to reach a certain learning goal. This means that if a game is to be used as an educational activity, it should always have two goals. So apart from the game goal, the learning goal of an educational game is that players need to learn something of value outside the game context. Within the game context players learn in order to master the game, whereas an educational game aims at learning for a broader context.

2.2 Intrinsic integration

When designing an educational game, most educators or educational researchers tend to focus on the educational aspects of the game, making sure that the educational content is all there (Van Eck, 2006). Then an educator usually adds game properties (such as adding points or a narrative) to make the game more engaging. This approach, however, can easily lead to a discrepancy between learning goal and the game goal. This could result in an unsuccessful educational game (Denham, 2016). To make this discrepancy as small as possible, the additional educational learning should be integrated with the learning that occurs anyway whilst playing a game, the learning of how to play the game.

This integration of educational learning with the game mechanics is referred to as intrinsic integration. Intrinsic integration in a game is thus defined as subject matter and game mechanics being integrated within the same game idea (Kafai, 1996). Several studies focused on integrating learning content with game environments (Habgood & Ainsworth, 2011; Denham, 2016; Ke, 2016; Vandercruysse & Ellen, 2017). However, it proves to be quite challenging to integrate learning with game mechanics white not affecting the enjoyability of games (Vandercruysse & Ellen, 2017).

2.3 Pedagogical approach

Any educational activity requires an underlying pedagogical approach. A pedagogical approach describes the steps that are seen as important in achieving the learning goal of the game. This means that the game mechanics should be designed in such a way that students will perform thinking activities relevant for learning. For instance, the game mechanics may be such that a real-life situation is mimicked, or that some kind of planning is required that has relevance for the learning goal.

The aim of the current paper is to investigate the way intrinsic integration can be reached, by aligning game goal and learning goal as well as game mechanics and pedagogical approach. We did this in the context of designing a game for learning elementary Newtonian mechanics.

2.4 Research question and hypothesis

The main research question in this paper is: *How can an educational game be designed where learning is integrated with the game mechanics?*

Our hypothesis on designing an intrinsically integrated game is shown in Fig. 1. To optimize the learning effect of an educational game, it is important to align the learning goal with the game goal. Only if the desired learning goal is reached should it be possible for players to reach the game goal. This alignment is in line with the intrinsic integration theory (Kafai, 1996). To optimize this effect, we propose an additional alignment between a pedagogical approach and game mechanics.

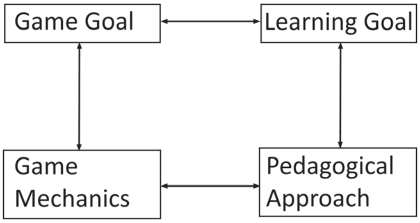


Figure 1. Guiding frame on alignment between the game goal, learning goal, pedagogical approach and game mechanics.

3. Design process: Newton's Race

3.1 Concretize the hypothesis

The design process followed the basic hypothesized elements. First the hypothesis was made concrete by instantiating the learning goal, pedagogical approach, game mechanics and game goal. The results lead to an initial design that was tested on a small scale in two iterations leading to several modifications. The final design was pilot tested on a group of 73 9th grade students, using a pre- and post-test quasi-experimental design.

Learning goal. The guiding frame (Fig. 1) is used from an educators point of view. As with designing any learning activity, we started with determining the subject matter and thus establishing the learning goal. The subject of Newton's laws was chosen not only because of their importance in the secondary school curriculum but also because the persistence of student's preconceptions resulting in conceptual challenges (Halloun & Hestenes, 1985). In the present research, we define preconceptions as pre-existing ideas based on daily life experiences. One of the conceptual challenges within Newton's laws is that force is proportional with acceleration, not with speed (Driver et al, 1994). This means that an object can move without working forces on it and if there is a net force working on an object the object is not just in motion, it is accelerating (or decelerating). The learning goal that matches with this conceptual challenge is that students can understand the effect of forces on different motions. This implies that students can predict motions with given forces and that they can explain the effects of forces when given a certain motion .

Pedagogical approach. Research has shown that in the case of force and motion, student's preconceptions are quite persistent (Halloun & Hestenes, 1985). Therefore the need to face students with their preconceptions is essential (Vosniadou, 1994; Duit & Treagust, 2003; Schumacher et al., 2016). This lead to the choice for the problem posing approach as the pedagogical foundation. In the problem posing approach situations are created in which preconceptions are no longer adequate explanations (Klaassen, 1995). The key element of this approach is that students put their preconceptions into the learning activity and experience the effects of those preconceptions. When they are confronted with something that counters their expectations, ideally, they should see the need for new theories to alter their preconceptions.

However, in our real world, students are not able to test all preconceptions, because our world provides a single case in which parameters of the general physical theories, such as friction, are fixed. The advantage of a digital environment is that the effects of students actions can be simulated with high precision, including movements without friction. In this case, students should be able to alter forces working on an object resulting in different motions.

Game mechanics. A brainstorm session resulted in two possible genres for our game: puzzle and race. For the problem posing approach, it is important that players truly experience the consequences of their ideas and concepts. Therefore, the game mechanics should provide a so-called setting phase where players can incorporate their own ideas. Therefore, the game mechanic of setting a force on an object is needed. Then players need to experience the effects of their choice, thus a design is needed were players can clearly see the effects of those forces on the motion of the chosen object. Therefore, a race-like environment seemed fitting with our chosen pedagogical approach. Some other game mechanics that fit with a race game are: navigating through levels and steering.

Game goal. Traditionally, the goal of a race game is to reach the end of a level as soon as possible. However, that would not fit our chosen learning goal, as the mimicking of a realistic, rather than a fast, movement is paramount. A more fitting game goal then would be to just finish a trajectory. To truly show effects of forces, a non-motorized object, a ball, was chosen for students to complete the trajectory with. A ball is a very familiar object that everybody knows. Thus, players will have experiences with possible motions a ball can make (after one kick, the ball will start to move, followed by a decrease in speed). A conflict with this expectation should occur when players select an scientifically incorrect setting in the setting phase. Ideally, this conflict results in failure to reach the end and this should prompt alteration of their preconception to scientific reasoning. This means that the learning goal of understanding the effects of forces resulting in different motions should be reached. Players then should select the scientifically correct setting and only then are able to finish the trajectory.

3.2 Initial game design and playtesting

In order to seek balance between students' skills and the challenges of the game and thus trying to reach the desired state of flow (Csíkszentmihályi, 1990) eight levels of increasing difficulty were included to the game. Each level consists of a different trajectory, starting with easier levels (no friction, straight path) building op to levels with turns, multiple surfaces (different frictions) and green and red platforms where the ball receives additional kicks respectively in the direction of motion or against the direction of motion. For each level the same game goal applies (get the ball to the finish line).

In the setting phase at the beginning of each level players decide if there is a constant force ($F_{constant}$) working on the ball to keep it moving after receiving an initial kick. They can set a value for that force by using a scrollbar. Whenever the ball receives a kick, a pow-icon is shown (see Fig. 2), so that students could see how and where a force is working on the ball. If a scientifically incorrect setting is chosen, the speed of the ball will be too high in turns of the trajectory. Therefore, the ball will fall off and that the game goal cannot be reached.

To strengthen players' experience of motions resulting from their preconceptions, it is important that the kind of motion (acceleration, deceleration, constant speed) of the ball is clearly visible. To make sure players could see the type of motion, several game attributes were added. As shown in Fig. 3, an accelerometer, speedometer and a tail proportional with speed were added to the game.

In order to complete trajectories, players need to be able to change the balls direction. This action must be scientifically correct. Therefore, players can give the ball a sideways kick (using arrow keys), perpendicular to the direction of motion.

To make the game more interactive and add some competition, the challenge of collecting coins was added. The coins were placed in such a way that the trajectory should become more difficult. For instance, coins were placed at harder to reach places, such as the inside of turns. Also, as conventional in race games, an overview map was added for players to anticipate on the trajectory.

In summary, the game design consists of two game mechanics within each level: setting a force and changing direction of the ball. The first mechanic is essential for the alignment with the pedagogical approach. To strengthen the effect of the pedagogical approach, game attributes were added to make the kind of motion visible. The second mechanic is needed to reach the game goal, since there are turns in the trajectories. In addition to the turns, collecting coins and green and red platforms were added to provide challenge for the players.

At this point a demo version (four levels) of the game was tested. Note that with every iteration bugs were eliminated, the game's interface was optimized and difficulty adjustments were made to optimize flow. Only results regarding the game's content will be discussed. This playtest showed a problem with the introductory texts in the setting phase of each level. Due to the length of the texts players were reluctant to read it or did not read it at all, resulting in not knowing what to do in a level.

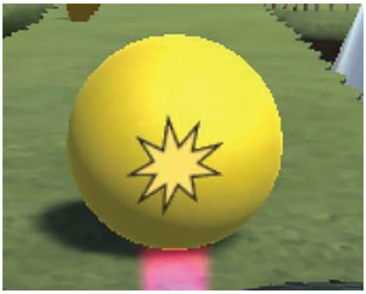


Figure. 2. The pow-icon when the ball receives a kick

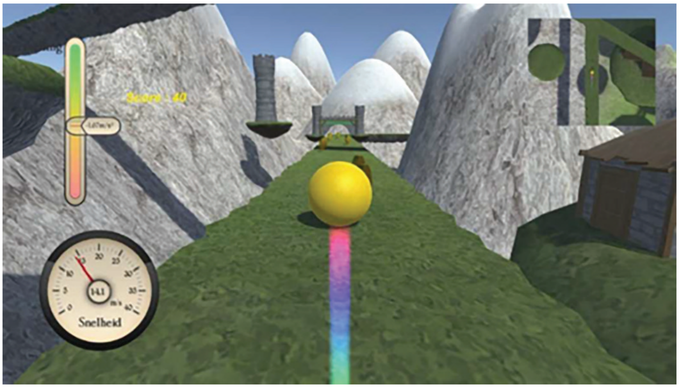


Figure 3. A snapshot of level 3 with the setting: $F_{constant}$ = 0N. In the upper left corner, the accelerometer is visible, the speedometer in the down left corner and the tail is visible behind the ball. The overview map is visible in the upper right corner.

3.3 First version

For the next version of the game (eight levels) the introductory texts were adjusted so that they only contained important information regarding completing a level. This version was tested with thirty 10th grade students, aged between 15 and 16.

Results showed three issues with the game. First, none of the players could finish level eight. In this level students were also able to set a value for the mass of the ball. This extra setting provided players with too many options, making the level too difficult. A mass adjustment was not essential to our learning goal, therefore this level was deleted for the following version of the game.

Second, there were doubts as to if students saw the difference between a motion with $F_{constant}$ (acceleration or constant speed, depending on the value of friction) and without $F_{constant}$ (deceleration). In the next version students played the level twice, once with each setting. A fitting adjustment would be playing the same level twice, with these different settings.

Finally, most importantly, it appeared to be unclear for the players that by using the arrow keys to change the balls direction of motion, a small force was exerted on the ball. This indicates a discrepancy between the pedagogical approach and game mechanics. For the pedagogical approach it is necessary that students understand that they need to exert a force on the ball in order to change its direction. To make this more explicit, giving the ball a force needs to be visible. In an attempt to show this, another pow-icon was added whenever the arrow keys are used change the ball's direction, shown in Fig. 4. With this added icon students are more likely to link changes in direction due to a kick, instead of an internal steering system, as is traditional in a racing game.

Figure 4. The pow-icon when the ball receives a sideways kick.

3.4 Pilot

The three adjustments were implemented for the pilot study. A quasi-experimental pre and post-test design was used to evaluate the latest version on learning and motivational effects. The game was tested in three groups (73 9th grade students in total). The control group followed a traditional lesson, the game group only played the game and the test group played the game followed by a classroom discussion. The duration of the experiment in all groups was one lesson of 40 minutes including a pre- and post-test.

Results of the pilot showed a significant motivational effect between the two groups who played the game and the control group. All groups did not yield a learning effect. However, the game group scored significantly lower on the post-test than the other two groups. The complete results of the pilot study go beyond the scope of the present paper, these results are elaborated on elsewhere (Van der Linden et al., 2016).

However, during the pilot we also found four important issues regarding the design of the game:

1. The learning goal and the game goal are not sufficiently aligned. More experienced gamers (with other games) could finish certain levels without the scientifically correct setting, thus reaching the game goal. This probably means that these players did not reach the desired learning goal.

2. Also, an issue was found with the alignment of the pedagogical approach and the game mechanics. When a ball receives a sideways kick, the ball makes a parabolic movement. This does not become clear in the game. This is probably due to the fact that the trajectory is quite small, therefore there is no room for players to see the parabolic movement. Also players still associate a change of the ball's direction with internal steering, not with acting forces. This indicates that a more clear game attribute is needed to visualize acting forces.

3. As mentioned above, students who only played the game scored significantly lower than students who played the game followed by a classroom discussion. This indicates the importance of embedding the educational game in other learning activities.

4. Players did not read texts, resulting in not understanding what to do in the setting phase of the game.

The effects of the four issues on the game design and the relation with our hypothesis will be elaborated on in the next section.

4. Discussion and conclusion

4.1 Design process

Our research question was: *How can an educational game be designed where learning is integrated with the game mechanics*?

A guiding frame was presented (Fig. 1) fitting with the intrinsic integration theory. Then we designed a game by concretizing this guiding frame. During this design process we found three main guidelines fitting with the guiding frame. Firstly, we used the guiding frame in a specific order. From an educators' point of view, any design process starts with forming a learning goal (step 1) and then finding a fitting pedagogical approach (step 2). Then we chose a suitable game genre from game mechanics that strengthened the pedagogical approach (step 3). From these game mechanics followed a game goal (step 4). The main implication is that in order to reach goal alignment, alignment of the game mechanics with the pedagogical approach is essential.

Secondly, to truly align the learning goal to the game goal, it is necessary that the game goal depends on the learning goal. This means that players must reach the learning goal before as a necessity for reaching the game goal. Results of the pilot study show that this is not trivial at all. Experienced gamers are able to finish a level without the scientifically correct setting ($F_{constant}$ = 0N), whereas less experienced gamers have difficulties finishing a level even with the correct setting. To make the discrepancy as small as possible, the scrollbar in the setting phase could be changed to a setting system with less options. Then it will not be possible for experienced players to set a small $F_{constant}$ close to 0N and thus are not able to finish a level with a small constant force.

Finally, we also found that aligning the pedagogical approach with the game mechanics was the most essential and difficult step. Therefore, this alignment was the focus during the iterations. In our case a big challenge is the visualization of movement and forces. With the learning goal on the relationship between forces and motion, it is important that players understand when forces are working on the ball and what type of movement (acceleration, deceleration or constant speed) the ball makes. Despite our efforts during the pilot study, we found that the added sideways pow-icons for instance, still did not reach the desired effect of understanding that a force is acting. Another challenge lies in the setting phase. Setting $F_{constant}$ is an essential game mechanic in order for our pedagogical approach to work. However, with players reluctance of reading text in the setting phase, this game mechanic is not optimally used. Even with the reduced text in the pilot study, a trial and error approach is opted by most players.

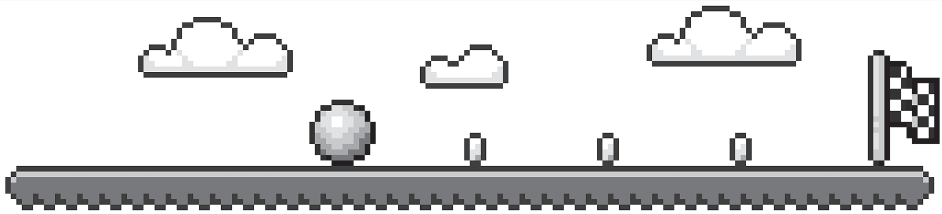
To our knowledge, few educational games are made with a specific focus on the alignment of game mechanics with a pedagogical approach. However, a clear pedagogical approach is needed to reach any learning goal. Therefore, we recommend giving this alignment explicit attention during the design process. All this applies to integrating the pedagogical approach within the game. In addition, with our hypothesis (Fig. 1) in mind the pedagogical approach can also be (partly) offered *outside* the game in additional learning activities. In this case the game should align with the other learning activities, thus alignment between game mechanics and a pedagogical approach is still necessary.

4.2 Further research

Newton' s Race is an educational game still in development. The game can be improved by adjusting mentioned issues. However, additional information is needed on how players interpret and use the game attributes (such as the accelerometer and speedometer) in order to improve the game further. In addition, research is needed on the influence of objects exerting forces on the ball to improve the visualization of acting forces.

Also, if Newton's Race is going to be used in educational practice, additional learning activities are needed. In line with Wouters and colleague's (2013) we found that embedding the game in other learning activities is necessary for students to reach the learning goal. However, it remains unclear what additional learning activities that should be. Research is needed to suggest possible effective additional learning activities.

Chapter 3 Learning Newtonian mechanics with an intrinsically integrated educational game



This chapter is based on:

Van der Linden, A., *Meulenbroeks*, R. F. G., & Van Joolingen, W. R. (2024). Learning Newtonian mechanics with an intrinsically integrated educational game. *Journal of Computer Assisted Learning*. http://doi.org/10.1111/jcal.12966

Abstract

Background: Research on cognitive effects of educational games in general shows promising results. However, there are large variations in learning outcomes between individual educational games. Research on the design process and different design elements of educational games has led to some interesting directions, but some design aspects remain unclear.

Objectives: We examined how an educational game designed on the basis of intrinsic integration theory, based on a strong alignment between game and learning goals, supports the learning of Newtonian mechanics.

Methods: This study applied a mixed-methods approach (N=223). A pre- and post-test design was used to examine possible learning and transfer effects fostered by playing the educational game, Newton's Race. To examine how players played the game, log data for each player were digitally recorded during gameplay.

Results and Conclusions: Our findings demonstrated a significant positive learning effect of Newton's Race (p = .003, d = .201). This can be explained through the acquired log data. Log data show that players' gameplay mostly matched expected learning during the game, with physically correct game settings occurring more and more as gameplay progressed. The ability to transfer learned knowledge to other situations was shown to be limited to situations closely resembling the game environment.

Implications: Similarly designed intrinsically integrated games on different (physics) subjects could also foster learning in a relative short time. To foster transfer to other situations we propose embedding the game within other instructional activities.

Key words

Educational games; Intrinsic integration; Newtonian mechanics; Secondary education.

1. Introduction

The potential benefits of using digital games for education (i.e., educational games) have not gone unnoticed by educational researchers (Tsai & Tsai, 2020; Lei et al., 2022). The benefits of using an educational game are mainly focused around the concept of flow (Csíkszentmihályi, 1990). In commercial games, this flow is evident in the player being fully immersed in the game, forgetting where they are and what time it is. As a result, when players are faced with a game-related problem they want to readily find the solution to continue the gameplay and keep the sense of flow. For educators, this apparent problem-solving attitude on the game level has sparked much research in the past decades (Schöbel et al., 2021; Ekin et al., 2023). An educational application of a digital game environment can be specifically interesting for some domains, such as physics. While hands-on, traditional physics experiments are bound to the actual laws of physics, a digital application allows for physical parameters to deviate from the set parameters on this earth. This creates new learning opportunities as the consequences of these deviating parameters become evident in the digital environment. Educational games are of course not the only way to use the digital domain for learning. Effective learning has been shown to occur in a variety of different (digital) learning activities, such as PhET simulations (online research-based science simulations), the use of model representations, experiments, visual representations, to name a few (Kirstein & Nordmeier, 2007; Wieman et al., 2008). This study focuses on the use of an educational game in the domain of secondary school physics.

2. Literature review

Research on cognitive effects of educational games in general shows promising results (Clark, Tanner-Smith & Killingsworth, 2016). However, vital academic contributions are easily missed by researchers, because the literature is so scattered across different disciplines (de Freitas, 2018). In addition, researchers mainly use self-reported questionnaires. Objective procedural data collection would strengthen the current body of research, such as setting data collection points in the game (Zeng et al., 2020). Also, there are large variations in learning outcomes between individual educational games. This could very well align with the large variations within the design of educational games (Clark et al., 2016; Denham, 2016; Ke, 2016; Lameras et al., 2017; Timotheou et al., 2022). Furthermore, increased interest in methodologies for educational game design (Ávila-Pesántez, Rivera & Alban 2017), is rarely reflected in detailed descriptions on the interaction between gameplay and learning objectives. Therefore, many intricacies of combining learning with gameplay remain obscure (Czauderna & Guardiola, 2019). As Zeng, Parks and Shang (2020) stated, “educational game design still has challenges to balance education and gameplay” (p. 193).

2.1 Intrinsic integration

A possible way to increase the educational benefits of a game may be to integrate the educational content with the gameplay itself (Denham, 2016). This is referred to as intrinsic integration: the subject matter and the game idea are integrated. Intrinsic integration is defined as the integration of educational subject matter and game mechanics within the same game (Kafai, 1996). In an intrinsically integrated game, the game goal is aligned with the learning goal as closely as possible, in the sense that, ideally, reaching the game goal coincides with reaching the learning goal. In practice, this is not easily achieved, however, and several studies detail the difficulties encountered in attempting to integrate learning with gameplay without affecting the enjoyability of the game (Vandercruysse & Elen, 2017; Czauderna & Guardiola, 2019).

In a game, the player interacts with the game environment through *game mechanics*, to reach a game goal. Sicart (2008) accordingly defines game mechanics as 'methods invoked by agents, designed for interaction with the game state'. Examples of game mechanics are jumping over obstacles, trading with other gamers, and climbing structures in the game environment. When designing an *educational game*, however, the game also becomes a learning environment, which requires a design based on a chosen pedagogical approach.

The main tool for integrating a pedagogical approach within a game are the game mechanics. Proper alignment of pedagogical approach and game mechanics might be expected to support the alignment of game goal and learning goal (Van der Linden, van Joolingen, & Meulenbroeks, 2019). This alignment of game goal with learning goal and the alignment of pedagogical approach with game mechanics constitutes the concept of *intrinsic integration*, aligning at both the goal level and the mechanism level.

In this study, we studied both educational benefits of the game and the effect of the implementation strategy. Through the log data on players' actions during gameplay, we evaluate the extent to which the goal of intrinsic integration was reached.

2.2 Implementation of intrinsic integration: Newton's Race

For the purpose of this study, a short description of the implementation of intrinsic integration, with the main focus on the pedagogical approach, is described below. A description of the gameplay of Newton's Race can be found in the materials and methods section of this paper and a more detailed version of the design process can be found here (Van der Linden, van Joolingen, & Meulenbroeks, 2019).

2.2.1 Learning goal

The subject context of Newtonian mechanics has been chosen because the conceptual challenges students encounter within this subject have been well-studied. Newtonian mechanics, or classical mechanics, is the sub-field of physics focusing on forces and motion within everyday scenarios. Within this subject, students' existing ideas based on daily life experiences have been reported to be persistent (Halloun & Hestenes, 1985; Fazio & Battaglia, 2018). One of the more persistent conceptual challenges for students concerns Newton's second law, stating that force is proportional to acceleration (i.e., the increase of velocity per unit of time), not to velocity (Driver, Squires, Rushworth & Wood-Robinson, 1994). This means that an object can move without forces acting on it, aligning with Newton's first law (an object at rest will stay at rest, unless a force acts upon it). If there is a net force (sum of all forces) working on an object it cannot remain in a state of constant velocity. It must necessarily be accelerating or decelerating (i.e., increasing or decreasing its velocity), aligning with Newton's second law. The learning goal that matches with this conceptual challenge is that *by the end of the game, players will be able to ensure required acceleration/deceleration by applying an appropriate net force in realistic everyday scenarios*. This implies that students, after playing the game, should be able to understand the effects of forces on motion.

2.2.2 Pedagogical approach

Pedagogical approaches in general are designed to support students in reaching a learning goal. Before receiving formal instruction in a subject related to daily reality (e.g., Newtonian mechanics), students generally have already gathered much daily experience with this subject (in this case: moving objects). When taught about those movements in a formal educational context, students must somehow integrate these daily experiences within the scientific theory. This integration is particularly difficult in physics education, due to the fact that students build their concepts on their intuition and, indeed, daily experience (Mufit, Asizal & Puspitasari, 2020). Students need to be confronted with the fact that their pre-existing ideas and concepts are insufficient in a more generalized situation or in contexts further removed from everyday life (Vosniadou, 1994; Duit & Treagust, 2003; Schumacher, Hofer, Rubin & Stern 2016). In other words, students need to be confronted with the consequences of their expectations and experience so-called cognitive conflict (Hewson & Hewson, 1984) in order for them to abandon or adjust their naïve theories and accept the new scientific one. Indeed, a recent meta-analysis shows that cognitive conflict is especially effective in better understanding scientific theories in physics education (Mufit, Asizal & Puspitasari, 2020). However, the emergence of cognitive conflict by itself is not sufficient to facilitate learning. Following Piaget's cognitive theory, in order for assimilation (integrating new information within an existing framework) and accommodation (making changes to exciting frameworks in order to integrate new information) to arise, several steps are needed (Piaget, 1976). First, the learner must pay attention (if someone does not pay attention, no learning can occur). Second, the learner must detect a problem (if the learner does not notice a problem, no learning will occur). Thirdly, the learner must care about the problem (if the learner does not care about the problem they are not going to solve it, and thus no learning will occur).

One pedagogical approach that follows the above theory is the so-called problem posing approach (Klaassen, 1995; Vollebregt, 1998; Kortland, 2001). This approach has been shown to produce promising results on several topics in physics, such as radioactivity and an initial particle model. The problem posing approach demonstrates that students should first see the point of what they are doing during the learning process, before accepting the need for new knowledge and new theories (Lijnse & Klaassen, 2004). The key element of this approach is to actually confront students with the *consequences* of their pre-existing ideas. When they are confronted with something that counters their expectations, ideally, students should see the need to alter their own theories and adopt the scientific one. This approach presumes the condition that students will indeed care enough about the problem to be interested in solving it.

In the context of Newtonian mechanics, the confrontation leading to cognitive conflict cannot generally be achieved with experiments in the real word, because we are bound to how forces actually work. For example, when riding a bike with a constant velocity in real life, you always actually need to apply force and a car driving at constant velocity does still consume energy. So, in daily life, moving with a constant velocity without exerting force is not a reality. In a digital world, however, players can freely test their ideas and experience the effects of those ideas. They can then answer the question: Does this correspond to a real life situation?, and adjust their formal ideas accordingly.

2.2.3 Game mechanics

From the problem posing approach, two main concepts arise that must be present in the game. First, players must be able to play around with different force options on an object and, secondly, they must experience the effect of their chosen setting on the object. Thus, in an attempt to align the pedagogical approach with game mechanics, game mechanics are required to allow players to experiment with different force options, letting players experience the effects of these options. The third condition in Piaget's reasoning (caring about the problem) is, ideally, fulfilled by having students engage in enjoyable and challenging gameplay with a specific game goal.

2.2.4 Game goal

As stated before, ideally, the game goal and learning goal are aligned in such a way that one cannot be reached without reaching the other as well. In the game considered here, Newton's Race, players have to finish a trajectory with a ball. Players are able to choose different force options on that ball. However, the trajectory is constructed so that players should only be able to reach the finish line when making a scientifically accurate motion. The resulting game goal then is to finish the last trajectory whilst the ball makes a scientifically accurate motion, meaning that the ball will decelerate when the only applied force is friction. Therefore, the learning goal (by the end of the game, players will be able to understand that (net) force is proportional to acceleration/deceleration in realistic everyday scenarios) is aligned with the game goal.

2.3 Research questions

Studies on previous versions of Newton's Race focused only on the design process and includes a small pilot (Van der Linden & van Joolingen, 2016; Van der Linden, van Joolingen, & Meulenbroeks, 2019). For the current paper, a large scale study was conducted to examine how playing Newton's Race actually supports the learning of Newtonian mechanics. We therefore pose the following research questions:

> *RQ1: To what extent does participants' conceptual understanding of Newtonian mechanics change as a consequence of playing the game?*
>
> *RQ2: To what extent does the acquired knowledge transfer to different situations that are not closely related to the game?*
>
> *RQ3: To what extent does the participants' gameplay demonstrate evidence of intrinsic integration?*

3. Materials and methods

3.1 Newton's Race: gameplay

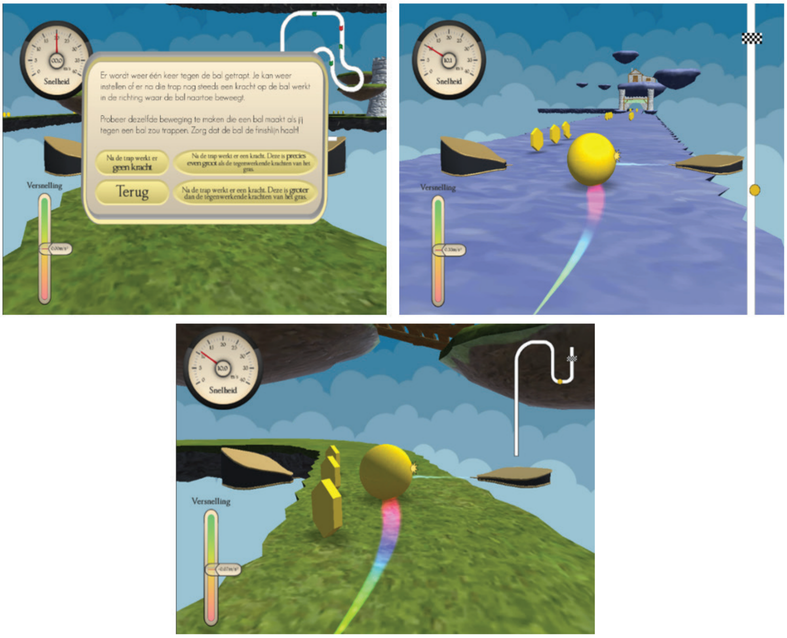
Newton's Race consists of five levels with increasing difficulty. In each level, players need to finish a trajectory with a ball. Levels start with a setting phase where players choose between different force options working on the ball after they kick the ball (see Figure 1). At the start of each level, a ball is kicked once, providing the ball with a fixed initial force, resulting in a short acceleration. After that, players' chosen force option works on the ball as a continuous force for the duration of the trajectory. The unit of force (F) used in the game is Newton (N), equal to 1 kg·m/s^2. In the game, friction is the resistance that the ball encounters whilst moving over the surface of the trajectory, working against the ball's direction of motion (in levels with a trajectory made of ice, friction is assumed to be negligible). Players are then asked to create a realistic motion. The force options are: (a) no force working on the ball in the direction of movement (i.e., F=0N), (b) a force working on the ball equal to the friction of the surface, meaning that the net force on the ball equals zero, because the applied force working on the ball is equal and opposite to the force of friction (F=friction) or (c) a force working on the ball which is bigger than friction (F>friction). After selecting an option, the ball starts moving by a push and the player must guide the ball to the finish line of the trajectory by exerting lateral forces on the ball. Depending on the chosen setting, the ball will: (a) decelerate, (b) move with a constant velocity or (c) accelerate.

Players can explore their pre-existing ideas about forces and motion by choosing different settings. For instance, players may choose setting (c) F>friction. In the game, this results in a ball accelerating without bound on a trajectory after the ball has been kicked once. Ideally, students will recognize that in the real world a ball will not accelerate forever on, e.g., grass, it will decelerate after the initial kick. Players are confronted with something that counters their expectations: they expect a deceleration, but they experience an acceleration. Then, again ideally, they will come to the realization that their current idea does not work and they may start to accept the need for a new theory. They can try different force options, until they find the one that corresponds with a real life situation, option (a). It is, of course, also entirely possible that players use a more trial and error approach in their chosen settings.

Assuming that additional learning steps are met (the player pays attention, cares about the problem and demonstrates their new understanding), players can only detect a problem if they can experience the effects of their chosen setting, therefore it is important that the resulting type of motion (acceleration, deceleration, constant velocity) is properly visualized. A speedometer, accelerometer, and a graphic comic-book like "tail" emanating from the ball and proportionate to the ball's velocity, are added to the game (see Figure 1). In addition, when a force is working on the ball, a star-icon highlights the point of engagement.

Players can change the direction of the ball by applying a force perpendicular to the direction of motion. On the way to the finish line, players can collect coins and accumulate points. The coins are placed in hard to reach places, such as the inside of turns, to make the game more challenging for more experienced gamers.

Levels are constructed in such a way that players should only be able to reach the finish line with the correct scientific setting. With the other settings the velocity of the ball is larger, or even always increasing, making it nearly impossible to get through certain turns in the trajectory. This results in the ball falling off the track and not reaching the finish line. Therefore, the game goal can only be reached with the correct scientific setting. This results in players needing to make a realistic movement with the correct scientific setting. If players do so, the learning goal is reached and only then can they reach the game goal; the game and learning goal are thus aligned.



Er wordt weer één keer tegen de bal getrapt. Je kan weer instellen of er na die trap nog steeds een kracht op de bal werkt in de richting waar de bal naartoe beweegt.

Probeer dezelfde beweging te maken die een bal maakt als jij tegen een bal zou trappen. Zorg dat de bal de finishlijn haalt!

Figure 1. Three screenshots of the game. The setting phase (top left), gameplay of level 1 where there is no friction (top right) and gameplay of level 3 (bottom) with friction.

3.2 Research design

A pre- and post-test design was used to examine possible learning and transfer effects fostered by playing Newton's Race (RQ1 and RQ2). For each player log data were digitally recorded during gameplay to examine gameplay (RQ3). Considering that this study focusses solely on if and how players learned from playing Newton's Race, without trying to make statements on how this learning compares to learning through other teaching methods, no control group was used. In addition to answering the research questions, data on different design elements were collected for recommendations on improving the game's visual interface. Therefore, four different versions of Newton's Race were created for this study, which differed only in visual aspects. An example of the difference in visuals can be found in Figure 2. Players were randomly assigned to one of the versions.

3.3 Participants

Participants were recruited in a science museum in the Netherlands. Children between the ages of 10 and 15 voluntarily participated in this study. Parents provided a written consent at the start of the study. From a total of 223 participants, 117 (52,5%) were boys and 106 (47,5%) were girls. 171 participants (76,7%) were in primary school and 52 participants (23,3%) were in lower secondary education.

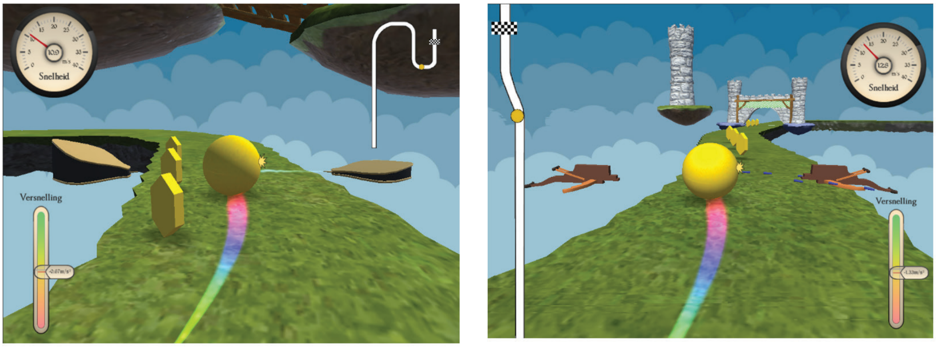


Figure 2. Screenshots of two different versions of the game. In addition to these two versions, a version with bellows and the meters on the right side of the screen and a version with the crossbows and the meters on the left side of the screen were used.

3.4 Instruments

The pre-test consisted of eight questions, three of which were to assess participants' baseline knowledge, necessary for playing the game. The other five questions were matched to five similar questions in the post-test to determine a possible learning effect. The post-test also contained two questions to assess knowledge transfer to other situations outside the game. These questions were paired with two similar questions that referred to situations in the game. The questions used in the pre- and post-test are based on questions of the Force Concept Inventory (Hestenes et al., 1992). The post-test included ten additional questions on the game experience, reflected in the use of, for example, the speedometer. With these questions, information on the speedometer, accelerometer, the game's difficulty and enjoyability was gathered by using Likert Scales ranging from -2 to 2 points. The pre- and post-test questions were translated from Dutch and can be found in appendix A and B.

3.5 Data collection and analysis

The duration of a game session was thirty minutes, including the pre- and post-test. Personal data, such as age and school grade, were registered using a tablet computer, along with the pre- and post-test questions. The same tablet was used for playing the game. The actual intervention time (playing the game) was fifteen minutes. For each player, log data were digitally recorded on attempts, settings and completion of each level. All data were collected in xml-files that were later processed in SPSS. For each participant, the pre-test score was calculated: the added score of the five pre-test questions on learning, with correct answers scoring 1 point and incorrect answers 0 points. Similarly, post-test scores were calculated on the five post-test questions on learning.

Q-Q plots of the pre- and post-test data show a small deviation on the normal distribution. This indicates that normality in the pre-test and post-test data cannot be assumed. Therefore, the non-parametric Kruskal-Wallis test was used to check whether there was a difference in learning effect for the different versions of the game. A paired sample *t*-test was used to determine a possible learning effect between the pre- and post-test questions (RQ1). A further paired sample *t*-test was used to evaluate the transferability of players' knowledge to different situations than a ball (RQ2). Effect sizes, Cohens d, were also calculated. Furthermore Spearman's correlation was calculated to examine an association between age and learning. With the pre-test scores, post-test scores and the log data on the settings of completed levels, the relation was examined between the use of the correct setting in the last completed level and pre- and post-test scores.

From the five levels of Newton's Race, only three levels are directly relevant to the learning goal. Level 1 is an introductory level for players to get used to the game mechanics. Level 4 introduces a new game element, that players get used to in this level. Therefore, levels 2, 3 and 5 are the key levels where we expect learning to take place.

4. Results

4.1 General game characteristics

Participants rated the difficulty and enjoyability on Likert Scales ranging from -2 to 2 points. The results are respectively M = -.45, SD = .994; t(222) = -6.806, $p < .001$ and M = .87, SD = 1.068; t(222) = 12.164, $p < .001$.

In the following, we do not consider the differences between the versions, since there was no statistically significant difference between the versions of the game for pre-test scores, as determined by Kruskal-Wallis (H(3) = .740, $p = .864$). There was also no significant difference between the versions for post-test scores (H(3) = 1.675, $p = .642$) either. Note that this may not be surprising, given the fact that the four versions of the game only differed in general appearance, not in the game mechanics.

4.2 RQ1: Conceptual understanding

The first sub-question was: To what extent does participants' conceptual understanding of Newtonian mechanics change as a consequence of playing the game?

Table 1: Results of the pre- and post-test scores (with a minimal value of 0 and a maximal value of 5).

	Mean	SD
Pre-test	1.66	.8218
Post-test	1.87	1.0132

A paired samples t-test was performed to examine the mean differences between the pre-tests scores (M = 1.66, SD = .821) and the post-tests scores (M = 1.87, SD = 1.013), see Table 1. A significant difference was found; t(222) = 3.000, $p = .003$; $d = .201$. Results of the Spearman correlation, which tested correlation between age and pre-test scores, indicated that there was no significant relation between players' age and the pre-test scores (r(221)= .007, $p = .913$). However, another Spearman correlation indicated that there was a significant positive relation between players' age and the post-test scores (r(221)= .190, $p = .004$). This may be interpreted as implying that the older the student is, the better the game fosters learning.

4.3 RQ2: Transfer

The second research question was: *To what extent does the acquired knowledge transfer to different situations that are not closely related to the game*?

Table 2: Results of the questions closely related to the game and questions about different situations (with a minimal value of 0 and a maximal value of 2).

	Mean	SD
Game situations	1.099	.569
Different situations	.700	.611

On the questions for knowledge transfer, we found that participants scored significantly lower on the transfer questions on different situations (M = .700, SD = .611) than on the similar questions on game situations (M = 1.099, SD = .569); t(222) = 7.865, $p < .001$; $d = .523$ (see Table 2). Results of the Spearman correlation again indicated that there was a significant positive association between players' age and the post-test transfer scores (r(221)= .165, $p = .014$).

4.4 RQ3: Gameplay

The final research question was: *To what extent does the participants' gameplay demonstrate evidence of intrinsic integration*?

To understand the game mechanics and the setting phase in each level, players require a certain level of baseline knowledge. An average score of 2.70 out of a maximum score of 3.00 (SD = .522) was measured. On the basis of this, the baseline knowledge was considered adequate. Results of the Spearman correlation, which tested correlation between age and scores, indicated that there was a significant relation between players' age and their baseline knowledge (r(221)= .172, $p = .010$).

The percentages of chosen settings of the key levels (the levels that are directly related to the learning goal; levels 2, 3 and 5) are shown in Table 3. An increase in the F=0N setting is found and a decrease in F> friction is found throughout the levels.

Table 3: For each key level, the percentage of the three different chosen settings, F is equal to 0N (scientific correct setting), F is equal to friction and F is bigger than friction, is shown. For these percentages, all attempts are taken into account.

	Level 2	**Level 3**	**Level 5**
F=0N	35%	44%	70%
F=friction	39%	39%	24%
F > friction	26%	17%	6%

To determine whether players reached the game goal in the intended way (by finishing the last trajectory whilst the ball makes a scientifically accurate motion), we must look at the data regarding player's chosen settings of their last completed level, as is shown in Table 4.

Table 4: Each player had to stop gaming at some point. Players either finished the game (completing level 5) or had to stop playing after 15 minutes, thus reaching different end levels. The percentage of the settings used for those completed final attempts is shown below.

	Level 2	**Level 3**	**Level 5**	**Total**
F=0N	10%	52%	22%	82%
F=friction	8%	0%	2%	11%
F > friction	5%	0%	1%	6%
Total	22%	53%	25%	100%

An independent sample *t*-test was performed to examine the mean differences between the post-test scores of players who used the correct setting (M = 1.88, SD = 1.026) and players who did not (M = 1.86, SD = .948). No significant difference was found; t(217) = .108, *p* = .914. This indicates that players who used the incorrect setting to complete their last level learned as much from the game as players who used the correct setting to complete their last level.

5. Conclusions and discussion

5.1 Conclusions

> *RQ1: To what extent does participants' conceptual understanding of Newtonian mechanics change as a consequence of playing the game?*

Results show a small (*d* = .201) but significant learning effect after playing Newton's Race for 15 minutes. This indicates that players' conceptual understanding of Newtonian mechanics improved significantly in the relatively short intervention time.

> *RQ2: To what extent does the acquired knowledge transfer to different situations that are not closely related to the game?*

The results show that players scored significantly lower on questions outside the game context in comparison with questions closely related to the game. This indicates that players were able to transfer some of the acquired knowledge to other situations; however, they were better at applying their knowledge to situations closely related to the game. This is not surprising, since players were only exposed to one scenario, namely the game scenario.

> *RQ3: To what extent does the participants' gameplay demonstrate evidence of intrinsic integration?*

Results indicate a shift of the chosen setting as players progress through the game. The correct setting (F=0) is chosen more often in the later levels of the game (Tables 3 and 4). As a notable exception, a few players were able to finish levels with an scientifically incorrect setting (Table 4) demonstrating a discrepancy between the game goal and the learning goal. Apparently some development of the game is necessary for these (experienced?) gamer players. Furthermore, successful last level completions with an incorrect setting occurred mainly in the easier level 2 (12%). In level 5 this was only 3%. The fact that some players completed their last level with incorrect settings raises the question of whether these players did in fact not reach the learning goal. However, results show no significant difference in learning effects between players who chose the incorrect and correct setting for their last completed level.

This brings us to our general conclusions. We found players' conceptual understanding of Newtonian mechanics improved significantly after playing Newton's Race for 15 minutes. We surmise that they reached this learning effect by toying with the different settings, especially in key level 2 (as is shown in Table 3), and opting for the correct setting more often as they progress through the levels. This is reflected in Tables 3 and 4, as the correct setting is chosen more often as the players progress. Table 4 also shows that most players finish their last level with the correct scientific setting, indicating that they knew that that was the one to use to complete the level, thus reaching the game goal the intended way. This, in combination with the found small significant learning effect, may be seen as evidence for the idea that the game goal and learning goal are aligned to some extent.

5.2 Situating the study

In educational game design, deliberately including both pedagogical aspects and game aspects is relatively rare (Ávila-Pesántez et al., 2017). However, some recent studies show a more in-depth analysis on the design of an educational game with the focus on combining gameplay with learning (Czauderna & Guardiola, 2019). The current study fits within the research body that emphasizes the importance of aligning gameplay with learning in educational games. Other studies focussing on intrinsic integration, or at least on specifically aligning learning with gameplay, also found positive learning outcomes, (Habgood & Ainsworth, 2011; Czauderna & Guardiola, 2019). These studies also acknowledge the continuous investigation of the design process of such an educational game. The value of the present study is the evidence for intrinsic integration as a key element in the design process, found by examining players' log data. Other studies have found a learning effect as well. However, we are able to clarify the underlying mechanism through the results of the log data. These results strengthen the implementation of intrinsic integration for designing an educational game.

5.3 Limitations and implications

In interpreting the results of the current study, some limitations must be taken into account. Firstly, we must consider the absence of a control group; although the current design is suitable for addressing the research questions, the absence of a group in which no gaming occurred limits the ability to gauge the learning effects after the gameplay to other types of approach. Second, participants were recruited on a voluntary basis, which could indicate a positive attitude toward games in general from the participants. This could have an influence on the attitude from the participants towards Newton's Race.

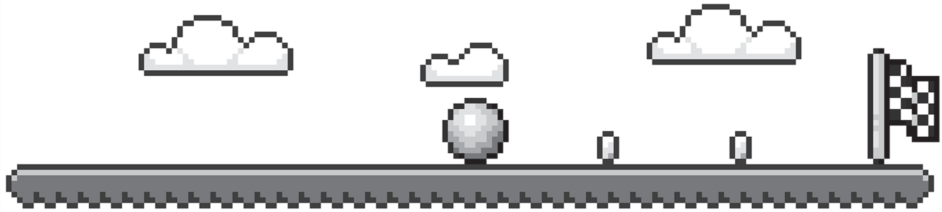
The learning effect we found was quite small. However, we must take into consideration that participants demonstrated a significant increase in their conceptual understanding in just 15 minutes of gameplay, as no additional learning activities were used in this study. This shows promising possibilities for the use of Newton's Race in physics education. Finally, at this point we cannot conclude anything about a retention effect, since no delayed post-test was conducted. With this study, we sought to make a step in players' conceptual understanding by playing Newton's Race. Research on a possible retention effect is a later step in the design process.

Results of this study show that an intrinsically integrated game on Newtonian mechanics can foster learning with just 15 minutes of gameplay. To extend the acquired knowledge on Newtonian mechanics and to transfer that knowledge to situations outside the game, additional learning activities are needed. This finding is in line with the findings of Wouters and colleagues (2013). Our results could imply that similarly designed games on different (physics) subjects could also foster learning in a relatively short time. A short educational game can thus be useful, because in a lesson there usually will the time to play the game and include additional learning activities.

5.4 Further research

For future research, two main aspects must be considered. Firstly, it is important to research how embedding the game in the curriculum can further foster comprehension and transfer (Wouters, van Nimwegen, van Oostendorp & Van der Spek, 2013). In such a lesson, the game should play a central role and the additional learning activities should be designed to gain more insight on how transfer can occur. This lesson can probably best be given in the lower classes of secondary education, where students start with Newtonian mechanics. Furthermore, findings indicate a positive correlation between age and post-test scores. In this study, younger players participated in primary education and older players in the lower levels of secondary education. Secondly, the game itself needs some improvements. Observations indicate that players found the 'steering' counterintuitive. This is due to the fact that in most commercial games objects are steered the other way around. This could be an interesting point for an additional learning activity, such as a classroom discussion. Implementing these ideas in a future study could result in a fun and effective lesson which fosters comprehension and transfer on Newtonian mechanics.

Chapter 4 Implementing an intrinsically integrated game on Newtonian mechanics in the classroom: outcomes in terms of conceptual understanding and transfer



This chapter is based on:

Van der Linden, A., Meulenbroeks, R. F. G., & Van Joolingen, W. R. Implementing an intrinsically integrated game on Newtonian mechanics in the classroom: outcomes in terms of conceptual understanding and transfer, *submitted*.

Abstract

Digital educational games have demonstrated large variations in learning outcomes and transfer. Furthermore, educational games are usually embedded in a larger educational setting. This case study evaluates in detail a lesson around an educational game designed to foster transfer. The game, Newton's Race, is an intrinsically integrated game on Newtonian mechanics. Outside of the game, lesson activities include a debriefing session, a generalisation assignment, and an assignment on transfer situations. This lesson was evaluated using a mixed-methods approach. A pre- post-test design (N=27) demonstrated a large significant learning effect (*p* = .002, d = .908). Transfer, as measured within the post-test, was also fostered significantly. In the qualitative part of the study, students' written statements on the worksheets and students' utterances during the discussion were analyzed using open coding. 79% Of all quotes were coded as scientifically correct.

Keywords

Educational games; Intrinsic integration; Newtonian mechanics; Secondary education

1. Introduction

Research on digital educational games shows promising results on potential learning benefits and their use in the classroom (Lamb et al., 2018; Tsai & Tsai, 2020). However, as shown in a large meta-analysis by Clark and colleagues (2016), huge variances exist in terms of measured learning outcomes. This raises questions on what elements in the design of a game contribute to its efficacy and how such elements can be designed into the game. One of the most important aspects of the design process is the combination of learning elements within the gameplay, so-called intrinsic integration (Kafai, 1996). As shown in a more recent meta-analysis by Lamb et al. (2018), implementing a specific pedagogical approach inside a game design is more effective than adding a pedagogical approach after the game has been developed. A third meta-analysis by Tsai and Tsai (2020) found that gaming mechanisms and learning mechanisms are equally important in students' science learning whilst playing educational games. However, concrete examples of how to combine learning with gameplay remain scarce and therefore methodologies of combining learning approaches with gameplay remain largely unexplored (Czauderna & Guardiola, 2019; Tsai & Tsai, 2020).

1.1 Implementation of educational games

Apart from this relative dearth of studies on the combination of learning with gameplay, an educational game usually is part of a larger structure, such as a classroom-based lesson or an online synchronous meeting. Classical interventions such as Inquiry Based Learning, Direct Instruction or different teaching and learning activities are often combined into a larger whole. As an example, the effect of inquiry-based learning methods may depend on the amount of guidance provided in the lesson (Capps & Crawford, 2013).

In order to increase the learning effects of educational games, it is important to consider how the game is embedded in the total set of learning activities (Wouters et al., 2013; Lamb et al., 2018). Several studies suggest that a "debriefing session" in the form of a classroom discussion after the gameplay (Wouters et al., 2013; Choi et al., 2017; Tokarieva et al., 2019) will enhance learning when compared to gameplay alone. Studies also emphasize the teacher's critical role in connecting the game with other learning activities and other outside-game scenarios (Long & Aleven, 2014; Tokarieva et al., 2019). Other instructional activities, such as practical work or other assignments, can complement the game activities in a lesson and thus further foster learning and transfer.

One of the major reasons for embedding a game in a larger learning environment is that conceptual knowledge should also be applicable outside of the game context. In other words, students should be able to *transfer* their newly acquired knowledge from the game context to a wider one. For example, in the case of Newtonian mechanics, one learning goal is about understanding the relationship between forces and motion. Students should be able to apply this relationship on many different types of situations. If the game situation is, e.g, a rolling ball on a trajectory, students then should also be able to apply the new knowledge to other situations, such as riding a bike, moving a box or shooting a hockeypuck.

Students' ability to transfer knowledge from one situation to another depends on their understanding of the underlying principles and concepts. If students are able to construct an abstract representation of these underlying principles and apply this in other situations, transfer is fostered (Rebello et al., 2007). One possible way to achieve transfer is by abstraction and finding connections (Perkins & Salomon, 1992). In terms of an educational game, this means that the specific game elements need to be taken to a more abstract level and connections with other parts of the educational program need to be made explicit. This points in the direction of embedding the educational game into a larger educational structure.

This case study focuses on learning and transfer of concepts in Newtonian mechanics when an educational game is embedded in a lesson. The game, Newton's race, is an example of a game in which intrinsic integration is applied (Van der Linden et al., 2019). In Newton's Race, players have to move a ball over a preset trajectory, with different levels for different trajectories.

The learning goal of the entire lesson is *that students will be able to apply the relationship between forces and motion by giving explanations and predictions in realistic everyday scenarios*. In order to achieve transfer from the game situation to a wider context, three lesson activities are added after students play the game. The first activity, designed in order to increase learning and to abstract the acquired knowledge from the educational game, is a teacher-directed debriefing session directly after gameplay (see e.g., Long & Aleven, 2014; Tokarieva et al., 2019). During this classroom discussion the teacher plays a central role by asking questions such as: 'What did you think you have learned from the game?' and 'can you explain what happens in this (game)scenario?' In the second activity, students are asked to construct an abstract representation of underlying principles (Perkins & Salomon, 1992). Students get a generalization assignment asking them to write down what they have learned. In order to prompt students to make general statements about forces and motion, they are asked to use certain terms, such as acceleration, deceleration, forward force, resistance, bigger than, equal to, etc. The final activity is designed in order to apply these abstract general statements in different transfer situations (Rebello et al., 2007). Students are presented with different outside game scenarios, such as a rocket in space and riding a bike. Students then are asked to describe the type of motion in each scenario and to give an explanation for their chosen type of motion.

1.2 Research questions

A previous study on an educational game on Newtonian mechanics (Newton's Race) showed that the game resulted in a significant increase of domain knowledge presented *within* the context of the game (Van der Linden et al., 2024). However, the post-test demonstrated that players were not able to transfer the acquired knowledge to other situations. As players only played the game for 15 minutes and as there were no additional instructional activities, this result may not come as a surprise. The question then becomes how to improve this transfer in cases where such an educational game is employed. Therefore, we raise the following research question:

> *What is the impact on learning outcomes in terms of conceptual understanding and transfer of embedding an educational game in a lesson?*

This question is subdivided in the following sub-questions:

> *SQ1: To what extent do students understand the relationship between forces and motion in both game related and transfer situations after the lesson?*
>
> *SQ2: What do students report on their understanding of the relationship between forces and motion in both game related and transfer situations?*

Based on the findings of the aforementioned study (Van der Linden et al., 2024) we hypothesize that by adding specific lesson activities, transfer can be fostered. Therefore, we expect a learning effect both in-game related and in transfer situations.

1.3 Theoretical background, intrinsic integration

Despite differences in exact terminology in studies on the combination of learning and gameplay, there is consensus on the main point: Learning and gameplay must be integrated during the design process in order to increase the learning effect of an educational game. This integration of subject matter with gameplay is defined by Kafai (1996) as *intrinsic integration*. However, designing a game on the basis of this principle is not straightforward (Walkington, 2021).

In an earlier study, we proposed a guiding frame for designing an intrinsically integrated game, shown in Figure 1. In this view, an intrinsically integrated game has four key elements that should be integrated; the learning goal, game goal, pedagogical approach and game mechanics. Integrating learning with gameplay means that the game goal is aligned as closely as possible with the learning goal (top part of Figure 1). In every game a player interacts with the environment through game mechanics in order to reach a certain game goal. Sicart (2008) defines game mechanics as 'methods invoked by agents, designed for interaction with the game state'. This is represented in the left part of Figure 1. Turning to the right part, in order to reach any learning goal, a specifically chosen pedagogical approach is required. Ideally, in designing an intrinsically integrated game, the pedagogical approach needs to be aligned with the game mechanics.

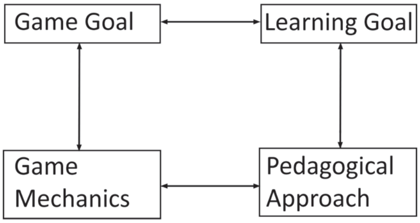


Figure 1. Guiding frame on alignment between the game goal, learning goal, pedagogical approach and game mechanics for designing an intrinsically integrated educational game, used for designing Newton's Race (Van der Linden et al., 2019).

1.4 Pedagogical approach and learning goal

For this study the intrinsically integrated game Newton's Race was used. Using the terminology from Figure 1 the design of Newton's Race, in order to establish the intrinsic integration, can be described. A more detailed version of the design process can be found here (Van der Linden et al., 2019).

The subject context of Newton's Race is Newtonian mechanics. The chosen *learning goal* for the game is that students can reason about the effects of forces on different types of motion. This implies that students can understand and apply the relationship between forces and motion. Students reach the learning goal when they understand which force (no force, a force equal to friction or a force bigger than friction) corresponds to a certain type of motion: (acceleration, deceleration or constant velocity).

Er wordt weer één keer tegen de bal getrapt. Je kan weer instellen of er na die trap nog steeds een kracht op de bal werkt in de richting waar de bal naartoe beweegt.

Probeer dezelfde beweging te maken die een bal maakt als jij één keer tegen een bal trapt. Zorg dat de bal de finishlijn haalt!

Figure 2. A. The setting phase at the start of each level. Translated: A ball is kicked once. You can set if there is a force working on the ball in the direction of motion. Try to make the same movement a real ball makes when you kick it once. Make sure the ball gets to the finish line! Options: 'After the kick: F = 0', 'After the kick: F = friction', 'After the kick: F > friction' or 'Go back'. **B**. Gameplay of level 2 of Newon's Race. **C**. Changing the direction of motion of the ball in order to collect coins and to take turns on the trajectory. **D**. On an acceleration platform (green) a force is applied in the direction of motion. On a deceleration platform (red) a force is applied in the opposite side of the direction of motion.

For intrinsic integration to apply, a specific, domain related *pedagogical approach* is needed that is integrated with game mechanics (Lamb et al., 2018; Walkington 2021; and Figure 1). The pedagogical approach chosen for the game is based on the problem posing approach. This approach has shown promising results on several topics in physics education (Klaassen, 1995; Vollebregt, 1998; Kortland, 2001). Before encountering Newtonian mechanics in formal education, students all have gathered daily experiences with moving objects, resulting in pre-existing ideas about this subject. In order to accept a new scientific explanation on these subjects, students need to be confronted with the value of their pre-existing ideas (Vosniadou, 1994; Duit & Treagust, 2003; Schumacher et al., 2016). Ideally, when students are confronted with the consequences of their pre-existing ideas, they experience something that counters their expectation and they are likely to experience a need to alter their own explanation to a new, scientific one.

In order to align the *game mechanics* with this pedagogical approach, two main concepts must be present in the game. First, players should be able to explore their pre-existing ideas. To accommodate this, a setting phase is required where players can set different forces on a moving object. Thus, players are confronted with the consequences of their pre-existing ideas. Therefore, the game mechanics must take into account the experience of the type of motion as a consequence of the setting phase.

Turning now to the game goal and game mechanics, the *game goal* is guiding a ball to the finish line of a preset trajectory. The integration of the game and learning goals is reflected in Newton's Race consisting of five levels, with each level designed in such a way that players can only reach the finish line, if their ball moves in a realistic fashion, thus using the scientifically correct setting in the setting phase.

The details on the gameplay can be found in an earlier publication (Van der Linden et al., 2024). As an illustration some screenshots of the game are included in Figure 2.

2. Materials and methods

2.1 Research design

For this study a mixed methods approach was used. Students participated in a lesson about Newtonian mechanics. The lesson plan used for this study can be found in Table I. A pre- and post-test design was used to examine what students learned about the relationship between forces and motion (SQ1). Audio data and worksheets were collected in order to qualitatively examine the students' understanding of this relationship (SQ2). The lesson plan was piloted in a 9th grade physics class in a medium-sized urban secondary school in the Netherlands, after which minor procedural adjustments were made for the final study.

2.2 Participants

Participants were selected on a voluntary basis from eight different classes in the same school and consisted of Dutch 9th grade students between the age of 14 and 15. They participated in the study in four groups of six, seven, and eight students, respectively. From a total of 27 participants, 21 (78%) were boys and 6 (22%) were girls. Since the division into groups was done arbitrarily on the basis of the availability of the students, results from all three groups will be lumped and no distinction between the groups will be made.

2.3 Instruments

The pre-test consisted of five questions about situations closely related to the game situation. These five questions were matched with the five same questions in the post-test to determine a possible learning effect. The post-test contained three additional questions regarding situations not closely related to the game, to determine a possible transfer effect (SQ1) as is shown in Figure 3. The questions used in the pre- and post-test are based on questions of the Force Concept Inventory (Hestenes et al., 1992) and Appendices C and D gives the exact pre- and post-test questions.

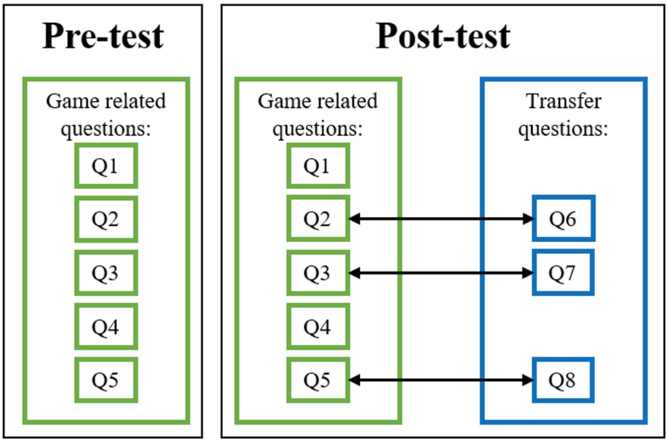


Figure 3. Visual representation of the pre- and post-test questions, showing the conceptual connections between the questions. E.g., Q2 and Q3 deal with the same concept, Q3 addresses the concept in a game related context and Q6 addresses the same concept in a different context. The complete pre- and post-tests can be found in Appendices C and D.

Table I gives an overview of the lesson plan. After the introduction and pre-test, students pre-existing ideas were activated by a discussion on an everyday life scenario: riding a bike in bad weather (3). Then, students were invited to play the educational game Newton's Race (4). Directly after playing the game, a classroom discussion consisting of three parts was held (5). The first part was about gameplay and visual representations. This part was primarily used for priming the discussion and to get a feeling for the way the game "handled". The results of this part of the study will not be discussed here, since they are not related to the research questions. In the second part the following general question was raised: What did you learn from the game? In the third part screenshots of Newton's Race were used to spark the discussion. Various in-game scenarios were shown on a handout, students were asked to discuss what happened to the ball on a particular moment, how they figured what type of motion the ball was in, and what kind of setting would be the correct one for that motion.

Table I gives an overview of the lesson plan. After the introduction and pre-test, students pre-existing ideas were activated by a discussion on an everyday life scenario: riding a bike in bad weather (3). Then, students were invited to play the educational game Newton's Race (4). Directly after playing the game, a classroom discussion consisting of three parts was held (5). The first part was about gameplay and visual representations. This part was primarily used for priming the discussion and to get a feeling for the way the game "handled". The results of this part of the study will not be discussed here, since they are not related to the research questions. In the second part the following general question was raised: What did you learn from the game? In the third part screenshots

of Newton's Race were used to spark the discussion. Various in-game scenarios were shown on a handout, students were asked to discuss what happened to the ball on a particular moment, how they figured what type of motion the ball was in, and what kind of setting would be the correct one for that motion.

The pre-test, post-test, statements and the worksheet, translated from Dutch, can be found in respectively Appendices C, D, E and F.

Table I: The lesson plan used for the study.

Duration (min)	Activity	Short description	Data collection
3	1. Introduction		
7	2. Pre-test		Pre-test
5	3. Discussion on statement 1		
	Activation of pre-existing ideas by a discussion on an everyday life scenario: riding a bike in bad weather.	Audio data	
15	4. Playing Newton's Race	Students play the game individually.	
15	5. Classroom discussion	A debriefing session consisting of three parts: 1. Gameplay and visual representations 2. What did you learn from the game? 3. Discussion based on screenshots of the game	Audio data
15	6. Worksheet	Students fill in a worksheet consisting of 2 assignments: 1. Generalization assignment 2. Applying the generalization to transfer situations	Worksheet & Audio data
5	7. Discussion on statement 2	As a closing activity: another discussion on an everyday life scenario: moving a heavy box.	Audio data
10	8. Post-test		Post-test

2.4 Data collection and analysis

Table II: The coding scheme used to code the transcribed statements. The coding scheme is translated from Dutch. In addition to the code categories, a + or – is assigned depending on the correctness of the statement.

Code	Category	Examples of statements
F	Force	I think F = 0 / It receives a force from the left / Resistance / If the forward force is greater than the opposing force… tegenwerkende kracht… & Als het even groot is, …
A	Acceleration	You see an acceleration / The ball is going faster and faster
D	Deceleration	You see a deceleration / The ball is slowing down / He stops
C	Constant velocity	You move with a constant velocity / constant speed
G	General or other statement about motion	You go forward / The ball is rolling / One goes twice as fast / The ball stands still

Table III: Some examples from coded statements, translated from Dutch.

Lesson activity	Statement	Codes
3. Discussion on statement 1	If all forces are the same, you just stand still	F-, G-
5. Classroom discussion	At the bottom one, there is still a force so it will probably accelerate the whole trajectory	F+, A+
6. Worksheet assignment 2	Because ice offers almost no resistance, it will remain at a constant velocity for a long time	F+, C-

The duration of the lesson was 75 minutes, including the pre- and post-test. General data, such as age and school grade, as well as pre- and post-test data were collected digitally using Google Forms. In order to answer SQ1, a paired sample *t*-test was performed on the pre- and post-test scores, in order to measure the direct learning effect. A paired sample *t*-test was also performed on the transfer questions in order to determine a possible transfer effect from game related situations to other situations.

In order to answer SQ2: The audio data of the discussions on the statements and of the second and third part of the classroom discussion were transcribed verbatim. The worksheets filled out by the students were collected anonymously. Open coding was used on both the transcripts and the worksheets in order to group statements related to forces and motion. Several categories were found in order to describe what the statement is about: A (acceleration), D (deceleration), C (constant velocity), G (General or other statement about motion) and F (force). Multiple codes could be assigned to a statement, e.g., in the case a statement on the relationship between forces and motion. Statements were also coded on the scientific correctness of that statement using a + or – sign. To gain more insight in the coding process, Table II presents the coding scheme and

Table III gives some coded examples. Two interrater reliability analysis were performed on 30% of the collected statements. For the different categories a Cohen's Kappa of .994 (*p* = .006) was found. For the correctness of statements a Cohen's Kappa of .989 (*p* = 011) was found.

3. Results

3.1 SQ1: Conceptual understanding

The first sub-question was: *To what extent do students understand the relationship between forces and motion in both game related and transfer situations?*

Table IV gives the results of the pre- and post-tests for game-related and transfer situations.

Table IV: Results of the pre- and post-tests (with a minimal value of 0 and a maximal value of 5 for the game related questions and a maximal value of 3 for the transfer questions).

	Game related		**Transfer**	
Questions	Pre-test	Post-test	Post-test	Post-test
	1,2,3,4,5	1,2,3,4,5	2,3,5	6,7,8
Mean	2.89	3.93	2.63	2.56
SD	1.15	1.14	.63	.64

A paired samples *t*-test was performed to examine the mean differences between the questions on game related situations in the pre-tests (M=2.89, SD=1.15) and the post-tests (M=3.93, SD=1.14). A significant difference was found; *t*(26) = -3.463, *p* = .002, Cohen's *d* = .908. Another paired samples *t*-test was performed to examine the mean differences between post-test questions on game related situations (M=2.63, SD= .63) and transfer situations (M=2.56, SD= .64), No significant difference was found; *t*(26) = 1.000, *p* = .327.

3.2 SQ2: Conceptual understanding

The second sub-question was: *What do students report on their understanding of the relationship between forces and motion in both game related and transfer situations?*

We start this section by presenting in Figure 4 the number of total codes per category. A distinction is made between the type of collected data: audio data or the individually filled out worksheets.

Looking at Figure 4, several aspects stand out.

1. Most statements were coded within the F+ category, 36% of all codes.
2. More scientifically correct codes (+) were given than incorrect codes (-), 79% of all codes were scientifically correct.
3. Incorrect statements on acceleration, deceleration and constant velocity (A-, D-, C-) were primarily given on the worksheets (64%, vs 36% on the audio data).

4. Statements on general or other type of movements (G) were primarily given (79%) on the audio data.

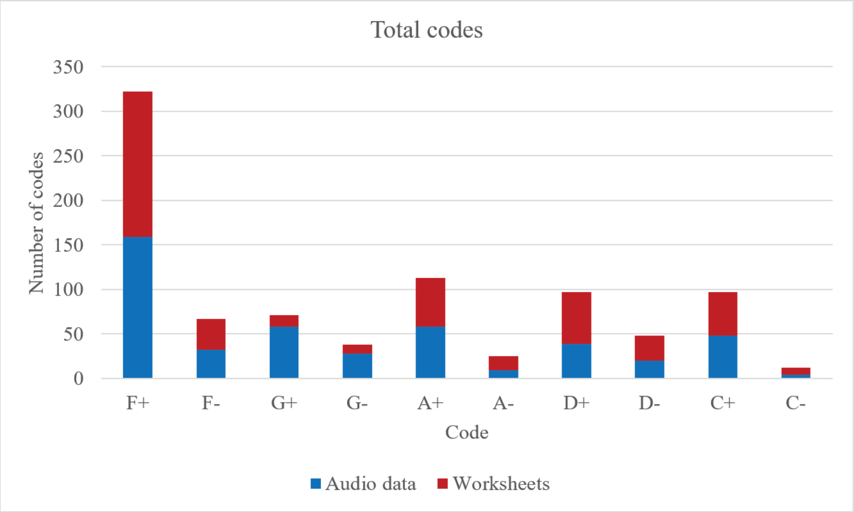


Figure 4: In this graph the number of codes is given per category. The categories are statements regarding: force (F), acceleration (A), deceleration (D), constant velocity (C) and other type of movements (G). Statements in each category were also coded scientifically correct (+) or incorrect (-).

3.2.1 Game related situations

In the second part of the discussion (5.2 in Table I) students are asked to describe what they think they have learned from the game. In each group something came up on forces and motion in an attempt to generalize what they experienced in the game. The following short excerpt from a transcript of a group discussion illustrates how a student responds to the question ‘What did you learn from the game’:

> R(esearcher): *Can anybody tell in their own words if they learned anything from the game and if so, what did you learn?*
>
> S(tudent): *What a force does to a ball.*
>
> R: *OK and what does a force do to a ball?*
>
> S: *Well, if F = 0, then he will slow down (ehr), the F is bigger, the force is bigger than friction, than it will keep getting faster.*

This statement shows that this student is referring to the game, by referring to ‘F=0’ (which is a game setting) and ‘ball’. This student in particular shows an understanding in game related situations of the relationship between acceleration and forces and deceleration and forces. In the last sentence two correct relationships are given (F+, D+ and F+, A+), however no statement is made on the relationship between force and moving with a constant velocity.

In the last part of the discussion (5.3 in Table I) the students were given a three-page handout with several screenshots from the game. On the first page the students were asked to tell the differences between two screenshots of the first level, a trajectory over ice. The screenshots differ as they represent different settings resulting in (1) a difference in type of motion (a constant velocity or acceleration) and (2) difference in force working on the ball. All groups were able to point out these two differences and were able also to explain how they could tell that there was a difference in motion (for instance by reading the accelerometer). The following excerpts from transcripts illustrates typical students responses on the difference between these two screenshots:

> S: *At the bottom one there is still a force, so it will accelerate the rest of the track* (F+, A+)
>
> R: *How can you tell that there is a force working?*
>
> S: *Because you see a point at the middle of the ball* (See Figure 2D)
>
> S: *With that one the dot is in the accelerated section and with the other it is in the constant section and one gets a force and the other doesn't.* (F+, A+, C+)

On the second page of the handout students had to tell the differences between two screenshots on ice and on grass, the ball moving with a constant velocity in both situations. The two important differences to be found here were: 1) the difference of the track (no friction vs. friction) and 2) the difference in force. Again all groups were able to spot these differences. Students statements also show that although the type of motion (constant velocity) is the same, the set force must be different in the two levels. The following two excerpts from a transcript illustrates students responses on the difference between these two screenshots:

> S: *The top one is blue and the bottom one is green*
>
> R: *And what does it mean that the top one is blue and the bottom one green?*
>
> S: *I assume that the blue represents ice, so there is less friction than green, the grass.* (F+)
>
> R: *Euhm I think that with the grass one that there an extra force must be applied on, because otherwise the grass will slow it down.* (F+, D+)
>
> R: *OK and what does that mean for the top picture?*
>
> S: *That there it is not the case*

On the third page three screenshots were shown, all with the ball moving on grass. The students were asked what kind of motion they saw and what force was set to create that motion. All groups could quickly state the correct type of motion that they saw in the screenshots and they were also able to reproduce the setting that was used to create that motion.

3.2.2 Transfer situations

In the first assignment of the worksheet (6.1 in Table I) students had to generalise their understanding on the relationship between forces and motion. Ideally, they were supposed to come up with three physically correct relationships:

1. When the applied force is bigger than friction, the object is accelerating.
2. When the applied force is smaller than friction, the object is decelerating.
3. When the applied force is equal to friction, the object is moving with a constant velocity.

As is shown in Table V, 48% of the students produced all the above relationships and 11% produced none of the relationships. From the 41% that partially produced the relationships, 45% produced relationship 1, 45% produces relationship 2 and 55% produced relationship 3.

Table V: Results of the generalization assignment.

	N	%
All relationships	13	48
Part of the relationships	11	41
No relationships	3	11

In the second assignment of the worksheet students had to apply their understanding on the three mentioned relationships in five different transfer situations. For each statement students had to give the correct motion and explain their answer by using the relationships. Each correct answer was coded with half a point and half a point for the correct explanation, so a maximum of 5 points could be gathered here. The actual results can be found in Table VI. NB: These results are independent of the transfer questions in the post-test.

Table VI: Results of the second worksheet assignment (with a minimum value of 0 and a maximum value of 5). The students are divided into three groups, dependent of their answers on the generalization assignment.

	N	Mean (out of 5)	SD
All relationships	13	3.54	.901
Part of the relationships	11	2.81	1.15
No relationships	3	2.83	.289
Total	27	3.17	1.01

There was no statistical significant difference between the answers of different groups as determined by a one-way ANOVA ($F(2,24) = 1.806$, $p = .186$).

4. Conclusions and discussion

4.1 Conclusions

Revisiting our sub questions:

> *SQ1: To what extent do students understand the relationship between forces and motion in both game related and transfer situations?*

Results show a large significant learning effect (*d* = .908) on the game related questions, confirming results of our hypothesis and earlier study (Van der Linden, 2024). Also confirming our hypothesis, transfer was fostered when the game is embedded in a lesson. This is based on the results showing no significant difference between the questions in the post-test on game related situations (Q2,3,5) and transfer situations (Q6,7,8 in Figure 3). In other words: after the complete lesson, students were able to apply their acquired knowledge with equal success in both game related and transfer situations. These findings indicate that after this lesson students' conceptual understanding on the relationship between forces and motion improved significantly in both game related and transfer situations.

> *SQ2: What do students report on their understanding of the relationship between forces and motion in both game related and transfer situations?*

As is shown in Figure 4, students most often used the concept of force in their utterances (both written and oral) compared to the other categories that are all about motion. Since the learning goal is about the relationship between forces and motion, it is to be expected that for each utterance on a type of motion (acceleration, deceleration or constant velocity) students also report something about the forces involved. The concept of force is thus expected to be used more often than the other categories.

Students statements were mostly scientifically correct (79%) indicating students overall ability to reason about forces and motion. The incorrect statements that were specifically made about acceleration, deceleration and constant velocity (A-, D-, C-) were primarily (64%) given on the worksheets, which were filled out individually. This could be interpreted in two ways. First, if a student is insecure about their answer, they could be inclined not to give that answer in a classroom discussion and remain silent. On the worksheet however, every student is expected to give an answer. Another explanation could be that on the worksheet students were explicitly prompted to use acceleration, deceleration and constant velocity in their answers. This is also in line with the finding that the general statements about motion (G) were mostly given during the discussions and not on the worksheets (79%).

During the debriefing session directly after students played the game, all groups proved to be capable to reason on the relationship between forces and motion in game related situations. During the discussion on screenshots from the game, all groups were able to interpreted the situations correctly. When asked the question 'what did you learn', students report scientifically correct, but sometimes incomplete, relationships between forces and motion.

In the generalization assignment of the worksheet, about half (48%) of the students were able to give a complete, and scientifically correct, set of statements on the relationship between forces and motion. Most of the other students (41%) gave correct, however incomplete set of statements, and only 11% of the students gave no correct statements at all. When comparing these groups in their results on the second worksheet assignment (with transfer situations), no significant differences in mean scores were found. Therefore, a better score on the generalization assignment did not translate into a significantly higher score on the assignment with transfer situations.

We now revisit the main research question: *What is the impact on learning outcomes in terms of conceptual understanding and transfer of embedding an educational game in a lesson?*

The findings of this case study indicate that students profit from a debriefing session after playing an educational game. During this debriefing session students demonstrate their understanding of the relationship between forces and motion in game related situations. Although no correlation is found between the scores of the two worksheet assignments on generalisation and transfer, we did find a learning and transfer effect in post-test scores. In comparison with the previous study (Van der Linden 2024), the effect size was larger (d =.201 vs. d = .908) and in the present study, transfer was fostered as well. We can thus conclude that the additional learning activities surrounding Newton's Race used in this study increased the learning effect and fostered transfer.

4.2 Situating the study

In an attempt to further close the gap on how to effectively implement an educational game in a lesson, this case study on Newton's Race shows positive results by explicitly describing and analysing lesson activities surrounding the intrinsically integrated game Newton's Race. Our findings are in line with our hypothesis based on a previous study (Van der Linden, 2024) and with other studies. The positive effect of the lesson as a whole is in line with studies on three lesson activities after playing Newton's Race. The three lesson activities being: a teacher directed debriefing session (Wouters et al., 2013; Long & Aleven, 2014; Tokarieva et al., 2019), a generalization assignment (Perkins & Salomon, 1992) and an assignment on different transfer situations (Rebello et al., 2007).

4.3 Limitations and implications

In interpreting the results of the current study some limitations must be taken into account. Firstly, participants were recruited on a voluntary basis, as a result a selection bias may have occurred, more boys than girls participated in this study. Participants may have had a positive attitude towards games in general before participating in the study. Secondly, the sample size was quite small (27 students). Thirdly, when interpreting the results of the worksheets one must keep in mind that the worksheet was discussed in a group discussion only after the students filled them out individually. Therefore, some overlap in coding inevitably occurred between the transcripts of the audio data of that discussion and the worksheets. Also, students could gain new insights during that discussion that was not reflected in their worksheets. Finally, no retention test was conducted. This study is meant to give an insight in how transfer can be fostered with regards to an intrinsically integrated game. Research on a possible retention effect is the next step in the design process.

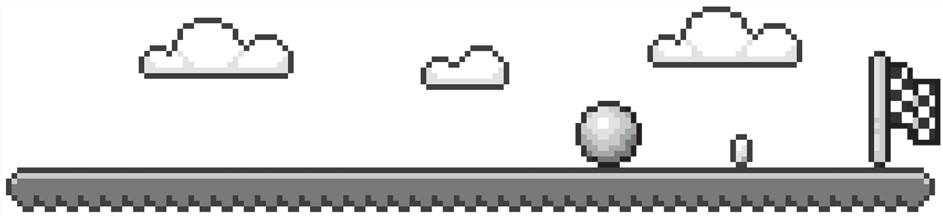
The findings of this study show the importance of embedding educational games in lessons in order to foster transfer. When designing a lesson where an educational game is used, the designer must also take additional activities into account, such as a debriefing session, a generalization assignment and an assignment on different transfer situations.

4.4 Further research

In this study a lesson is evaluated where no feedback from the teacher was given regarding answers being right or wrong or any type of explanation on the relationship between forces and motion, even if the students explicitly asked for it. This was necessary for this study in order to gain a true insight on students' reasoning without their teacher's feedback on how they were doing. In reality, of course, the importance of the role of (teachers) feedback on learning has been proven time and time again (e.g., Hattie & Timperley, 2007) When implementing this lesson in the actual classroom, there will of course be teacher's feedback at the end of a discussion, affirming the understanding of students' relationship between forces and motion, especially in transfer situations.

The findings of this case study show some promising directions on how to foster transfer using an intrinsically integrated game on Newtonian mechanics in a lesson situation. The next step is to expand these findings by evaluating a lesson around Newton's Race that fosters transfer in a real classroom situation. For this to happen, the developed lesson needs to be adjusted accordingly. After all, teaching eight students (the maximum number of students in one of the four groups in this case study) is not the same as teaching 30 students in a full class. Also, research on a possible retention effect is needed to further evaluate the effects of a lesson where an intrinsically integrated game, such as Newton's Race, is implemented.

Chapter 5 Embedding an intrinsically integrated game in a realistic classroom situation



This chapter is based on:

Van der Linden, A., Meulenbroeks, R. F. G., & Van Joolingen, W. R. Embedding an intrinsically integrated game in a realistic classroom situation, *submitted*.

Abstract

Research on digital game-based learning reports mixed results, with effects on student learning generally being reported as positive. This study focuses on embedding an intrinsically integrated game, Newton's Race, in a lesson on Newtonian mechanics. For this study two classroom implementations focusing on game-based exercises (game reinforcement group) or general exercises (transfer group) are designed and compared. The lessons were evaluated using a mixed-methods approach. A pre- post-test design (N=213) demonstrated a small significant learning effect (p = .001, d = .038) for all participants. No significant differences between the two groups in terms of learning outcomes are found, with pre-test scores being a significant predictor for all other test scores. Differences between the groups in students' transfer reasoning are found; the game reinforcement group scored higher on a generalisation assignment and the transfer group scored higher on an assignment on other transfer scenarios. A correlation between these two assignments is found. Students who scored higher on the generalisation assignment, also scored higher on transfer assignment.

Keywords

Game-based learning; Intrinsic integration; Newtonian mechanics; Secondary education

1. Introduction

It is not surprising that educational research tends to follow technological trends, to try and use them for educational purposes (Timotheou et al., 2022). Using digital games is one of them and research generally reports positive effects on learning (e.g., Lamb et al., 2018; Tsai & Tsai, 2020; Lei et al., 2022). However, a large meta-analysis by Clark and colleagues (2016) elucidates the huge individual differences in learning outcomes. One of the outcomes of a recent literature review even suggest that the using technological tools in education depends on different variables, not the technological tool per se (Timotheou et al., 2022). These results raise questions on how to successfully design and implement an educational game in a classroom setting; which design choices yield learning and which do not?

1.1 Digital game based learning

Game-based learning (GBL) is the use of games to enhance the learning experience (Sheldon, 2011). GBL can refer to both analogue and digital games, where games can be of the shelf games used for educational purposes and games specifically designed for education. For this study we focus on digital GBL. There are motivational and engagement aspects of gaming. Games can be adaptive to players' specific needs or situation and a game environment offers a safe space to practice and make mistakes (Plass et al., 2015). Moreover, digital GBL provides different approaches for learning and games can offer a nice start-up activity for certain topics (Greipl et al., 2020). Although research offers mixed results, in general research on digital GBL shows positive effects on learning. These effects may be strengthened by the use of theoretical frameworks, clear goals and carefully developed game design to meet students' needs (Greipl et al., 2020; Tsai & Tsai, 2020).

1.2 Intrinsic integration

As mentioned above, the use of a theoretical framework can strengthen the effects of digital GBL. A promising principle in this respect is intrinsic integration. Intrinsic integration is the integration of subject matter (learning) with gameplay (Kafai, 1996). Although different terminology is used in studies, the main point is, that in order to increase the learning effect of an educational game, learning and gameplay must be integrated during the design process. Even though the design process can be challenging and is not straightforward (Walkington, 2021), research on intrinsically integrated games show value of this approach. For example, a study on Zombie Division, a game to teach mathematics, compares an intrinsic and extrinsic version of the game, results show that players learn more form the intrinsic version and were more willing to play the intrinsic version (Habgood & Ainsworth, 2011).

1.3 Embedding educational games in lessons

Just like for any other lesson activity, it is important that an educational game is embedded in other learning activities to form a complete lesson. To enhance learning from gameplay, several studies suggest a classroom discussion after gameplay (Wouters et al., 2013; Lamb et al., 2018; Choi et al., 2017; Tokarieva et al., 2019). Studies also emphasise an active teacher role in connecting the game with other activities and scenarios (Long & Aleven, 2014; Tokarieva et al., 2019).

To make digital GBL useful in formal education, students must reach a certain (curriculum) learning goal at the end of a lesson or lesson series. This learning goal is most often a general learning goal were students must be able to use their skills into different contexts. In other words, for digital GBL to be successful, students must be able to transfer their acquired knowledge from gameplay to other scenarios. The success of a technological intervention, such as GBL, is based on both the technological activity itself and the chosen pedagogical approach (Garzón & Acevedo, 2019).

Looking at research on implementing game-related activities in the classroom, such as simulations and escape rooms, similar findings are found. A literature review by Smetana & Bell (2012) emphasizes not only the importance of support within the simulation program, but also the support provided by the teacher. In contrast to approaches such as escape rooms the role of teachers in GBL can be delicate, since during gameplay teachers' interventions can be experienced as disruptive with students' immersion and feelings of autonomy are at stake (Veldkamp et al., 2020). Furthermore, with escape rooms being inherently time constrained, reflective breaks do not fit with this setting. However, a debriefing session actively linking and decontextualize that knowledge seems crucial in any GBL session (Veldkamp et al., 2020).

1.4 Guiding frame

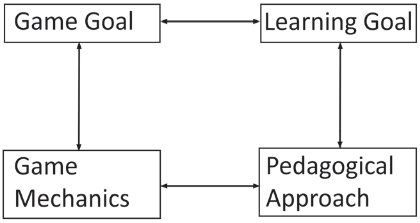


Figure 1. Guiding frame on alignment between the game goal, learning goal, pedagogical approach and game mechanics for designing an intrinsically integrated educational game, used for designing Newton's Race (Van der Linden et al., 2019).

In order to design an intrinsically integrated game a guiding frame, shown in Figure 1 can be used. This guiding frame was developed in an earlier study with the design elements for intrinsic integration in mind. In the guiding frame four key elements are integrated with each other; the game goal, learning goal, pedagogical approach and game mechanics. The top and bottom parts of Figure 1 show the integration of learning with gameplay, by aligning the game goal as closely as possible with the learning goal and by (ideally) aligning the pedagogical approach with the game mechanics. In addition, the alignment between the game goal and game mechanics are represented in the left half of Figure 1. Just as in any game, the player interacts with the game environment through game mechanics in order to try and reach the learning goal. Lastly, the right part of Figure 1 shows that in order to reach the learning goal a pedagogical approach is required.

Using this guiding frame we developed an intrinsically integrated game on Newtonian mechanics, Newton's Race (Van der Linden et al., 2019; Van der Linden et al., 2024), to gain further insight on both the design process of intrinsically integrated games and on how to effectivity implement them in the classroom.

1.5 Transfer

An important reason for embedding educational games with other lesson activities is to foster transfer. Students should also be able to use knowledge gained by playing an educational game outside the game context in other scenarios. In order for students to reach transfer, they must be able to 1) construct an abstract representation of the underlying principles and 2) apply these principles in all kinds of scenarios (Rebello et al., 2007).

1.6 Research question

In line with other research, the previous study on Newton's Race (Van der Linden et al., 2023) shows promising possibilities for the use of a debriefing session and classroom discussions after playing the game (Wouters et al., 2013; Choi et al., 2017; Tokarieva et al., 2019; Veldkamp et al., 2020). During that study, the debriefing session was held with small groups of students, not with an entire classroom. In an actual classroom setting, a teacher is not able to participate in every small group discussion taking place in class. The previous study (Van der Linden et al., 2023) also shows promising possibilities for using transfer worksheets in groups of small students in processing the conceptual knowledge and experience gained during the gameplay. We aim to gain insight on learning outcomes using learning activities, based on previous findings, that can be used in a realistic classroom setting. This raises the following research question:

> *How do different means of embedding an intrinsically integrated game in a realistic classroom situation affect students' conceptual development and transfer?*

Since the positive learning effects of a teacher-led debriefing sessions are known, the lesson activities used in this study were without teacher intervention. For this study two scenarios are created and compared, where after playing an intrinsically integrated game, students practice with the content in small groups, on the basis of worksheets. The first scenario focuses on first reinforcing aquired conceptual knowledge during gameplay, before proceeding to practice with transfer situations. As an alternative to the teacher-led debriefing session, students fill in a worksheet with questions about screenshots from the game and discuss those answers in small groups. This scenario will be referred to as the *game reinforcement group*. The second scenario emphasises on practicing with transfer situations. During this scenario students fill in a worksheet with questions on all sorts of transfer situations and discuss those in small groups. The second scenario will be referred to as the *transfer group*.

2. Materials and methods

2.1 Research design

For this study a quasi-experimental comparative design was used, see Figure 2. All students of five ninth-grade classes at a medium-scale urban school in the centre of the Netherlands were randomly assigned to the game reinforcement group and the students of five other classes to the transfer group. In both groups, the students participated in a game-based lesson on Newtonian mechanics without any teacher intervention. The teacher only facilitated the lesson and gave procedural instructions. The groups differed only in terms of the assignments they were asked to complete after gameplay.

The lesson plans used for this study can be found in Table 1 and Figure 2. At the beginning of the 80-minute lesson, students of both groups received general information about the lesson structure and subsequently performed a conceptual pre-test (appendix C). Table 1 refers to these activities as phase 1 and 2, respectively. It was made explicit that the results of these tests would not be used for their grade point average. Individual informed consent was obtained for all students. The students of both groups then proceeded, in pairs, to play the educational game Newton's race without any further instruction (phase 3).

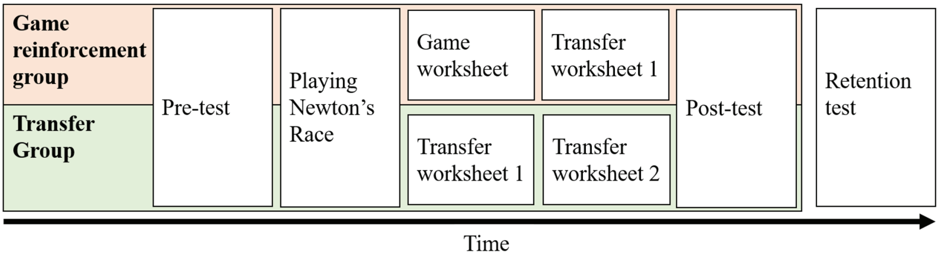


Figure 2. Visual representation of the lesson plan of both groups.

At this moment, both groups receive different assignments. The game reinforcement group received a worksheet filled with screenshots and game-specific questions (phase 4). For each screenshot, students had to figure out what type of motion is shown in the screenshot and what the corresponding setting was. They were also asked to explain their answers in writing. After filling out this worksheet individually, students discussed their answers in small groups of three or four persons. After that, the worksheets were collected by the teacher and the game reinforcement group received transfer worksheet 1, consisting of two assignments (phase 5). In the first assignment students were asked to generalize the acquired knowledge from the game. They were prompted to make the connection between forces and the resulting type of motion (acceleration, deceleration or constant velocity). In the second assignment students were five different transfer situations. For each situation they had to give the type of motion and explain their answer. Again, students started filling out the worksheet individually, and later were allowed time to discuss their answers in small groups and make additions to their work before the worksheets were collected.

Students from the transfer group started with transfer worksheet 1 (phase 4). They also started individually and later discussed their answers in small groups. Their worksheets were then collected and the transfer group was given a second worksheet (transfer worksheet 2) with additional transfer questions (phase 5). These were again filled out individually first and were then discussed with their peers before being collected by the teachers. Note that the transfer group did not engage in any game-based worksheets but were given double the amount of time to work on transfer worksheets, with questions unrelated to the game they just played.

Table 1: The lesson plan used for the study.

Duration (min)	Activity	Short description	Data collection
10	1. Introduction		
10	2. Pre-test		Pre-test
20	3. Playing Newton´s Race	Students play the game in pairs	Audio data
15	4. Worksheet	*Game reinforcement group*: Students fill in a worksheet with screenshots from the game were they have to decide on the type of motion, the thereby chosen setting and explain their answer *Transfer group*: Students fill in a worksheet consisting of 2 assignments: 1. Generalization assignment 2. Transfer assignment	Worksheets
15	5. Worksheet	*Game reinforcement group*: Students fill in a worksheet consisting of 2 assignments: 1. Generalization assignment 2. Transfer assignment *Transfer group*: Students fill in a worksheet with additional transfer situations.	Worksheets
10	6. Post-test		Post-test
10	7. Retention test	Two weeks after the lesson, students fill in a retention test.	Retention test

The lesson ended with a post-test for both groups (phase 6). Students entered a unique self-generated code on their worksheets and on their pre- and post-test to identify the different parts of their assignments in an anonymous way. Two weeks after the lesson students of both groups were asked to complete a retention test (phase 7). The pre-test, post-test, worksheets and retention test, translated from Dutch, can be found in Appendices C, D, F, and G respectively.

Note that neither the game reinforcement group nor the transfer group received any teacher instruction on the subject for the duration of the lesson. Both groups played the same educational game. The differences between the groups were confined to differences in assignments relating to the subject and the game (Table 1). The effective intervention thus consisted of different worksheets to be filled out during 30 minutes of the total lesson duration of 80 minutes (Table 1). This small specific intervention without teacher involvement was deliberately chosen, because the effects of teacher guided (small) group discussions and feedback were studied in an earlier experiment and the explicit goal for this study was to limit teacher involvement to procedural tasks (Van der Linden et al., 2023). Note also that this design does not entail a "control group" as such. In other words, there is no third group receiving a more traditional form of instruction, such as direct instruction. This study compares two groups of students following two different game-based lesson plans.

2.2 Participants

Ten classes of Dutch 9th grade students participated in this study. From a total of 220 participants (109 F/ 102 M / 9 other, average age 13.9 +/- 1.06), 111 were in the game reinforcement group (five classes) and 109 were in the transfer group (five classes).

2.3 Instruments

Pre-, post- and retention test

The pre-test consisted of five open questions about situations closely related to the game situation. Five identical questions were part of the post-test, to examine conceptual development. The post-test, however, contained three additional questions regarding situations not closely related to the game, to determine a possible transfer effect (Figure 3). The questions used in the pre- and post-test are based on questions of the Force Concept Inventory (Hestenes et al., 1992) and Appendices C and D gives the exact pre-, post- and retention test questions.

Newton's Race

Newton's Race was designed according to the guiding frame (Fig. 1). Several design iterations preceded the final version used in this study. Newton's Race consists of 5 levels, increasing in difficulty. The game goal for each level is to get a ball to finish a trajectory, the easiest way to do this is by forcing the ball to make a realistic movement. Players can do this at the beginning of each level. Players start each level with a setting screen where they can choose between different force options (Fig. 4A). After selecting a setting, the trajectory starts (Fig. 4B). Players then can only exert a force on the ball perpendicular on the movement of the ball, resulting in a change of direction (Fig. 4C). In later levels acceleration and deceleration platforms are added (Fig. 4D).

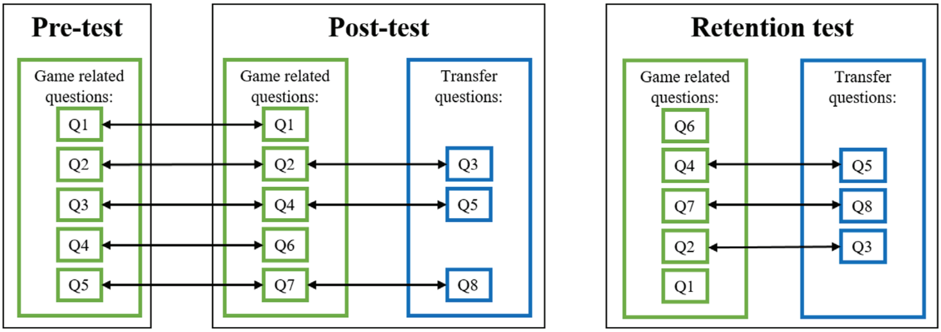
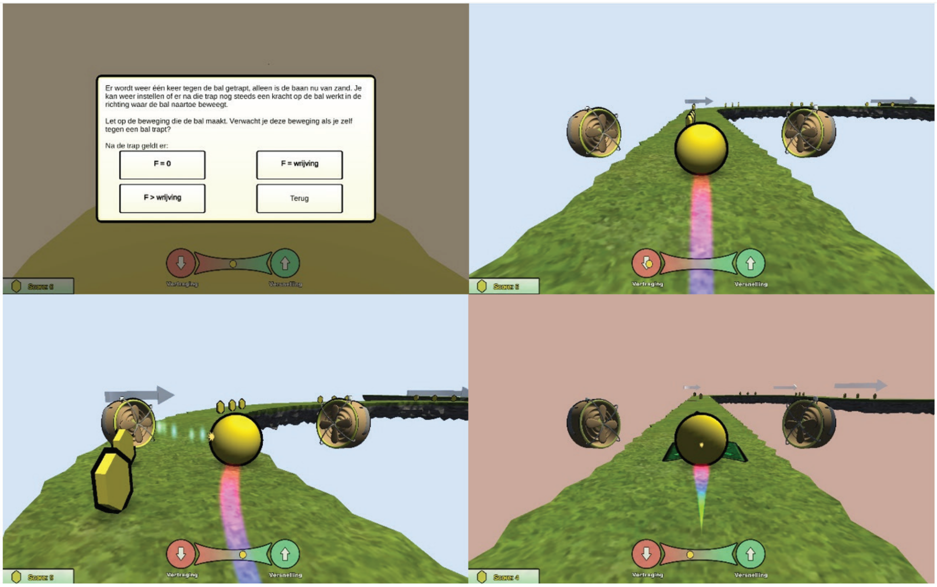


Figure 3. Visual representation of the pre-, post- and retention test questions, showing the conceptual connections between the pre- and post-test questions. E.g., Q2 and Q3 deal with the same concept, Q2 addresses the concept in a game related context and Q3 addresses the same concept in a different context. In the retention test the questions were shuffled. The complete pre-, post- and retention test can be found in Appendices C and D.


Er wordt weer één keer tegen de bal getrapt, alleen is de baan nu van zand. Je kan weer instellen of er na die trap nog steeds een kracht op de bal werkt in de richting waar de bal naartoe beweegt.

Let op de beweging die de bal maakt. Verwacht je deze beweging als je zelf tegen een bal trapt?

Na de trap geldt er:

Figure 4. A. The setting phase at the start of each level. Translated: A ball is kicked once. You can set if there is a force working on the ball in the direction of motion. Try to make the same movement a real ball makes when you kick it once. Make sure the ball gets to the finish line! Options: ‘After the kick: F = 0’, ‘After the kick: F = friction’, ‘After the kick: F > friction’ or ‘Go back’. **B.** Gameplay of level 2 of Newon’s Race. **C.** Players can change the direction of motion of the ball in order to take turns on the trajectory and collect coins if desired. **D.** On an acceleration platform (green) a force is applied in the direction of motion. On a deceleration platform (red) a force is applied in the opposite side of the direction of motion.

Worksheets

Three worksheets were used during the lesson (Fig. 2; Table 1). Transfer worksheet 1 consisted of two assignments, a generalisation assignment and a transfer assignment (Appendix F). Transfer worksheet 2 was only used in the transfer group, consisting of more transfer assignments. The game reinforcement group filled out the game worksheet (Appendix G) before they started with transfer worksheet 1.

2.4 Data collection and analysis

Pre-, post, and retention test were scored for correct answers, as were the questions on the worksheets. Participants filled out all the tests and worksheets anonymously, the different tests and worksheets were linked together per participant by a four-digit number that the participants generated themselves, thus preserving anonymity.

Table 2: Data collection elements for each student.

Data collection	Max score
Pre-test results	5
Post-test: game related questions (post-GR)	5
Post-test: transfer questions (post-T)	3
Retention test: game related questions (ret-GR)	5
Retention test: transfer questions (rest-T)	3
Transfer worksheet 1: generalization assignment	3
Transfer worksheet 1: transfer assignment	10
Game worksheet (only for the game reinforcement group)	n/a
Additional data: age, gender	n/a

Pre-, post- and retention test analysis

An independent samples *t*-test was performed to examine the mean differences between the game reinforcement group and the transfer group of pre-test scores. To control for the difference in pre-test scores, an ANCOVA was used to determine differences in post-test and retention test scores between both groups. Unfortunately, due to the conditions during the covid-19 pandemic, the number of completed retention tests was relatively low (N=152, or 69%). Therefore, we opted to also conduct the ANCOVA on the post-test scores for all the available post-test data (N=213, or 97%) and not only on post-test scores with matching retention test scores.

In addition, to measure a possible learning and retention effect, paired samples *t*-tests were performed on the pre-, post- and retention-test scores of all students (both groups). Another paired samples *t*-test was performed on the transfer questions for all students in order to determine a possible transfer effect from game related situations to other situations.

Worksheet analysis

An ANCOVA was performed on the generalization assignment scores and on the transfer assignment scores, controlling on pre-test scores. An additional ANCOVA was performed on the transfer assignment scores, controlling for the generalization assignment scores. Pearson's *r* was calculated for both groups to determine a possible correlation between the generalization assignment and transfer assignment scores. To gain a deeper understanding of students reasoning examples of typical student answers were gathered.

To evaluate student's understanding of concepts of motion and force during the game, the results of the game worksheet were scored for correct answers. Note that only students from the game reinforcement group filled out the game worksheet (N = 110).

3. Results

3.1 Pre-, post- and retention test

Table 3 gives the descriptive statistics of the pre-, post- and retention tests for game related and transfer situations. Notable is the difference in pre-test scores between the game reinforcement group and the transfer group. Also, the post-test scores and retention test scores are fairly similar. Since the maximum score is 5 for the pre- and post-test, the average scores are quite low.

Table 3: Results of the pre- and post-tests (with a minimal value of 0 and a maximal value of 5 for the game related questions and a maximal value of 3 for the transfer questions).

	Game reinforcement group		**Transfer group**	
	Mean	SD	Mean	SD
Pre-test	1.92	.929	1.66	.743
Post-test game related questions (post-GR)	2.07	1.04	1.95	.970
Retention test game related questions (ret-GR)	2.04	1.08	2.07	1.33
Post-test transfer questions (post-T)	1.26	.843	1.39	.747
Retention test transfer questions (ret-T)	1.24	.899	1.26	.854

The ANCOVA on post-GR scores found that the covariate of pre-test scores significantly predicts post-GR scores, F(1, 210) = 41.927, $p < .001$. There is no significant effect of groups on post-GR scores after controlling for the pre-test scores, F(1, 210) = 0.004, $p = .951$.

The ANCOVA on ret-GR scores also found that the covariate of pre-test scores significantly predicts ret-GR test scores, F(1, 149) = 18.748, $p < .001$. There is no significant effect of groups on ret-GR scores after controlling for the pre-test scores, F(1, 49) = 1.00, $p = .319$.

The ANCOVA on post-T scores found that the covariate of pre-test scores significantly predicts post-T scores, F(1, 210) = 12.969, *p* < .001. There is no significant effect of groups on post-T scores after controlling for the pre-test scores, F(1, 211) = 2.76, *p* = .098.

Finally, the ANCOVA on ret-T scores also found that the covariate of pre-test scores significantly predicts ret-T scores, F(1, 149) = 6.362, *p* = .013. There is no significant effect of groups on ret-T scores after controlling for the pre-test scores, F(1, 149) = .371, *p* = .543.

Paired samples *t*-tests were performed to examine the mean differences of all participants (N=213). The first paired sample t-test between the pre-test scores (M=1.77, SD=.844) and the post-tests scores on game related situations (M=2.00, SD=1.01) found a significant increase in conceptual understanding; *t*(212) = -3.313, *p* = .001, Cohen's *d* = .038.

The second paired samples *t*-test was performed to examine the mean differences between the total post-test scores (M=3.40, SD= 1.65) and the total retention test scores (M=3.30, SD= 1.78). No significant difference was found; *t*(148) = .883, *p* = .379.

The last paired samples *t*-test was performed to examine the mean differences between post-GR scores (M=1.43, SD= .700) and post-T scores (M=1.32, SD= .801). No significant difference was found; *t*(213) = 1.909, *p* = .058.

In short, no significant differences in terms of learning outcomes between the game reinforcement group and the transfer group were found. Pre-test scores were a significant predictor for all other test scores. A small significant difference between pre- and post-tests for all participants was found. No significant difference was found between post- and retention test scores. Also, no significant difference was found between the game related and transfer scores on the post-test.

3.2 Worksheets

Table 4 gives the results of the two assignments of transfer worksheet 1; the generalization assignment and the transfer assignment.

Table 4: Results of the worksheet two assignments: Generalization assignment (with a minimal value of 0 and a maximal value of 3) and the transfer assignment (with a minimal value of 0 and a maximum value of 10).

	Game reinforcement group		**Transfer group**	
	Mean	SD	Mean	SD
Generalization assignment (max. score: 3)	.806	1.25	. 458	1.00
	26.9%	155%	15.3%	218%
Transfer assignment (max. score: 10)	3.69	2.36	4.66	1.99
	36.9%	64.0%	46.6%	42.7%

An ANCOVA on the scores of the generalisation assignment found that the covariate of pre-test scores did not significantly predict generalisation assignment scores, F(1, 214) = .020, *p* = .889. After controlling for the pre-test scores, there is a significant effect in terms of the generalisation assignment scores, favouring the game reinforcement group, F(1, 214) = 4.905, *p* = .028.

An ANCOVA on the scores of the transfer assignment found that the covariate of pre-test scores did not significantly predict transfer assignment scores, F(1, 214) = .524, *p* = .470. Also in this case, however, there is a significant effect in the scores for the transfer assignment after controlling for the pre-test scores, F(1, 214) = 11.265, *p* = .001, however, in this case favouring the transfer group.

An additional ANCOVA on the scores of the transfer assignment found that the covariate of the scores of the generalisation assignment did significantly predict transfer assignment scores, F(1, 216) = 63.727, *p* < .001. Also, there is a significant effect in the scores for the transfer assignment after controlling for the scores of the generalisation assignment, F(1, 216) = 18.981, *p* < .001, favouring the transfer group.

In order to determine a possible correlation between the two worksheet assignment scores, Pearson's *r* was calculated for both groups on the generalization assignment and the assignment on transfer situations. The scores of were found to be correlated for the game reinforcement group, *r*(108) = .52, *p* < .001 and the transfer group *r*(107) = .42, *p* < .001.

Table 5: Examples of students' typical answers.

	Generalization assignment:	**Transfer assignment**
	Make a list for yourself: what have you learned?	Give the kind of motion that is being made, explain your answer. A hockey puck is being hit by a hockey stick.
Correct answer	If the forward force is greater than the opposing force, there is an acceleration. If the opposing force is greater than the forward force, there is an deceleration. If the forward force is equal to the opposing force, there is a constant velocity.	Acceleration, the forward force is greater than the opposing force.
Partially correct answer	There are different velocity options, with an acceleration the ball goes faster, with a deceleration slower. If the opposing force is greater than the forward force, the ball goes slower. There is a constant velocity if the forward force is equal to the opposing force.	Acceleration / Forward force
Incorrect answer	? / I don't know / Something with forces / no answer	No answer

To gain further insight on students reasoning a few examples of students typical answers, translated from Dutch, are given for both assignments in Table 5.

Table 5 in combination with the quantitative data (Table 4) demonstrate that some students are able to give complete correct answers. However, the majority of students give partially correct or incorrect answers, leaving the answer sheet (partially) blank most of the time.

Figure 5 shows the results of the game worksheet filled out by students from the game reinforcement group. It shows that most students are able to identify the type of motion from the game. Fewer students can select the corresponding setting and most students fail to give an explanation for their answer.

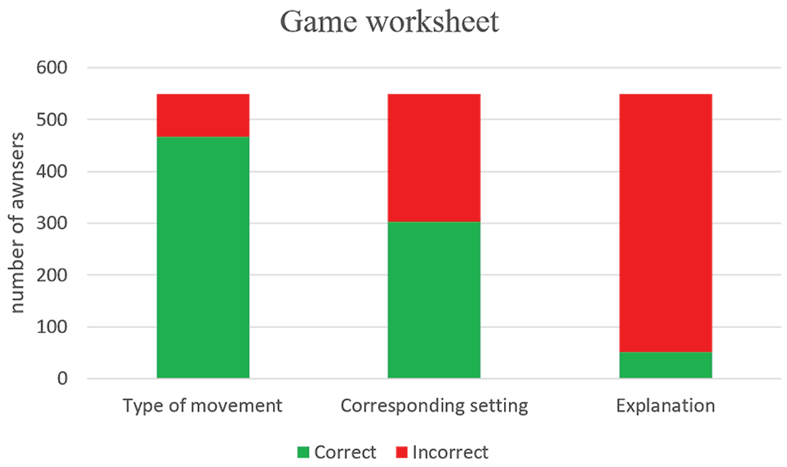


Figure 5. Results of the game worksheet (only filled out by the game reinforcement group, N = 110). This worksheet consists of five screenshots of Newton's Race with three questions each. 1) What type of motion does the ball make (deceleration, constant velocity, acceleration, I do not know)? 2) What is the corresponding setting (F=0N, F=friction, F>friction, I do not know)? 3) How do you know the chosen setting from question 2 corresponds with the chosen type of movement from question 1? Note that incorrect answers include 'I do not know' and missing values.

4. Conclusions and discussion

4.1 Situating the study

This study further attempts to gain information on how to effectively embed an educational game into the classroom, by using Newton's Race as an case study. Newton's Race was designed on the basis of intrinsic integration (Van der Linden et al., 2019). In a follow-up study, the learning effect of Newton's Race as a stand-alone intervention was measured (N = 223) and information on how players interacted with the game was gathered (Van der Linden et al., 2024). A small learning effect was found and with information on players interactions, the design of Newton's Race was further improved. After that, a lesson surrounding Newton's Race was designed to foster transfer, this lesson was tested in small groups of about seven students (Van der Linden et al., 2023).

Results were promising and for the present study the lesson was altered to fit classrooms of thirty students, without teacher intervention. The learning effect of the previous study was much larger than this study (*d* = .908 vs. *d* = .038). It is to be expected that a debriefing session after playing Newton's Race actively led by a teacher in a small group of about seven students is more effective than students working on worksheets and discussing them by themselves. Other studies also emphasise the importance of teacher involvement and an debriefing session (Wouters et al., 2013; Long & Aleven, 2014; Lamb et al., 2018; Choi et al., 2017; Tokarieva et al., 2019).

4.2 Conclusions

We now revisit the research question:

> *How do different means of embedding an intrinsically integrated game in a realistic classroom situation affect students' conceptual development and transfer?*

Pre-, post- and retention test

The game reinforcement group scored significantly higher on the pre-test than the transfer group. The pre-test scores are shown to be a significant predictor for the post- and retention test scores. This can be seen as an confirmation of the well-known fact that students' prior knowledge is a strong predictor of learning outcomes (Ausubel, 1968; Hattie, 2007).

General learning effect

We found a small significant learning effect (d = .038) between pre-test and post-test scores for all students. The limited learning effect is to be expected with such a short intervention time. All students apparently retained the newly acquired knowledge, since no significant differences between post-test and retention test were found in either group.

Difference in embedding

After controlling for the pre-test scores, there were no significant differences between the game reinforcement group and the transfer group in post-test and retention test scores. Working on game-related questions or transfer questions – not related to the game – led to the same learning outcome. A possible explanation is that the difference between the learning experience of both groups is the relatively small, namely the difference in worksheets during phase 4.

Transfer

No significant difference was found in the post-test scores between the game related questions and the transfer questions, this indicates that all students were able to transfer their new acquired knowledge to different situations.

Game worksheet

Results from the game worksheet show that most students select the correct type of motion the ball makes (in the game) from a list . However they find it more difficult to select the corresponding setting for that motion. Apparently, they did not reach the learning goal from solely playing the game. The large majority of students was not able to offer an acceptable explanation for their answers, indicating that working with an assignment that was explicitly based on the game has not proved to be a viable strategy in this case.

Transfer worksheets

The game reinforcement group scored significantly higher on the generalisation assignment and the transfer group scored significantly higher on the transfer assignment. In general however, the majority of students gave partially correct or incorrect answers by leaving the question (partially) blank on the worksheet. A correlation is found between the assignments of transfer worksheet 1. Students who scored higher on generalisation, also scored higher on transfer. This is in line with other research on transfer (Perkins & Salomon, 1994).

In summary, students' conceptual development and transfer shows a small but significant increase through an the embedded intrinsically integrated game in a lesson. Results from the game worksheet indicate that playing the game and filling out a worksheet about gameplay in small groups, is not enough for students fully understand the physics of the game. The way the game is embedded has an effect on conceptual development and transfer. This is supported by the fact that the game reinforcement group scored better on the generalisation assignment and that the transfer group scored better on the transfer assignment. Apparently, even though post-test scores indicate no significant differences in learning effects between both groups, there are differences in how they learn. Therefore, it is important to think about what and how do you want your students to learn and take that into account whilst implementing an intrinsically integrated game in a lesson.

4.3 Practical limitations

For this study we deliberately implemented a small specific intervention, this resulted in a lower power. Due to the fact that schools shut down as a consequence of the COVID-19 pandemic, the data collection could not be performed in the right time during the curriculum. When regular classes continued, students' motivation for the subject of Newtonian mechanics was therefore lower, because students were currently working on a different physics subject. Also, as an effect of the corona pandemic guidelines, more students stayed home than expected in regular times, resulting in fewer retention test participants.

4.4 Implications

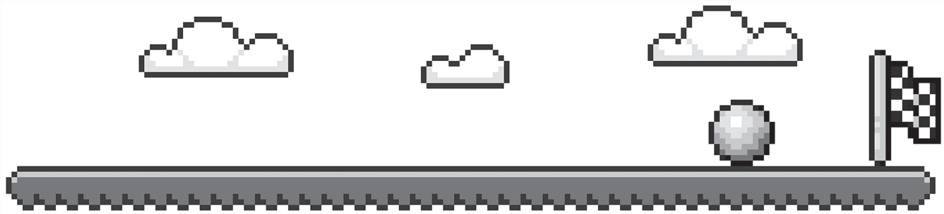
The findings of this study show that it is not only important to embed an educational game in the classroom, but it is also important how you do it. In the previous study on Newton's Race (Van der Linden et al., 2023) the positive effects of a teacher-led discussion are demonstrated. For this study we wanted to gain insight on learning effects without teacher intervention and, although focusing on students transfer with a generalization and transfer assignment, one cannot rule out the effects of a teacher intervention (Long & Aleven, 2014; Tokarieva et al., 2019).

4.5 Further research on embedding games in the classroom

The findings of this study demonstrate some promising directions on how to implement an intrinsically integrated game into the classroom. The next step would be focussing on teacher involvement, still working with a realistic classroom environment. It would be interesting to see how students reasoning change, for instance, with a teacher-led classroom debriefing session after playing the game. An increased learning effect then is to be expected, however does that also apply for non-participatory students? An increased learning effect is also expected when students receive feedback on their worksheet, but how does that change their reasoning?

With such interventions a learning effect is expected to increase. The point of interest lies in qualitative research: How does students reasoning change? This may be studied with think-aloud procedures. With a greater understanding of the influence of interventions on students reasoning, more fitting activities can be designed and implemented for student to transfer their in-game knowledge to out-game scenarios.

Chapter 6 General discussion



1. Main research question

This dissertation addresses the subject of digital educational games in secondary education, with an emphasis on physics. Let us revisit the main research question of this dissertation:

> *How can a digital intrinsically integrated game be designed and implemented in a lesson fostering conceptual knowledge and transfer regarding Newtonian mechanics?*

This question, and hence the dissertation, can be split into two parts. The first part (Study 1 and Study 2) focuses on the design of such a digital educational game and the second part (Study 3 and Study 4) on how that game can be implemented in a lesson. To answer the main research question, we now give an overview of the findings for each study. We will also provide some implications for educational practices, the research field and future directions.

Study 1 (Chapter 2) concluded that integrating learning with gameplay (intrinsic integration) should be the basis of designing a digital educational game. However, this is not self-evident, since a design choice flowchart or adding certain design elements for a guaranteed effective intrinsically integrated game, are not available to our knowledge.

In an attempt to bridge this gap we constructed a guiding framework (Fig. 1), based on the idea of *intrinsic integration*, as a basis for the game design process. We used the guiding frame in a specific order, starting with formulating the learning goal (step 1), as one would do for any educational activity. For Newton's Race the learning goal became that *by the end of the game*, *players will be able to apply the relationship between forces and motion by giving explanations and predictions in realistic everyday scenarios.* We proceeded to select a fitting pedagogical approach for students to reach that particular learning goal (step 2). We chose a pedagogical approach based on the idea that students should experience the effects of their existing ideas, so that they find the need to adjust those to scientific theories. After the pedagogical approach is chosen, suitable game mechanics to strengthen that approach need to be found (step 3). In the case of Newton's Race a setting phase was required for players to enter their existing ideas about forces working on an object. In addition, players should experience the effects of those ideas, thus the resulting types of motion must be made visible. Finally, from the game mechanics a fitting game goal should emerge (step 4). Finishing a trajectory with a simple, real-world object, such as a ball, fits with the chosen game mechanics. For true intrinsic integration the game goal must align with the learning goal. Therefore, the game goal in Newton's Race is to finish a trajectory with a realistic (scientifically correct) moving ball.

In short, the final version of Newton's race consists of five levels, increasing in difficulty. Players start each level with a setting screen where they choose a force option that works on the ball during its trajectory (Fig. 2A). Then, after the ball gets its initial push, the trajectory starts with the chosen setting (Fig. 2B). During the trajectory, players can only exert forces perpendicular on the movement of the ball to change direction (Fig. 2C). In later levels acceleration and deceleration platforms are added (Fig. 2D).

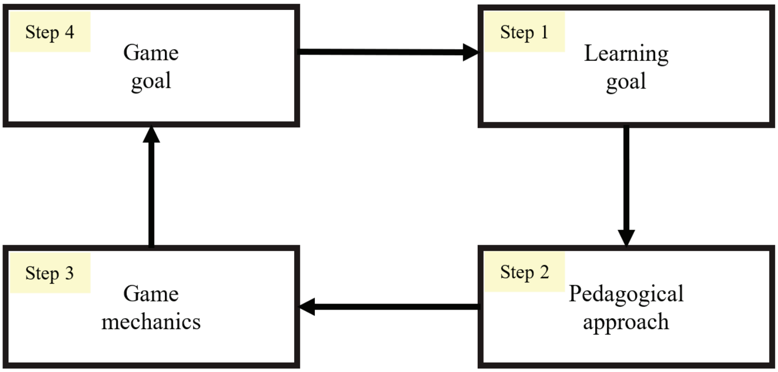
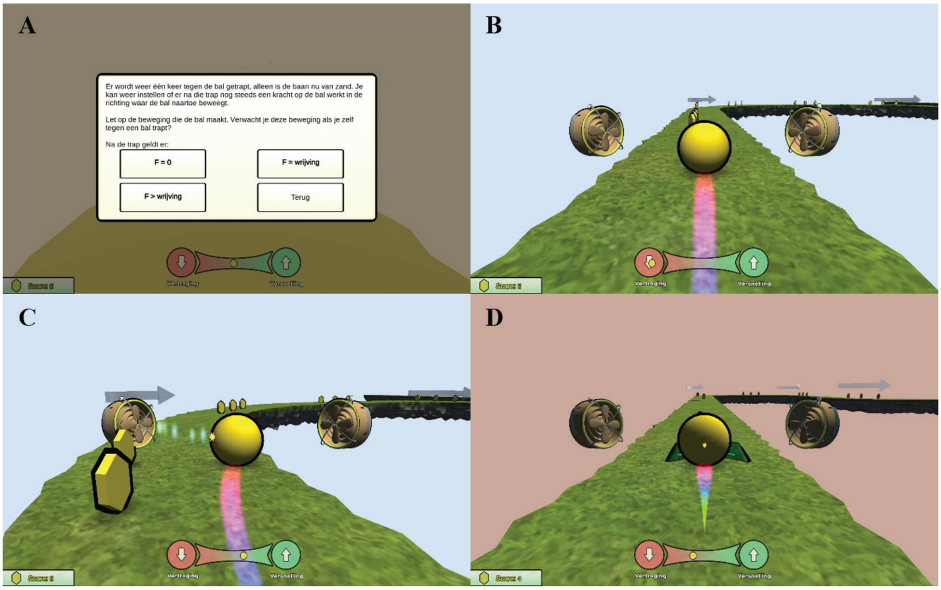


Figure 1. Guiding frame for intrinsic integration on aligning the learning goal, pedagogical approach, game mechanics and the game goal.

Ideally, reaching the game goal also implies reaching the related learning goal, meaning that players must reach the learning goal as a necessity for reaching the game goal. Note that according to intrinsic integration, these goals need to be strongly interconnected. As a counterexample, for instance, the requirement in a platform game in which at the end of each level players need to solve a mathematical equation to proceed to the next level, is in contrast with intrinsic integration. Aligning learning and game goals is not self-evident, and Study 1 shows the difficulties that arise when players work around the intended alignment of these goals. For instance, we demonstrated that a few experienced gamers were able to reach the end of the final level without the scientifically correct setting, thus without reaching the learning goal.

Even though the alignment of goals was a difficult step, we found that aligning the game mechanics and pedagogical approach (step 3) is an even more difficult step. We used several iterations focusing on this step in the educational game used in this study. Newton’s Race, relies on players’ experimentation with the different force settings for our in-game pedagogical approach.

A key element in Newton’s Race is the setting phase at the start of each level. When playing a level in a commercial racing game, players usually first encounter some sort of selection phase before they actually start racing. In commercial racing games, this setting phase could consist of, for instance, selecting a vehicle, driver or trajectory. Although it is common to have a setting phase in a race-like game, in Newton’s Race the setting phase is a bit different, as it prompts players to think about and experiment with different force settings. On the one hand, this setting phase is a very useful intervention. It ensures that during gameplay players can both experience *flow* (Csíkszentmihályi, 1990) and reflection, without getting in each other’s way. On the other hand, reading text during the setting phase appeared to be too much to ask from some players. Therefore, understandably, some players opted for a trial-and-error approach, as evidenced from the game logs. With this approach players can still experience the effects of different settings and even learn which setting works best to reach the finish lines. We concluded that for the trial-and-error type of players it is even more essential to offer additional activities, to make the step from in-game learning to conceptual understanding more explicit. Educational games in general need to offer additional learning activities for players to be able to transfer their acquired knowledge from in-game scenarios to different ones (Wouters et al., 2013; Choi et al., 2017; Tokarieva et al., 2019).



Er wordt weer één keer tegen de bal getrapt, alleen is de baan nu van zand. Je kan weer instellen of er na die trap nog steeds een kracht op de bal werkt in de richting waar de bal naartoe beweegt.

Let op de beweging die de bal maakt. Verwacht je deze beweging als je zelf tegen een bal trapt?

Na de trap geldt er:

F = 0

F = wrijving

F > wrijving

Terug

Figure 2. A. The setting phase at the start of each level. Translated: A ball is kicked once. You can set if there is a force working on the ball in the direction of motion. Try to make the same movement a real ball makes when you kick it once. Make sure the ball gets to the finish line! Options: 'After the kick: F = 0', 'After the kick: F = friction', 'After the kick: F > friction' or 'Go back'. **B.** Gameplay of level 2 of Newton's Race. **C.** Players can change the direction of motion of the ball in order to take turns on the trajectory and collect coins if desired. **D.** On an acceleration platform (green) a force is applied in the direction of motion. On a deceleration platform (red) a force is applied in the opposite side of the direction of motion.

Study 1 demonstrated some design difficulties, making it necessary to improve and reevaluate Newton's Race before we could move on to the design of the additional educational activities. Even though literature shows that these activities are needed to strengthen learning and transfer, at this point we first need to know how players learn from Newton's Race itself.

Having designed an intrinsically integrated educational game on Newtonian mechanics, study 2 focused on how players learn while playing an improved version of Newton's Race. Results show that players' conceptual understanding of Newtonian mechanics improved significantly over a relatively short intervention time (15 minutes). The mechanism behind this apparent learning was studied based on game log data, showing that players' gameplay mostly matched expected learning during the game. For instance, log data shows that players opt for the scientific correct setting more often as they progress through the game. Indicating that players start by toying with different settings, but learning which is the correct setting during gameplay.

Study 2 showed that the improvement of conceptual understanding was mainly evident in game-related scenarios. In a post-test, players performed significantly worse on transfer questions than on game-related questions, e.g., questions about riding a bike in comparison with questions about kicking a ball. This emphasized the need to study how to embed the game within other educational activities with the goal of enhancing transfer of the knowledge gained during the game to other situations.

For Study 3 (Chapter 4) such educational activities were designed and evaluated to gain insight on how to implement an intrinsically integrated game and thus foster not only learning in game-related situations, but also in transfer situations. Newton's Race itself is based on a student centred pedagogical approach. To fit with this approach, the lesson as a whole fits within Inquiry Based Learning. In short, students start the lesson with activating their pre-existing ideas. Then they play Newton's Race, followed by a debriefing session. To foster transfer, students work on a generalisation and a transfer assignment using dedicated worksheets. Findings of Study 3 show, in comparison with Study 2, an increase of conceptual understanding and transfer. Activating students' pre-existing ideas before starting the game, strengthens the pedagogical approach during gameplay. The combination of the debriefing session with the generalisation and transfer assignments after gameplay resulted in student's enhanced ability to transfer in comparison with Study 2.

Thus, as expected, embedding Newton's Race in additional learning activities is essential to strengthen learning and transfer. The promising results of the case study (Study 3) prompted a follow-up on how to implement our approach within a larger context.

Based on the assumption that small and guided group discussions combined with a full debriefing session guided by a teacher is not feasible in a full classroom and within time constraints, a realistic lesson plan was designed for Study 4 (Chapter 5), our question being whether the learning outcomes of a lesson relying only on teacher procedural guidance? Two versions of a lesson plan were used: 1) with a game-related debriefing worksheet after gameplay, without additional transfer assignments (reinforcement group) and 2) without a debriefing worksheet, but with the additional transfer assignments (transfer group).

Results from Study 4 show that filling out a debriefing worksheet about gameplay in small groups, is not enough for students to reach sufficient conceptual understanding. They (reinforcement group), however, performed better on the generalisation assignment, in comparison with students from the transfer group. Students in the transfer group, however, indeed performed better on the transfer assignments. These results indicate that the way the game is embedded influences the learning process and the conceptual development and transfer. Therefore, it is important to think about what and how teachers want their students to learn and take that into account whilst implementing an intrinsically integrated game in a lesson.

Importantly, the overall gains in conceptual understanding and transfer from Study 4 were lower than Study 3. The main difference between both studies was the teacher's role in the lesson and the size of the group. During Study 4, we noticed that students actually asked for feedback, they really wanted to know whether or not their thought process was correct. But in this particular design, this was not accommodated. Apparently, and confirmed by many other studies, the teacher's role is an essential one (Long & Aleven, 2014; Tokarieva et al., 2019), especially during debriefing after gameplay. In Study 3, after the debriefing session, all groups were able to reason on the relationship between forces and motion in game related situations. They also were able to interpret the situations on the screenshots correctly. It seems better to have a full classroom debriefing session that is guided by a teacher, than letting students debrief with a worksheet in small groups without a teacher's guidance.

Between Study 3 and Study 4 Newton's Race was not changed in terms of game mechanics, therefore one could argue that the chosen pedagogical approach should work equally in both studies. However, due to the changes in additional lesson activities we think that the pedagogical approach better fulfilled its potential in Study 3. There is a significant change at the start of the lesson. In Study 4 only a small introduction was held, in Study 3 the lesson started with explicit activation of pre-existing ideas. One of the elements of our chosen pedagogical approach relies on the need for students to see the point of what they are doing (Lijnse & Klaassen, 2004), which is strengthened in Study 3.

In addressing the main research question, we get a dual answer. First, to design a digital intrinsically integrated game on Newtonian mechanics we recommend using the guiding frame (Fig. 1), based on the intrinsic integration principle, in a specific order. Starting with the learning goal and pedagogical approach and from there finding suitable game mechanics and a game goal, that in turn also is aligned with the learning goal. Truly aligning both goals and aligning the pedagogical approach with game mechanics, is by no means self-evident and requires several design iterations. Second, to foster conceptual knowledge and transfer, the intrinsically integrated game preferably is embedded within other learning activities, that complement the chosen pedagogical approach during game design. For example, an exercise to activate students' pre-existing ideas, a debriefing session and assignments to enhance transfer. During this lesson, the teacher should play an active role guiding the learning process by helping students make connections between in-game learning and other situations.

2. Implications for educational practice

Based on the findings in this dissertation we propose some implications for using an intrinsically integrated game in the classroom and for using Newton's Race specifically.

2.1 General implications

There are two main implications for using a digital game in a lesson. First, the role of a teacher is essential for guiding students in their learning process and for providing feedback. Second, the way that a digital educational game is embedded, is crucial for the learning process. Based on our findings, some recommendations can be made.

First and foremost, a teacher guided debriefing session is strongly recommended in all cases. Study 3 and 4 show that a debriefing session, guided by the teacher, is necessary for students to truly comprehend the content learning in the game and making their conceptual understanding explicit. In such a debriefing session, the teacher leads a discussion with the students making sure, they (scientifically) understood what happened during gameplay. Screenshots of gameplay can be used as a tool for such a debriefing session.

Second, most learning goals are formulated in such a way, that students must be able to use knowledge in all kinds of different contexts. To be able to transfer newly acquired in-game experiences to other contexts, an assignment on transfer is recommended. For the content of this assignment, teachers can make choices depending on how they want students to learn, making choices that fit with their preferred teaching style. For instance, teachers can choose to make a more open ended or closed generalisation assignment, depending on classroom needs. In one class it can work to ask more openly '*what have you learned about Newtonian mechanics today*', whereas in another class it works better to provide the students with keywords that they need to use in their answer. In any case, we recommend a combination of some sort of generalisation assignment and an assignment to practise with situations that are not closely related to the game situation.

Besides the above mentioned recommendations, other more general recommendations to enhance learning in a formal setting, such as providing feedback and activating prior knowledge, also apply.

For teachers to actually use a digital game in their lesson some conditions need to be met. Teachers are busy enough as it is, therefore using a digital game in their lesson should be accessible, useful and preferably fun. For these reasons, the educational game should be free and easily downloadable for any device. Currently Newton's Race is only compatible with Android devices. To make Newton's Race usable on any device, a web-based version could be made. The game should come with complementary materials were the learning goal and the game goal, are made clear. This should provide the teacher with enough information to make an informed decision if the game fits with the curriculum. It would also be helpful if the pedagogical approach behind the game and game mechanics were briefly explained. This helps the teacher better understand the game as a tool for learning and a basis for the debriefing session. The complementary materials should also include a basis for the debriefing session and examples for additional learning activities. This way, teachers do not need a full training to use digital games in their lessons, and they can assemble a lesson that fits with their needs, such as their class time.

2.2 Implementing Newton’s Race: a recommendation

Based on the findings of Study 3 and 4 (Chapters 4 and 5) and the aforementioned recommendations, we propose a final design for implementing Newton’s Race in the classroom (Fig. 3). Newton’s Race itself is still based on a student centred approach, therefore it is fitting that the lesson is also student centred.

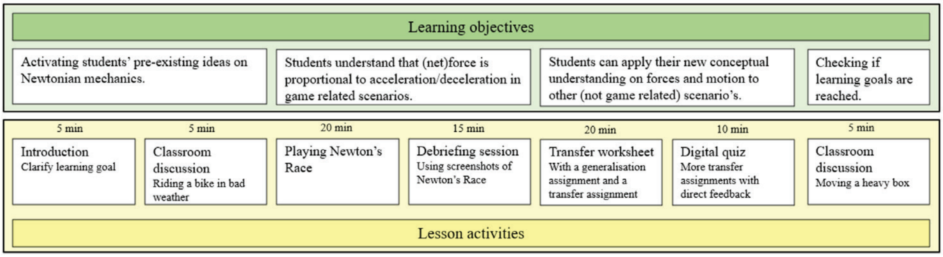


Figure 3. Overview of our proposed lesson design implementing Newton’s Race.

The lesson starts with clarifying the learning goal. In our case: *By the end of the lesson, you will be able to explain the relationship between (net) force and motion and make predictions hereof in various scenarios*.

To activate students’ pre-existing ideas on the subject, Newtonian mechanics, the teacher guides a short classroom discussion on a statement about riding a bike with constant velocity in bad weather (Appendix E). Students can simply raise their hands for with which statement they agree, or if more active participation is preferred, send them to different corners of the classroom. Then let them argument their case and see if students change their original idea. For the third activity they play Newton’s Race, depending on the facilities, they can play solo or in pairs. In the latter case they should alternate taking turns.

After gaming, a teacher must facilitate a debriefing session on the basis of screenshots from the game to discuss with the class what type of motion is shown, which is the corresponding setting and why so. Then students get a worksheet with a generalisation assignment and a transfer assignment (Appendix G). It is recommended to first let them start on the worksheets individually, then discussing in small groups and thereafter discussing the worksheet with the whole class, where the teacher can provide appropriate feedback. To further promote transfer, students then practice with all kinds of scenarios in the form of a digital quiz, with all kinds of scenarios where students have to choose the type of motion and explain why they have chosen that type of motion. This way every student gets direct feedback on every question.

As a final activity, we would recommend giving the students another discussion statement (Appendix E). In addition to completing the lesson, this also provides quick insight for the teacher on the student’s learning gains.

3. Implications for the field

We started our study by analysing the, at that point in time, most recent meta-analysis on digital games, design and learning. (Clark et al., 2016). The summarisation of the main take-away point is that research on cognitive effects of educational games in general shows promising results, however there are large variations in learning outcomes between individual educational games. This could very well align with the large variations within the design of educational games.

Now, about seven years later, when we look at recent review studies and meta-analysis on digital game-based learning (Manzano-León et al., 2021; Wang et al., 2022; Timotheou et al., 2023), that is basically still the main take-away point. These review studies and meta-analyses also promote that more research is needed on internal game mechanisms to better understand their effects (Wang et al., 2022), how to use educational games more efficiently at different levels of formal education (Manzano-León et al., 2021) and the improvement of the overall effectiveness of educational games (Yu et al., 2020).

This dissertations' added value to the current body of literature on digital game based learning lies in the case study approach. This approach makes it possible to do an in depth analysis on intrinsically integrated game design and embedment in the classroom.

Even though the need for research on educational game design has been voiced for some time now, most studies focus on the effects of educational games on learning, with only few giving additional insight on the design process (Fanfarelli, 2020). Whilst the insight on the design process of various educational games is precisely what is needed to gain a deeper understanding on how students learn from educational games. In addition, the theory of intrinsic integration has been around for decades (Kafai, 1996) and its application has shown promise for increasing learning from educational games (Cutting & Iacovides, 2022). Despite that, intrinsic integration has not resulted in a large body of research. Our study, specifically Study 1 and Study 2, focuses on using intrinsic integration to design, develop and evaluate learning by playing an intrinsically integrated game. Which therefore fits with the current need in research on educational game design, specifically the need for more studies on designing and developing intrinsically integrated games (Pan & Ke, 2023).

For teachers to actually use a digital educational game, the learning goal of the game needs to fit with a learning goal in the curriculum. The review of Pan and colleagues (2022) indicate that the learning goal is crucial in determining the use of game genre and mechanics. Our results are in line with that, strengthening their assumption that there is an association between learning goal, learning content (pedagogical approach) and game genre (game mechanics and game goal). It also fits with the order of design steps in our guiding frame (Fig. 1), since they recommend that game developers should ensure that the game is designed as a pedagogical instrument first and the game activities second (Pan et al., 2022).

Tokarieva and colleagues (2019) show that the integration of digital educational games into formal education is still relatively low. However, integrating educational games into formal education entails more than just letting students play the game. Embedding educational games into other learning activities strengthens learning and transfer (Wouters et al., 2013; Pan et al., 2022). An educational game should be a tool in a teacher's toolbox, not a substitute for them or to use as a complete lesson. As we found in Study 4, the teacher is still a key element to make learning happen. We believe that a teacher is needed to guide the learning process, helping students make connections between in-game learning and other situations. In line with findings of Tokarieva et al. (2019), we find that a teacher is needed for briefings and debriefings. A game cannot simulate every situation, therefore the teacher cannot be replaced by a game.

4. Future directions

Finally, our results give some interesting insights for future research. Here are a few concrete recommendations for future research: the study design and the extension to other educational domains.

In terms of study design, the use of a control group is debated in GBL research, the question being what a true control group would mean in GBL? Surely, comparing a test group with a group receiving no educational intervention at all makes little sense, as we can assume that a group receiving any kind of learning activity would perform better than a group receiving no learning activity at all. But there are so many options for lesson activities to compare with, what makes a logical control group? One obvious comparison would be to study the differences between a lesson based on GBL (Section 6.2.2) vs a lesson without GBL, especially regarding a retention effect.

On a personal note, I have students in my present-day physics classes who participated in one of the studies three years ago. They still recollect playing Newton's Race, without me prompting them, they sometimes start talking about it. Which makes me wonder, if they still have active memories about playing Newton's Race, the learning activity at least made an impression, would a more traditional lesson have the same effect? Perhaps this effect is similar to the effects of experiential learning (Kolb et al., 2014; Morris, 2020). Of course, playing a game is by definition not a real-world experience such as, for example, a field trip is. However, evidence is found that virtual field trips also can yield positive effects on enjoyment and retention (Makransky & Mayer, 2022). In addition, playing a game in formal education still is a challenging and novel experience that requires active participation. This is an interesting direction for future research.

The log data collected in Study 2 provides some insights on how students learn through the pedagogical approach implemented by intrinsic integration with the game mechanics. To deepen our understanding, more research with different techniques is recommended. For instance, to follow more closely what students do during gameplay, eye tracking technology can be used. In addition, the Think-Aloud method could also give insight on students decision making and reasoning during gameplay.

To further strengthen the research body on intrinsic integration, more research in different educational domains is needed. This can be done by designing more intrinsically integrated games based on our proposed guiding frame (Fig.1). We now designed the game for something that students encounter in everyday life, it is also interesting if one could use the guiding frame to design a game on more abstract scientific models, such as quantum mechanics or electromagnetism in physics education. The guiding frame should also be tested in other educational domains, such as language education or teaching history, to gain more insight on how the guiding frame translates to designing intrinsically integrated games outside the physics domain.

The digital nature of intrinsically integrated games seems suitable for some sort of in-game adaptability, differentiating at individual learners' levels. It would be interesting to explore possibilities where the gameplay adjusts for individual player's needs.

Overall, this dissertation shows how an intrinsically integrated game on Newtonian mechanics can be successfully designed and implemented in a lesson. Even though there seems to be an abundance of research on game-based learning, the field still askes for more in-depth analysis on game design and implementation. Our studies provide such an in-depth analysis, giving more insight on students' learning and providing recommendations for others who want to venture into the wonderful world of educational game didactics.

References

Ávila-Pesántez, D., Rivera, L., & Alban, M. (2017). Approaches for serious game design: A systematic literature review. *Computers in Education Journal*, *8*(3), 1–11. https://doi.org/10.3390/info14050277

Ausubel, D. (1968). *Educational psychology: A cognitive view*. Holt, Rinehart, & Winston.

Bellotti, F., Kapralos, B., Lee, K., Moreno-Ger, P., & Berta, R. (2013). Assessment in and of serious games: An overview. *Advances in human-computer interaction*, 2013, 1-1. https://doi.org/10.1155/2013/136864

Capps, D.K., & Crawford, B.A. (2013). Inquiry-based instruction and teaching about nature of science: are they happening? *Journal of Science Teacher Education*, *24*(3), 497–526. https://doi.org/10.1007/s10972-012-9314-z

Choi, G. W., Pursel, B. K., & Stubbs, C. (2017). Supporting educational games in higher education: the creation and implementation of custom game engine for a university. *TechTrends*, *61*(4), 341-348. http://dx.doi.org/10.1007/s11528-017-0163-7

Clark, D. B., Tanner-Smith, E. E., & Killingsworth, S. S. (2016). Digital games, design, and learning: A systematic review and meta-analysis. *Review of Educational Research*, *86*(1), 79–122. https://doi.org/10.3102/0034654315582065

Csíkszentmihályi, M. (1990). Flow: The psychology of optimal experience. Harper & Row.

Cutting, J., & Iacovides, I. (2022). Learning by doing: Intrinsic Integration directs attention to increase learning in games. *Proceedings of the ACM on Human-Computer Interaction*, *6*(CHI PLAY), 1-18. https://doi.org/10.1145/3549503

Czauderna, A., & Guardiola, E. (2019). The gameplay loop methodology as a tool for educational game design. *Electron. J. E-Learn.* , *17*, 207–221. https://doi.org/10.34190/JEL.17.3.004

Denham, A. (2016). Improving the design of a learning game through intrinsic integration and playtesting. *Technology, Knowledge and Learning*, *21*(2), 175–194. https://doi.org/10.1007/s10758-016-9280-1

Driver, R., Squires, A., Rushworth, P., & Wood-Robinson, V. (1994). *Making sense of secondary science: Research into children's ideas*. Routledge. https://doi.org/10.4324/9781315747415

Duit, R., & Treagust, D. (2003). Conceptual change: A powerful framework for improving science teaching and learning. *International Journal of Science Education*, *25*, 671–688. https://doi.org/10.1080/09500690305016

Van Eck, R. (2006). Digital game-based learning: It's not just the digital natives who are restless. *EDUCAUSE review, 41*(2), 16.

Ekin, C. C., Polat, E., & Hopcan, S. (2023). Drawing the big picture of games in education: A topic modeling-based review of past 55 years. *Computers & Education*, 194, 104700. https://doi.org/10.1016/j.compedu.2022.104700

Fanfarelli, J. R. (2020). Impact of narrative and badging on learning and engagement in a psychology learning game. *British Journal of Educational Technology, 51*(2), 387–419. https://doi.org/10.1111/bjet.12838

Fazio, C., & Battaglia, O.R. (2018). Conceptual understanding of Newtonian mechanics through cluster analysis of FCI student answers. *International Journal of Science and Mathematics Education*, *17*, 1–21. https://doi.org/10.1007/s10763-018-09944-1

De Freitas, S. (2018). Are games effective learning tools? A review of educational games. *Journal of Educational Technology & Society*, *21*(2), 74–84. http://www.jstor.org/stable/26388380

Garzón, J., & Acevedo, J. (2019). Meta-analysis of the impact of Augmented Reality on students' learning gains. *Educational Research Review*, *27*, 244–260. https://doi.org/10.1016/j.edurev.2019.04.001

Greipl, S., Moeller, K., & Ninaus, M. (2020). Potential and limits of game-based learning. *International Journal of Technology Enhanced Learning*, *12*(4), 363–389. https://doi.org/10.1504/IJTEL.2020.10028417

Habgood, M. P. J., & Ainsworth, S. E. (2011). Motivating children to learn effectively: Exploring the value of intrinsic integration in educational games. *Journal of the Learning Sciences*, *20*(2), 169–206. https://doi.org/10.1080/10508406.2010.508029

Halloun, I. A., & Hestenes, D. (1985). Common sense concepts about motion. *American Journal of Physics*, *53*(11), 1056. https://doi.org/10.1119/1.14031

Hattie, J. A. C., & Timperley, H. (2007). The power of feedback. *Review of Educational Research*, *77*(1), 81–112. https://doi.org/10.3102/003465430298

Hestenes, D., Wells, M., & Swackhamer, G. (1992). Force concept inventory. *The Physics Teacher*, *30*(3), 141–158. https://doi.org/10.1119/1.2343497

Hewson, P. W., & Hewson, M. G. (1984). The role of conceptual conflict in conceptual change and the design of science instruction. *Instructional Science*, *13*, 1–13. https://doi.org/10.1007/BF00051837

Kafai, Y. (1996). Learning design by making games: Children's development of strategies in the creation of a complex computational artifact. In Y. Kafai & M. Resnick (Eds.), *Constructionism in practice: Designing, thinking and learning in a digital world*. Erlbaum. https://doi.org/10.4324/9780203053492

Ke, F. (2008). Computer games application within alternative classroom goal structures: cognitive, metacognitive, and affective evaluation. *Educational Technology Research and Development*, *56*, 539–556. https://doi.org/10.1007/s11423-008-9086-5

Ke, F. (2016). Designing and integrating purposeful learning in game play: A systematic review. *Educational Technology Research and Development*, *64*(2), 219–244. https://doi.org/10.1007/s11423-015-9418-1

Kirstein, J., & Nordmeier, V. (2007). Multimedia representation of experiments in physics. *European Journal of Physics*, *28*(3), S115. https://doi.org/10.1088/0143-0807/28/3/S11

Klaassen, K. (1995). *A problem-posing approach to teaching the topic of radioactivity*. Cdβ Press.

Kolb, D. A., Boyatzis, R. E., & Mainemelis, C. (2014). Experiential learning theory: Previous research and new directions. In *Perspectives on thinking, learning, and cognitive styles* (pp. 227–247). Routledge.

Kortland, J. (2001). *A problem posing approach to teaching decision-making about the waste issue*. Cdβ Press. https://doi.org/10.1007/978-1-4614-6258-3_10

Lamb, R. L., Annetta, L., Firestone, J., & Etopio, E. (2018). A meta-analysis with examination of moderators of student cognition, affect, and learning outcomes while using serious educational games, serious games, and simulations. *Computers in Human Behavior*, *80*, 158–167. https://doi.org/10.1016/j.chb.2017.10.040

Lameras, P., Arnab, S., Dunwell, I., Stewart, C., Clarke, S., & Petridis, P. (2017). Essential features of serious games design in higher education: Linking learning attributes to game mechanics. *British Journal of Educational Technology*, *48*(4), 972–994. https://doi.org/10.1111/bjet.12467

Lei, H., Chiu, M. M., Wang, D., Wang, C., & Xie, T. (2022). Effects of game-based learning on students' achievement in science: A meta-analysis. *Journal of Educational Computing Research*, *60*(6), 1373–1398. https://doi.org/10.1177/0735633121106454

Lijnse, P. L., & Klaassen, K. (2004). Didactical structures as an outcome of research on teaching learning sequences? *International Journal of Science Education*, *26*(5), 537–554. https://doi.org/10.1080/09500690310001614753

Van der Linden, A., & Van Joolingen, W. R. (2016). A serious game for interactive teaching of Newton's laws. *Proceedings of the 3rd Asia-Europe Symposium on Simulation and Serious Gaming - 15th ACM SIGGRAPH Conference on Virtual-Reality Continuum and its Applications in Industry*, VRCAI 2016, 165–167. https://doi.org/10.1145/3014033.3014040

Van der Linden, A., Van Joolingen, W. R., & Meulenbroeks, R. F. G. (2019). Designing an intrinsically integrated educational game on Newtonian mechanics. *International Conference on Games and Learning Alliance*, 11385, 123–133. https://doi.org/10.1007/978-3-030-11548-7_12

Van der Linden, A., Meulenbroeks, R. F., & Van Joolingen, W. R. (2023). *Implementing an intrinsically integrated game on Newtonian mechanics in the classroom: Outcomes in terms of conceptual understanding and transfer*. arXiv preprint arXiv:2307.01714.

Van der Linden, A., Meulenbroeks, R. F. G., & Van Joolingen, W. R. (2024). Learning Newtonian mechanics with an intrinsically integrated educational game. *Journal of Computer Assisted Learning*. http://doi.org/10.1111/jcal.12966

Long, Y., & Aleven, V. (2014). Gamification of joint student/system control over problem selection in a linear equation tutor. In Trausan-Matu, S., Boyer, K. E., Crosby, M., & Panourgia, K. (Eds.), *12th International Conference on Intelligent Tutoring Systems*, ITS 2014, Honolulu, 378–387. https://doi.org/10.1007/978-3-319-07221-0_47

Makransky, G., & Mayer, R. E. (2022). Benefits of taking a virtual field trip in immersive virtual reality: Evidence for the immersion principle in multimedia learning. *Educational Psychology Review*, *34*(3), 1771-1798. https://doi.org/10.1007/s10648-022-09675-4

Manzano-León, A., Camacho-Lazarraga, P., Guerrero, M. A., Guerrero-Puerta, L., Aguilar-Parra, J. M., Trigueros, R., & Alias, A. (2021). Between level up and game over: A systematic literature review of gamification in education. *Sustainability*, *13*(4), 2247. https://doi.org/10.3390/su13042247

Morris, T. H. (2020). Experiential learning–a systematic review and revision of Kolb's model. *Interactive Learning Environments*, *28*(8), 1064–1077. https://doi.org/10.1080/10494820.2019.1570279

Mufit, F., Asrizal, A., & Puspitasari, R. (2020). Meta-analysis of the effect of cognitive conflict on physics learning. *Jurnal Penelitian & Pengembangan Pendidikan Fisika*, *6*(2), 267–278. https://doi.org/10.21009/1.06213

Pan, Y., & Ke, F. (2023). Effects of game-based learning supports on students' math performance and perceived game flow. *Educational Technology Research and Development*, 1–21. https://doi.org/10.1007/s11423-022-10183-z

Pan, Y., Ke, F., & Xu, X. (2022). A systematic review of the role of learning games in fostering mathematics education in K-12 settings. *Educational Research Review*, *36*, 100448. https://doi.org/10.1016/j.edurev.2022.100448

Piaget, J. (1976). Piaget's Theory. In B. Inhelder, H. H. Chipman, & C. Zwingmann (Eds.), *Piaget and his school.* Springer Study Edition. https://doi.org/10.1007/978-3-642-46323-5_2

Perkins, D., & Salomon, G. (1994). Transfer of learning. In T. Husen, & T. Postlethwaite (Eds.), *The international encyclopedia of education: Vol. 11* (4th ed.). Elsevier Science Ltd.

Plass, J. L., Homer, B. D., & Kinzer, C. K. (2015). Foundations of game-based learning. *Educational Psychologist*, *50*(4), 258–283. https://doi.org/10.1080/00461520.2015.1122533

Rebello, N. S., Cui, L., Bennett, A. G., Zollman, D. A., & Ozimek, D. J. (2007). Transfer of learning in problem solving in the context of mathematics and physics. In D. H. Jonassen (Ed.), *Learning to solve complex scientific problems* (pp. 223–246). Erlbaum. https://doi.org/10.4324/9781315091938-10

Schöbel, S., Saqr, M., & Janson, A. (2021). Two decades of game concepts in digital learning environments–A bibliometric study and research agenda. *Computers & Education*, *173*, 104296. https://doi.org/10.1016/j.compedu.2021.104296

Schumacher, R. S., Hofer, S., Rubin, H., & Stern, E. (2016). How teachers can boost conceptual understanding in physics classes. In C. K. Looi, J. L. Polman, U. Cress, & P. Reimann (Eds.), *Transforming learning, empowering learners: The international Conference of the Learning Sciences: Vol. 2* (pp. 1167–1168). International Society of the Learning Sciences.

Sheldon, L. (2011). *Multiplayer classroom: Designing coursework as a game*. Cengage learning. https://doi.org/10.1201/9780429285035

Sicart, M. (2008). Defining game mechanics. Inter*national Journal of Computer Game Research*, *8*(2).

Smetana, L. K., & Bell, R. L. (2012). Computer simulations to support science instruction and learning: A critical review of the literature. *International Journal of Science Education*, *34*(9), 1337–1370. https://doi.org/10.1080/09500693.2011.605182

Timotheou, S., Miliou, O., Dimitriadis, Y., Sobrino, S. V., Giannoutsou, N., Cachia, R., Monés, A. M., & Ioannou, A. (2023). Impacts of digital technologies on education and factors influencing schools' digital capacity and transformation: A literature review. *Education and Information Technologies*, *28*(6), 6695–6726. https://doi.org/10.1007/s10639-022-11431-8

Tokarieva, A.V., Volkova, N.P., Harkusha, I.V., Soloviev, V.N. (2019). Educational digital games: models and implementation. In A.E. Kiv & V. N. Soloviev (Eds.), *Proceedings of the 6th Workshop on Cloud Technologies in Education* (CTE 2018), Kryvyi Rih, Ukraine, 74–89. https://doi.org/10.31812/educdim.v53i1.3872

Tsai Y.L., & Tsai C.C. (2020). A meta-analysis of research on digital game-based science learning. *J Comput Assist Learn*, *36*, 280–294. https://doi.org/10.1111/jcal. 12430

Vandercruysse, S., & Elen, J. (2017). Towards a game-based learning instructional design model focusing on integration. In P. Wouters & H. van Oostendorp (Eds.), *Instructional techniques to facilitate learning and motivation of serious games*. Springer International Publishing Switzerland. https://doi.org/10.1007/978-3-319-39298-1_2

Veldkamp, A., van de Grint, L., Knippels, M. C. P., & van Joolingen, W. R. (2020). Escape education: A systematic review on escape rooms in education. *Educational Research Review*, *31*, 100364. https://doi.org/10.1016/j.edurev.2020.100364

Vollebregt, M. J. (1998). *A problem posing approach to teaching an initial particle model*. Cdβ Press.

Vosniadou, S. (1994) Capturing and modeling the process of conceptual change. *Learning and Instruction*, *4*, 45–69. https://doi.org/10.1016/0959-4752(94)90018-3

Walkington, C. (2021). Intrinsic integration in learning games and virtual instruction. *Education Tech Research Dev*, *69*, 157–160. https://doi.org/10.1007/s11423-020-09886-y

Wang, L. H., Chen, B., Hwang, G. J., Guan, J. Q., & Wang, Y. Q. (2022). Effects of digital game-based STEM education on students' learning achievement: a meta-analysis. *International Journal of STEM Education*, *9*(1), 1–13. https://doi.org/10.1186/s40594-022-00344-0

Wieman, C. E., Adams, W. K., & Perkins, K. K. (2008). PhET: Simulations that enhance learning. *Science*, *322*(5902), 682-683. https://doi.org/10.1126/ science.1161948

Wouters, P., van Nimwegen, C., van Oostendorp, H., & Van der Spek, E. D. (2013). A meta-analysis of the cognitive and motivational effects of serious games. *Journal of Educational Psychology*, *105*(2), 249–265. https://doi.org/10.1037/a0031311

Yu, Z., Gao, M., & Wang, L. (2021). The effect of educational games on learning outcomes, student motivation, engagement and satisfaction. *Journal of Educational Computing Research*, *59*(3), 522-546. https://doi.org/10.1177/0735633120969214

Zeng, J., Parks, S., & Shang, J. (2020). To learn scientifically, effectively, and enjoyably: A review of educational games. *Human Behavior and Emerging Technologies*, *2*(2). https://doi.org/10.1002/hbe2.188

Appendices

All appendices are translated from Dutch

Appendix A: Pre-test Study 2

1. If you kick a stationary ball, the ball will start moving.

True / False / I do not know

2. If the ball starts moving after a kick, there will be a force working on the ball in the direction of motion.

True / False / I do not know

3. You kick a ball through long grass. When you stop kicking, the ball will stop moving immediately.

True / False / I do not know

4. You kick a ball once, so that it rolls over grass. The ball will stop moving eventually.

True / False / I do not know

5. You kick a ball once, so that it rolls over grass. Does a force work on the ball in the direction of motion after the kick?

After the kick:

A. There is no force working.

B. There is a force working. The force is equal to opposing forces (from the grass).

C. There is a force working. The force is bigger than opposing forces (from the grass).

D. I do not know.

6. To let a ball roll across a soccer field (grass), you must kick the ball 10 times. If this soccer field was made of ice, would you have to kick the ball less, as many times of more often?

A. Less

B. As many times

C. More often

D. I do not know.

7. You kick a ball once, so that it will roll across grass. What kind of motion will the ball make?

A. First faster and then slower.

B. Ever slower.

C. First slower and then faster.

D. Ever faster.

E. A constant velocity.

F. I do not know.

8. You kick a ball across grass, so that the ball moves with a constant velocity. The forwards kick-force on the ball is:

A. Bigger than opposing forces (from for instance the grass).

B. Smaller than opposing forces (from for instance the grass).

C. Equal to opposing forces (from for instance the grass).

D. I do not know.

Appendix B: Post-test Study 2

1. If you kick a stationary ball, the ball will start moving. After the kick, there will be a force working on the ball in the direction of motion.

True / False / I do not know

2. You kick a ball through long grass. When you stop kicking, the ball will stop moving immediately.

True / False / I do not know

3. You roll a hockey ball through long grass. When you stop pushing, the ball will stop moving immediately.

True / False / I do not know

4. You kick a ball once, so that it rolls over grass. Does a force work on the ball in the direction of motion after the kick?

After the kick:

A. There is no force working.

B. There is a force working. The force is equal to opposing forces (from the grass).

C. There is a force working. The force is bigger than opposing forces (from the grass).

D. I do not know.

5. You kick a ball once, so that it will roll across grass. What kind of motion will the ball make?

A. First faster and then slower.

B. Ever slower.

C. First slower and then faster.

D. Ever faster.

E. A constant velocity.

F. I do not know.

6. You kick a ball across grass, so that the ball moves with a constant velocity. The forwards kick-force on the ball is:

A. Bigger than opposing forces (from for instance the grass).

B. Smaller than opposing forces (from for instance the grass).

C. Equal to opposing forces (from for instance the grass).

D. I do not know.

7. You roll a hockey ball across grass, so that the ball moves with a constant velocity. The forwards roll-force on the ball is:

A. Bigger than opposing forces (from for instance the grass).

B. Smaller than opposing forces (from for instance the grass).

C. Equal to opposing forces (from for instance the grass).

D. I do not know.

Appendix C: Pre-test Study 3 and Study 4

1. By kicking a stationary ball, the ball starts moving. Then there will be a force working on the ball in the direction of motion.

True / False / I do not know

2. You kick a ball through long grass. When you stop kicking, the ball will stop moving immediately.

True / False / I do not know

3. You kick a ball once, so that it rolls over grass. Does a force work on the ball in the direction of motion after the kick?

After the kick:

A. There is no force working.

B. There is a force working. The force is equal to opposing forces (from the grass).

C. There is a force working. The force is bigger than opposing forces (from the grass).

D. I do not know.

4. You kick a ball once, so that it will roll across grass. What kind of motion will the ball make?

A. First faster and then slower.

B. Ever slower.

C. First slower and then faster.

D. Ever faster.

E. A constant velocity.

F. I do not know.

5. You kick a ball across grass, so that the ball moves with a constant velocity. The forwards kick-force on the ball is:

A. Bigger than opposing forces (from for instance the grass).

B. Smaller than opposing forces (from for instance the grass).

C. Equal to opposing forces (from for instance the grass).

D. I do not know.

Appendix D: Post-test Study 3 and Study 4

Retention test Study 4 with different question order

1. By kicking a stationary ball, the ball starts moving. Then there will be a force working on the ball in the direction of motion.

True / False / I do not know

2. You kick a ball through long grass. When you stop kicking, the ball will stop moving immediately.

True / False / I do not know

3. You slide a couch across the floor. When you stop pushing, the couch will stop moving immediately.

True / False / I do not know

4. You kick a ball once, so that it rolls over grass. Does a force work on the ball in the direction of motion after the kick?

After the kick:

A. There is no force working.

B. There is a force working. The force is equal to opposing forces (from the grass).

C. There is a force working. The force is bigger than opposing forces (from the grass).

D. I do not know.

5. You are riding a bike and at a certain moment you stop pedaling. Does a force work the direction of motion after you stop pedaling?

After the kick:

A. There is no force working.

B. There is a force working. The force is equal to opposing forces.

C. There is a force working. The force is bigger than opposing forces.

D. I do not know.

6. You kick a ball once, so that it will roll across grass. What kind of motion will the ball make?

A. First faster and then slower.

B. Ever slower.

C. First slower and then faster.

D. Ever faster.

E. A constant velocity.

F. I do not know.

7. You kick a ball across grass, so that the ball moves with a constant velocity. The forwards kick-force on the ball is:

A. Bigger than opposing forces (from for instance the grass).

B. Smaller than opposing forces (from for instance the grass).

C. Equal to opposing forces (from for instance the grass).

D. I do not know.

8. You roll a hockey ball across grass, so that the ball moves with a constant velocity. The forwards roll-force on the ball is:

A. Bigger than opposing forces (from for instance the grass).

B. Smaller than opposing forces (from for instance the grass).

C. Equal to opposing forces (from for instance the grass).

D. I do not know.

Appendix E: Statements

Statement 1:

You ride your bike to school and there is a lot of headwind and rain. Because of that you always ride with 14 km/h to school. The following applies for your pedaling force:

1. The pedaling force is 0 N.

2. The pedaling force is smaller than the opposing forces (for example by the wind).

3. The pedaling force is equal to the opposing forces (for example by the wind).

4. The pedaling force is bigger than the opposing forces (for example by the wind).

5. I do not know.

Statement 2:

You are moving and you slide a heavy box across the floor. When you stop pushing, the box will slide a bit further. The following applies:

1. There is no fore working in the direction of motion.

2. There is a fore working in the direction of motion. This force is smaller than the opposing forces (for example by the floor).

3. There is a fore working in the direction of motion. This force is equal to the opposing forces (for example by the floor).

4. There is a fore working in the direction of motion. This force is bigger than the opposing forces (for example by the floor).

5. I do not know.

Appendix F: Transfer worksheet

1. Write down for yourself what you have learned. Use the following terms:

forward force; acceleration; bigger than; deceleration; smaller than; opposing force; equal to; constant velocity.

You may use the terms more than once.

2. Indicate for the situations below what kind of motion applies. Give an explanation for the chosen motion, using your answer form task 1.

a. A rocket turns off its thrusters in space.

b. A hockey puck is being hit by a hockey stick.

c. After a hockey puck has been hit, it continues to move across grass.

d. After an ice hockey puck is hit, it continues to move over ice.

e. You cycle down a hill, you roll down without pedaling.

Appendix G: Game worksheet

For each image answer the corresponding questions:

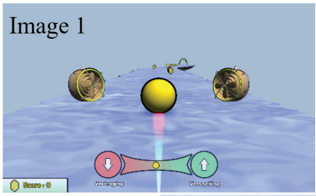


Image 1

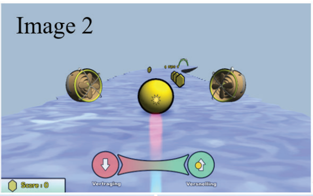


Image 2

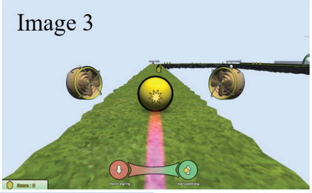


Image 3

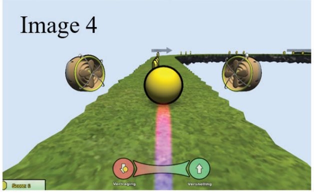


Image 4

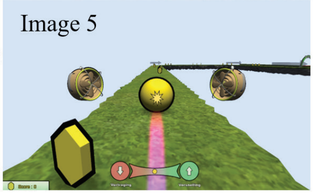


Image 5

a. What kind of motion does the ball make?

A. Acceleration B. Constant velocity

C. Deceleration D. I do not know

b. What is the corresponding setting?

A. F = 0N B. F = friction

C. F > friction D. I do not know

c. How do you know that the setting of 1b corresponds with the movement of 1a?

Summary

Research on digital game-based learning (DGBL) in general reports promising results. However large variations between learning outcomes between individual educational games exist. It appears that learning effects of DGBL can be increased by ensuring that learning and gameplay are integrated with each other in a process dubbed intrinsic integration. Designing an intrinsically integrated game can be quite challenging since the alignment between (formal) learning and gameplay is not self-evident. To use a game in formal education, students should also be able to transfer their acquired conceptual knowledge from the game context to other scenarios. This is possible by embedding the game in other learning activities. This thesis aims to develop some guidelines on how to design and implement an intrinsically integrated game by using a case study approach in the context of Newtonian mechanics. During this in depth analysis, four studies were conducted to answer the main research question of this dissertation:

> *How can a digital intrinsically integrated game be designed and implemented in a lesson fostering conceptual knowledge and transfer regarding Newtonian mechanics?*

Study 1 (Chapter 2): Designing an intrinsically integrated educational game on Newtonian mechanics

In this study we proposed a guiding frame for designing an intrinsically integrated game. The guiding frame expands on the idea of intrinsic integration, where the learning goal and game goal are aligned, by adding an additional alignment between a pedagogical approach and game mechanics. In this study the design process of the game, Newton's Race, is described using the proposed guiding frame. Our findings suggest some guidelines in using this guiding frame. First, the guiding frame incorporates a specific order starting with forming a learning goal, then choosing a pedagogical approach, selecting fitting game mechanics and ending with the game goal and checking this against the learning goal. Also, to optimize the alignment between the learning goal and the game goal, it should only be possible for players to reach the game goal when the desired learning goal is reached as well. Typically, this process of alignment requires several iterations of the design process, with the focus is on aligning the pedagogical approach with the game mechanics.

Study 2 (Chapter 3): Learning Newtonian mechanics with an intrinsically integrated educational game

The second study aimed to gain insight on how playing the resulting intrinsically integrated game supports the learning of Newtonian mechanics. The findings demonstrated a significant positive learning effect, which can be explained through acquired log data form player's gameplay. Log data show that players' gameplay mostly matched expected learning during the game, with scientifically correct game settings occurring more and more as gameplay progressed. The ability to transfer learned knowledge to other situations was shown to be limited to situations closely resembling the game environment.

Study 3 (Chapter 4): Implementing an intrinsically integrated game on Newtonian mechanics in the classroom: outcomes in terms of conceptual understanding and transfer

This study involves a thorough evaluation of a lesson design around the intrinsically integrated game, played in groups of about seven students. Outside of the game, lesson activities include: activation of pre-exciting ideas, a debriefing session, a generalisation assignment, an assignment on transfer situations and a closing activity. The findings indicate that students benefit from a teacher-led debriefing session after gameplay. After the complete lesson, students were able to apply their acquired knowledge with equal success in both game related and transfer situations, indicating that the additional learning activities surrounding Newton's Race used in this study increased conceptual understanding and fostered transfer.

Study 4 (Chapter 5): Embedding an intrinsically integrated game in a realistic classroom situation

The last study explored possibilities of using an intrinsically integrated game, Newton's Race, in a realistic classroom environment without explicit teacher intervention. For this study two classroom implementations focusing on game-based exercises or general exercises are designed and compared. Students' conceptual development and transfer show a small but significant increase through both lessons. Results from game-based exercises indicate that playing the game and filling out a worksheet about gameplay in small groups, is not enough for students to fully understand the physics of the game. A difference between the groups in students' transfer reasoning was found, indicating that the way the game is embedded has an effect on conceptual development and transfer reasoning. In other words, it is not only important to embed an educational game in the classroom, but it is also important how you facilitate it. A game cannot replace a teacher.

General conclusions

This dissertation shows how an intrinsically integrated game on Newtonian mechanics can be designed and implemented in a lesson. The four studies provide an in-depth analysis, giving more insight on how students learn using a digital educational game. Effectively aligning the learning goal with the game goals and aligning the pedagogical approach with game mechanics, proved to be the main challenge. Our proposed guiding frame served as a useful tool during the design process. To foster students' conceptual knowledge and transfer, the intrinsically integrated game is preferably embedded within other learning activities. During these activities, the teacher should play an active role guiding the learning process by helping students make connections between in-game learning and other situations.

Samenvatting

Onderzoek naar *game-based* leren (het gebruik van games tijdens het leerproces) laat over het algemeen veelbelovende resultaten zien. Er bestaan echter grote verschillen tussen leerresultaten van individuele, educatieve spellen. Het lijkt erop dat de leereffecten van *game-based* leren kunnen worden vergroot als de leeractiviteiten geïntegreerd worden in de game-activiteiten. Dat proces heet intrinsieke integratie. Intrinsieke integratie betekent dat het doel van de game samenvalt met het leerdoel waar de game voor is ontworpen. Het ontwerpen van een intrinsiek geïntegreerde game kan een behoorlijke uitdaging zijn, omdat het verband tussen (formeel) leren en gamen niet vanzelfsprekend is. Om een game in het formele onderwijs te kunnen gebruiken, moeten leerlingen hun geleerde conceptuele kennis ook vanuit de gamecontext kunnen gebruiken in andere scenario's. Dit kan door de game in te bouwen in andere leeractiviteiten. In dit proefschrift is een aantal richtlijnen ontwikkeld voor het ontwerpen en implementeren van een intrinsiek geïntegreerde game door gebruik te maken van een *casestudy* benadering in de context van de natuurkunde (Newtoniaanse mechanica). Tijdens deze diepgaande analyse zijn vier onderzoeken uitgevoerd om de overkoepelende onderzoeksvraag van dit proefschrift te beantwoorden:

> *Hoe kan een intrinsiek geïntegreerde game worden ontworpen en geïmplementeerd in een les die conceptuele kennis en overdracht van Newtoniaanse mechanica bevordert?*

Studie 1 (Hoofdstuk 2): Het ontwerpen van een intrinsiek geïntegreerd educatieve game over Newtoniaanse mechanica

In de eerste studie hebben we een raamwerk voorgesteld om te gebruiken tijdens het ontwerp van een intrinsiek geïntegreerde game. Dit raamwerk bouwt voort op het idee van intrinsieke integratie, waarbij het leerdoel en het speldoel met elkaar verweven worden, door middel van een vergaande integratie tussen een didactische aanpak en de mechanismen van de game (*game mechanics)*. In deze studie wordt het ontwerpproces van onze game, *Newton's Race*, beschreven aan de hand van ons raamwerk. De bevindingen suggereren enkele richtlijnen binnen ons raamwerk. In het raamwerk houden we een specifieke volgorde aan: we beginnen bij het vormen van een leerdoel, om vervolgens een didactische aanpak te kiezen, daarna passende *game mechanics* te selecteren en te eindigen met het speldoel. In het geval van een optimale integratie van leerdoel en speldoel is het voor spelers alleen mogelijk om het speldoel te bereiken als het gewenste leerdoel ook bereikt is. Tijdens de iteraties van het ontwerpproces ligt de nadruk dan ook op de integratie van de didactische aanpak met de *game mechanics*.

Studie 2 (Hoofdstuk 3): Het leren van Newtoniaanse mechanica door middel van een intrinsiek geïntegreerde educatieve game

Het tweede onderzoek had het doel om inzicht te krijgen in hoe het spelen van de intrinsiek geïntegreerde game, *Newton's Race*, het leren van Newtoniaanse mechanica ondersteunt. De bevindingen lieten een positief leereffect zien, dat kan worden verklaard op basis van de verkregen loggegevens van de spelers die verzameld werden tijdens het spelen. De loggegevens laten zien dat de *gameplay* van spelers grotendeels overeenkwam met het verwachte leerproces, waarbij de natuurkundig correcte spelinstellingen steeds vaker voorkwamen naarmate de game vorderde. Het vermogen van spelers om de geleerde kennis over te dragen naar andere situaties bleek daarentegen beperkt te zijn tot situaties die sterk leken op de spelomgeving.

Studie 3 (Hoofdstuk 4): Het implementeren van een intrinsiek geïntegreerde game over Newtoniaanse mechanica in de klas: resultaten in termen van conceptueel begrip en transfer

In dit onderzoek werd een lesontwerp gebaseerd op de intrinsiek geïntegreerde game geëvalueerd. De game werd gespeeld in een lessituatie in groepen van ongeveer zeven leerlingen. Naast het spelen van de game, bestonden de lesactiviteiten uit: het activeren van voorkennis, een nabespreking, een generalisatieopdracht, een opdracht over transfersituaties en een afsluitende activiteit. De bevindingen laten zien dat leerlingen na het spelen van de game, baat hebben bij een klassengesprek dat door een docent begeleid wordt. Na de volledige les waren de leerlingen in staat om hun vergaarde kennis met evenveel succes toe te passen in de game-gerelateerde situaties als in andere situaties (transfer), wat aangeeft dat de aanvullende leeractiviteiten rond *Newton's Race* die in dit onderzoek werden gebruikt, zowel het conceptuele begrip als transfer bevorderden.

Studie 4 (Hoofdstuk 5): Het inbouwen van een intrinsiek geïntegreerde game in een realistische klassensituatie

In het laatste onderzoek werden de mogelijkheden onderzocht van het gebruik van een intrinsiek geïntegreerde game, *Newton's Race*, in een realistische klassensituatie waarin de rol van de docent beperkt was tot het begeleiden van het proces. Twee lessen, één gericht op game-gerelateerde oefeningen en één gericht op algemene oefeningen, zijn ontworpen en met elkaar vergeleken in termen van de leeropbrengsten. De conceptuele ontwikkeling en transfer van leerlingen laat in beide lessen een kleine maar significante stijging zien. Resultaten van game-gerelateerde oefeningen laten zien dat het spelen van de game en het invullen van een werkblad over *gameplay* in kleine groepen, niet voldoende is om leerlingen de natuurkundige principes van het spel volledig te laten begrijpen. Tussen de twee groepen werden verschillen gevonden in de manier waarop leerlingen redeneerden in transfersituaties, wat aangeeft dat de manier waarop het spel is ingebouwd in de les, een effect heeft op zowel de conceptuele ontwikkeling en de transfer. Het is dus niet alleen belangrijk om een educatieve game überhaupt in een les in te bouwen, maar het is ook belangrijk hoe je dat doet. De docent speelt hierin een essentiële rol.

Algemene conclusies

Dit proefschrift laat zien hoe een intrinsiek geïntegreerde game over een belangrijk onderwerp in de natuurkunde, de Newtoniaanse mechanica, ontworpen kan worden en geïmplementeerd kan worden in een les. De vier onderzoeken bieden een diepgaande analyse, die meer inzicht geeft in de manier waarop leerlingen leren met behulp van een educatieve game. Het volledig integreren van het leerdoel met het speldoel en het integreren van de didactische aanpak met de *game mechanics*, bleek de grootste uitdaging. Het door ons voorgestelde raamwerk bleek een nuttig hulpmiddel tijdens het ontwerpproces. Om de conceptuele kennis en *transfer* van leerlingen te bevorderen, kan de intrinsiek geïntegreerde game het beste worden ingebouwd in andere leeractiviteiten. Tijdens de les is het belangrijk dat de docent een actieve rol speelt bij het begeleiden van het leerproces, door leerlingen te helpen het verband te leggen tussen de game-uitkomsten en andere situaties.

Dankwoord

Het avontuur in mijn promotiewereld komt ten einde. Zoals bij elke goede queeste is de reis pas echt compleet met een mooi mijmermoment. Ik wil van dit moment gebruik maken om mensen te bedanken die deze reis de moeite waard gemaakt hebben.

Daarmee begin ik natuurlijk met mijn begeleiders; Wouter, mijn promotor, zonder jou was dit avontuur er niet eens geweest. Al in de meest prille fase van het project (mijn masterscriptie) was jij erbij. Bedankt dat jij toen de potentie zag om samen met mij verder te gaan met het onderwerp in een PhD-project. Mede dankzij jouw expertise is dit proefschrift geworden tot wat het is, bedankt! Ralph, mijn copromotor, bedankt voor je steun en positiviteit gedurende het proces. Je creativiteit en enthousiasme werkt heerlijk aanstekelijk en na een meeting met jou had ik dan ook altijd weer frisse energie of een nieuwe invalsoek om mee verder te gaan. ROCK ON! Wouter en Ralph, heel erg bedankt voor jullie betrokken begeleiding en gezellige momenten. Ik heb genoten van hoe we als drie natuurkundigen (met een goed gevoel voor humor, al zeg ik het zelf) dit avontuur beleefd hebben. Ik kijk met plezier terug op onze tijd samen, van onze inhoudelijke meetings tot goede gesprekken over andere belangrijkere zaken des levens; zoals de avonturen van Fred en George.

Lieve Esther en Irmgard, mijn paranimfen. Esther, bedankt voor het vechten aan mijn zijde tijdens deze queeste. Naast het delen van een kamer op het FI, deelden we ook echt het lief en leed van onze avonturen met elkaar. Jij weet als geen ander hoe het is om een promotieonderzoek te combineren met lesgeven. Daarnaast klikten we ook nog eens goed op een persoonlijk level. Zo kijk ik bijvoorbeeld met veel plezier terug op onze lunches, Helsinki, Bologna, onze vrijgezellenfeesten en de Efteling. Irmgard, wat vind ik het toch ontzettend fijn dat wij elkaar op het Boni gevonden hebben. Wat begon als het organiseren van een personeelsuitje, eindigde naast een langdurige samenwerking in allerlei projecten (waar wij elkaar feilloos aanvullen met onze verschillende kwaliteiten), ook in een vriendschap. Bedankt paranimfen; voor het letterlijk en figuurlijk aan mijn zijde staan tijdens de verdediging van mijn proefschrift.

Ook wil ik (oud)PhD'ers en collega's van het FI bedanken voor de goede sfeer en betrokkenheid. In het bijzonder wil ik Nico bedanken voor de begeleiding aan het begin van het project, Paul voor het vervullen van de rol als *second coder* in de derde studie, Esther en Rayendra *for being my roomies during most of the process* en Nathalie voor alle onmisbare hulp met het afronden van mijn proefschrift.

Zonder de studenten die tijdens dit PhD project gewerkt hebben aan Newton's Race, was er niets geweest om te onderzoeken; Bas, Yannick, Wouter en Chrisjan, bedankt voor jullie werk en inzet.

Verder wil ik mijn collega's van het Boni bedanken, voor het tonen van betrokkenheid, interesse en geduld. Daarnaast wil ik mijn (oud)sectiegenoten ook bedanken voor het gebruik van hun lessen en leerlingen voor mijn dataverzameling. Gedurende mijn PhD-avontuur heb ik me enorm gesteund gevoeld door het Boni, daar wil ik een aantal mensen in het bijzonder voor uitlichten: Carolien, Marjolein, Cor, Dirk, Kees, Jan, Tjalle, Martie, Ad, Hanneke S., Hanneke H., Jenneke, Jeannine, Mariëtte, Miriam, Embert, Irmgard en alle sciencepleinpauzegangers, bedankt!

Naast alle 'professionele' bedankjes, is er natuurlijk ook een aardig aantal mensen die op een andere manier bedankt verdienden te worden. Om te beginnen, mijn broer Bart; mijn game-avontuur begon al die jaren geleden met jouw oude, paarse *Game Boy Color* en jouw, ook paarse, *Gamecube*. Bedankt voor het delen van jouw hobby met je kleine zusje en alle steun en gezellige momenten die volgden in de jaren sindsdien.

Lieve papa en mama, bedankt voor de onvoorwaardelijke liefde en steun, wat bij jullie elk op geheel eigen manier tot zijn recht komt. Jullie stonden altijd voor me klaar en wisten altijd precies wanneer ik een ouderlijk verzorgmomentje nodig had, bedankt voor alles.

Alle andere familie en vrienden die me gesteund, gestuurd, opgevangen en de nodige *sidequests* (afleiding) gegeven hebben tijdens dit avontuur; met name Anieck, Bartje, Liv, Rijk, Janique, Roel, Jacqueline, Hein, Bart K., Simone, Jimmy, Suzanne, Tamara, Inge-Lot, Martijn, Martine, Katie, Ruben, Jeroen, Maartje, Margo, Maikel, Maaike en Marloes, bedankt!

Mijn *hamster support crew*; Dotje, Fred en George bedankt voor alle schattige momenten, gekkigheid en gespreksstof.

Lieve Geertièn, woorden op papier kunnen de steun die ik van jou ervaar niet tot zijn recht doen. Je bent de Rory voor mijn Amy, de Chandler voor mijn Monica, de Sam voor mijn Rosie. Bedankt voor het zijn wie je bent. Jij bent onmisbaar geweest in mijn avonturen in deze proefschriftwereld en ik kijk uit naar alle avonturen die we nog samen gaan beleven: *Adventure is out there*!

Curriculum vitae

Anne van der Linden was born on 22 May 1992 in Soest, the Netherlands. She completed her secondary education at the Griftland College in Soest in 2010. With becoming a physics teacher in mind, she went to Utrecht University to study the Bachelor Physics and Astronomy, which she completed in 2014. She then proceeded with the Master Science Education and Communication, also at Utrecht University, during which she obtained her teaching degree for physics.

During her Master, in February 2015, she started teaching physics at the RSG Slingerbos in Harderwijk. Since August 2015 she has been working as a physics teacher at the St. Bonifatiuscollege in Utrecht.

As part of her Master's research project, she started designing an educational game, which would later become the starting point for her PhD project. After completing her Master in 2016, Anne acquired the Promodoc Grant from the Ministry of Culture, Science and Education (OCW). This enabled her to perform her PhD research at Utrecht University's Freudenthal Institute, during which she continued to work as a physics teacher in secondary education. Her PhD research focussed on designing and embedding an intrinsically integrated game on Newtonian mechanics.

After obtaining her PhD, Anne will continue working as a physics teacher at the St. Bonifatiuscollege in Utrecht.

Publications and presentations related to this dissertation

Publications

Van der Linden, A., & Van Joolingen, W. R. (2016). A serious game for interactive teaching of Newton's laws. *Proceedings of the 3rd Asia-Europe Symposium on Simulation and Serious Gaming - 15th ACM SIGGRAPH Conference on Virtual-Reality Continuum and its Applications in Industry, VRCAI 2016*, 165–167. https://doi.org/10.1145/3014033.3014040

Van der Linden, A., Van Joolingen, W. R., & Meulenbroeks, R. F. G. (2019). Designing an intrinsically integrated educational game on Newtonian mechanics. International Conference on Games and Learning Alliance, 11385, 123–133. https://doi.org/10.1007/978-3-030-11548-7_12

Van der Linden, A., Meulenbroeks, R. F. G., & Van Joolingen, W. R. (2024). Learning Newtonian mechanics with an intrinsically integrated educational game. *Journal of Computer Assisted Learning*, *advance online publication*. http://doi.org/10.1111/jcal.12966

Van der Linden, A., Meulenbroeks, R. F. G., & Van Joolingen, W. R. Implementing an intrinsically integrated game on Newtonian mechanics in the classroom: outcomes in terms of conceptual understanding and transfer, *submitted with preprint available from* https://doi.org/10.48550/arXiv.2307.01714

Van der Linden, A., Meulenbroeks, R. F. G., & Van Joolingen, W. R. Embedding an intrinsically integrated game in a realistic classroom situation, *submitted*

Presentations

Van der Linden, A. (2017). *And next in on the playing ground… Newton*! Pitch presentation at the Breaking Science competition in Utrecht, the Netherlands, 20 March.

Van der Linden, A. (2017). *And next in on the playing ground… Newton*! Pitch presentation at the Breaking Science Utrecht Final in Utrecht, the Netherlands, 28 March.

Van der Linden, A. (2018). *Newton's Race: Een game ontwerpen en gebruiken in de (natuurkunde)les*. Workshop at the Conferentie Gamedidactiek conference in Utrecht, the Netherlands, 1 February.

Van der Linden, A., Van Joolingen, W. R., & Meulenbroeks, R. F. G. (2018). *Designing and implementing an educational game on Newtonian Mechanics*. Poster presentation at the European Science Education Research Association (ESERA) Summer School in Jyväskylä, Finland, 25 June - 1 July.

Van der Linden, A., Van Joolingen, W. R., & Meulenbroeks, R. F. G. (2018). *Newton's Race: Educatief gamen tijdens de les*. Workshop at the Werkgroep Natuurkunde Didactiek Conferentie (WND) in Noordwijkerhout, the Netherlands, 14-15 December.

Van der Linden, A., Van Joolingen, W. R., & Meulenbroeks, R. F. G. (2019). *Designing an intrinsically integrated educational game on Newtonian mechanics*. Presentation at the International Conference on Games and Learning Alliance (GALA) in Palermo, Italy, 5-7 December.

Van der Linden, A., Van Joolingen, W. R., & Meulenbroeks, R. F. G. (2019). *Learning Newtonian mechanics with an intrinsically integrated educational game*. Presentation at the European Science Education Research Association (ESERA) conference in Bologna, Italy, 26-20 August.

Van der Linden, A., Van Joolingen, W. R., & Meulenbroeks, R. F. G. (2019). *An intrinsically integrated educational game on Newtonian mechanics to promote conceptual development.* Poster presentation at the European Science Education Research Association (ESERA) conference in Bologna, Italy, 26-20 August.

FI Scientific Library

(formerly published as CD-β Scientific Library)

120. Hattinga van 't Sant, E.A. (2023). *De mythe van de alfaman - De dominantie van dominantie in de behavioural sciences, 1920-2020. Een historische reconstructie.*

119. Bachtiar, R. W. (2023). *Animated reasoning - Supporting students' mechanistic reasoning in physics by constructing stop-motion animations*

118. Harskamp, M. van (2023). *Ask, find out, and act: Fostering environmental citizenship through science education*.

117. Boels, L. (2023). *Histograms - An educational eye*.

116. Huang, L. (2022). *Inquiry-based learning in lower-secondary mathematics education in China (Beijing) and the Netherlands*.

115. Jansen, S. (2022). *Fostering students' meta-modelling knowledge regarding biological concept-process models*.

114. Pieters, M.L.M. (2022). *Between written and enacted: Curriculum development as propagation of memes. An ecological-evolutionary perspective on fifty years of curriculum development for upper secondary physics education in the Netherlands*.

113. Veldkamp, A. (2022). *No Escape! The rise of escape rooms in secondary science education*.

112. Kamphorst, F. (2021). *Introducing special relativity in secondary education*.

111. Leendert, A.-M. J. M. van (2021). *Improving reading and comprehending mathematical expressions in Braille*.

110. Gilissen, M. G. R. (2021). *Fostering students' system thinking in secondary biology education*.

109. Dijke-Droogers, M.J.S. van (2021). *Introducing statistical inference: Design and evaluation of a learning trajectory*.

108. Wijnker, W. (2021). *The unseen potential of film for learning. Film's interest raising mechanisms explained in secondary science and mathematics education*.

107. Groothuijsen, S. (2021). *Quality and impact of practice-oriented educational research.*

106. Wal, N.J. van der (2020). *Developing techno-mathematical literacies in higher technical professional education.*

105. Tacoma, S. (2020). *Automated intelligent feedback in university statistics education.*

104. Zanten, M. van (2020). *Opportunities to learn offered by primary school mathematics textbooks in the Netherlands*

103. Walma, L. (2020). *Between Morpheus and Mary: The public debate on morphine in Dutch newspapers, 1880-1939*

102. Van der Gronde, A.G.M.P. (2019). *Systematic review methodology in biomedical evidence generation.*
101. Klein, W. (2018). *New drugs for the Dutch republic. The commodification of fever remedies in the Netherlands (c. 1650-1800)*.
100. Flis, I. (2018). *Discipline through method - Recent history and philosophy of scientific psychology (1950-2018).*
99. Hoeneveld, F. (2018). *Een vinger in de Amerikaanse pap. Fundamenteel fysisch en defensie onderzoek in Nederland tijdens de vroege Koude Oorlog*.
98. Stubbé-Albers, H. (2018). *Designing learning opportunities for the hardest to reach: Game-based mathematics learning for out-of-school children in Sudan*.
97. Dijk, G. van (2018). *Het opleiden van taalbewuste docenten natuurkunde, scheikunde en techniek: Een ontwerpgericht onderzoek*.
96. Zhao, Xiaoyan (2018). *Classroom assessment in Chinese primary school mathematics education.*
95. Laan, S. van der (2017). *Een varken voor iedereen. De modernisering van de Nederlandse varkensfokkerij in de twintigste eeuw*.
94. Vis, C. (2017). *Strengthening local curricular capacity in international development cooperation*.
93. Benedictus, F. (2017). *Reichenbach: Probability & the a priori. Has the baby been thrown out with the bathwater*?
92. Ruiter, Peter de (2016). *Het mijnwezen in Nederlands-Oost-Indië 1850- 1950.*
91. Roersch van der Hoogte, Arjo (2015). *Colonial agro-industrialism. Science, industry and the state in the Dutch Golden Alkaloid Age, 1850- 1950.*
90. Veldhuis, M. (2015). *Improving classroom assessment in primary mathematics education.*
89. Jupri, Al (2015). *The use of applets to improve Indonesian student performance in algebra.*
88. Wijaya, A. (2015). *Context-based mathematics tasks in Indonesia: Toward better practice and achievement*.
87. Klerk, S. (2015). *Galen reconsidered. Studying drug properties and the foundations of medicine in the Dutch Republic ca. 1550-1700*.
86. Krüger, J. (2014). *Actoren en factoren achter het wiskundecurriculum sinds 1600*.
85. Lijnse, P.L. (2014). *Omzien in verwondering. Een persoonlijke terugblik op 40 jaar werken in de natuurkundedidactiek*.
84. Weelie, D. van (2014). *Recontextualiseren van het concept biodiversiteit*.
83. Bakker, M. (2014). *Using mini-games for learning multiplication and division: a longitudinal effect study.*

82. Ngô Vũ Thu Hằng (2014). *Design of a social constructivism-based curriculum for primary science education in Confucian heritage culture*.
81. Sun, L. (2014). *From rhetoric to practice: enhancing environmental literacy of pupils in China.*
80. Mazereeuw, M. (2013). Th*e functionality of biological knowledge in the workplace. Integrating school and workplace learning about reproduction.*
79. Dierdorp, A. (2013). *Learning correlation and regression within authentic contexts.*
78. Dolfing, R. (2013). *Teachers' professional development in context-based chemistry education. Strategies to support teachers in developing domain-specific expertise.*
77. Mil, M.H.W. van (2013). *Learning and teaching the molecular basis of life*.
76. Antwi, V. (2013). *Interactive teaching of mechanics in a Ghanaian university context.*
75. Smit, J. (2013). *Scaffolding language in multilingual mathematics classrooms*.
74. Stolk, M. J. (2013). *Empowering chemistry teachers for context-based education. Towards a framework for design and evaluation of a teacher professional development programme in curriculum innovations.*
73. Agung, S. (2013). *Facilitating professional development of Madrasah chemistry teachers. Analysis of its establishment in the decentralized educational system of Indonesia.*
72. Wierdsma, M. (2012). *Recontextualising cellular respiration*.
71. Peltenburg, M. (2012). *Mathematical potential of special education students*.
70. Moolenbroek, A. van (2012). *Be aware of behaviour. Learning and teaching behavioural biology in secondary education*.
69. Prins, G. T., Vos, M. A. J., & Pilot, A. (2011). *Leerlingpercepties van onderzoek & ontwerpen in het technasium.*
68. Bokhove, Chr. (2011). *Use of ICT for acquiring, practicing and assessing algebraic expertise.*
67. Boerwinkel, D. J., & Waarlo, A. J. (2011). *Genomics education for decision- making. Proceedings of the second invitational workshop on genomics education, 2-3 December 2010.*
66. Kolovou, A. (2011). *Mathematical problem solving in primary school*.
65. Meijer, M. R. (2011). *Macro-meso-micro thinking with structure-property relations for chemistry. An explorative design-based study*.
64. Kortland, J., & Klaassen, C. J. W. M. (2010). *Designing theory-based teaching-learning sequences for science. Proceedings of the symposium in honour of Piet Lijnse at the time of his retirement as professor of Physics Didactics at Utrecht University.*

63. Prins, G. T. (2010). *Teaching and learning of modelling in chemistry education. Authentic practices as contexts for learning*.
62. Boerwinkel, D. J., & Waarlo, A. J. (2010). *Rethinking science curricula in the genomics era. Proceedings of an invitational workshop*.
61. Ormel, B. J. B. (2010). *Het natuurwetenschappelijk modelleren van dynamische systemen. Naar een didactiek voor het voortgezet onderwijs*.
60. Hammann, M., Waarlo, A. J., & Boersma, K. Th. (Eds.) (2010). *The nature of research in biological education: Old and new perspectives on theoretical and methodological issues – A selection of papers presented at the VIIth Conference of European Researchers in Didactics of Biology.*
59. Van Nes, F. (2009). *Young children's spatial structuring ability and emerging number sense.*
58. Engelbarts, M. (2009). *Op weg naar een didactiek voor natuurkunde-experimenten op afstand. Ontwerp en evaluatie van een via internet uitvoerbaar experiment voor leerlingen uit het voortgezet onderwijs*.
57. Buijs, K. (2008). *Leren vermenigvuldigen met meercijferige getallen*.
56. Westra, R. H. V. (2008). *Learning and teaching ecosystem behaviour in secondary education: Systems thinking and modelling in authentic practices*.
55. Hovinga, D. (2007). *Ont-dekken en toe-dekken: Leren over de veelvormige relatie van mensen met natuur in NME-leertrajecten duurzame ontwikkeling*.
54. Westra, A. S. (2006). *A new approach to teaching and learning mechanics*.
53. Van Berkel, B. (2005). *The structure of school chemistry: A quest for conditions for escape.*
52. Westbroek, H. B. (2005). *Characteristics of meaningful chemistry education: The case of water quality.*
51. Doorman, L. M. (2005). *Modelling motion: from trace graphs to instantaneous change.*
50. Bakker, A. (2004). *Design research in statistics education: on symbolizing and computer tools.*
49. Verhoeff, R. P. (2003). *Towards systems thinking in cell biology education*.
48. Drijvers, P. (2003). *Learning algebra in a computer algebra environment. Design research on the understanding of the concept of parameter*.
47. Van den Boer, C. (2003). *Een zoektocht naar verklaringen voor achterblijvende prestaties van allochtone leerlingen in het wiskundeonderwijs*.
46. Boerwinkel, D. J. (2003). *Het vormfunctieperspectief als leerdoel van natuuronderwijs. Leren kijken door de ontwerpersbril*.
45. Keijzer, R. (2003). *Teaching formal mathematics in primary education. Fraction learning as mathematising process*.

44. Smits, Th. J. M. (2003). *Werken aan kwaliteitsverbetering van leerlingonderzoek: Een studie naar de ontwikkeling en het resultaat van een scholing voor docenten*.

43. Knippels, M. C. P. J. (2002). *Coping with the abstract and complex nature of genetics in biology education – The yo-yo learning and teaching strategy*.

42. Dressler, M. (2002). *Education in Israel on collaborative management of shared water resources.*

41. Van Amerom, B.A. (2002). *Reinvention of early algebra: Developmental research on the transition from arithmetic to algebra*.

40. Van Groenestijn, M. (2002). *A gateway to numeracy. A study of numeracy in adult basic education.*

39. Menne, J. J. M. (2001). *Met sprongen vooruit: een productief oefenprogramma voor zwakke rekenaars in het getallengebied tot 100 – een onderwijsexperiment*.

38. De Jong, O., Savelsbergh, E.R., & Alblas, A. (2001). *Teaching for scientific literacy: context, competency, and curriculum.*

37. Kortland, J. (2001). *A problem-posing approach to teaching decision making about the waste issue*.

36. Lijmbach, S., Broens, M., & Hovinga, D. (2000). *Duurzaamheid als leergebied; conceptuele analyse en educatieve uitwerking.*

35. Margadant-van Arcken, M., & Van den Berg, C. (2000). *Natuur in pluralistisch perspectief – Theoretisch kader en voorbeeldlesmateriaal voor het omgaan met een veelheid aan natuurbeelden.*

34. Janssen, F. J. J. M. (1999). *Ontwerpend leren in het biologieonderwijs. Uitgewerkt en beproefd voor immunologie in het voortgezet onderwijs*.

33. De Moor, E. W. A. (1999). *Van vormleer naar realistische meetkunde Een historisch-didactisch onderzoek van het meetkundeonderwijs aan kinderen van vier tot veertien jaar in Nederland gedurende de negentiende en twintigste eeuw.*

32. Van den Heuvel-Panhuizen, M., & Vermeer, H. J. (1999). *Verschillen tussen meisjes en jongens bij het vak rekenen-wiskunde op de basisschool – Eindrapport MOOJ-onderzoek.*

31. Beeftink, C. (2000). *Met het oog op integratie – Een studie over integratie van leerstof uit de natuurwetenschappelijke vakken in de tweede fase van het voortgezet onderwijs*.

30. Vollebregt, M. J. (1998). *A problem posing approach to teaching an initial particle model.*

29. Klein, A. S. (1998). *Flexibilization of mental arithmetics strategies on a different knowledge base – The empty number line in a realistic versus gradual program design.*

28. Genseberger, R. (1997). *Interessegeoriënteerd natuur- en scheikundeonderwijs – Een studie naar onderwijsontwikkeling op de Open Schoolgemeenschap Bijlmer*.

27. Kaper, W. H. (1997). *Thermodynamica leren onderwijzen*.

26. Gravemeijer, K. (1997). *The role of context and models in the development of mathematical strategies and procedures*.

25. Acampo, J. J. C. (1997). *Teaching electrochemical cells – A study on teachers' conceptions and teaching problems in secondary education*.

24. Reygel, P. C. F. (1997). *Het thema 'reproductie' in het schoolvak biologie*.

23. Roebertsen, H. (1996). *Integratie en toepassing van biologische kennis– Ontwikkeling en onderzoek van een curriculum rond het thema 'Lichaamsprocessen en Vergift'*.

22. Lijnse, P. L., & Wubbels, T. (1996). *Over natuurkundedidactiek, curriculumontwikkeling en lerarenopleiding*.

21. Buddingh', J. (1997). *Regulatie en homeostase als onderwijsthema: een biologie-didactisch onderzoek.*

20. Van Hoeve-Brouwer G. M. (1996). *Teaching structures in chemistry – An educational structure for chemical bonding*.

19. Van den Heuvel-Panhuizen, M. (1996). *Assessment and realistic mathematics education.*

18. Klaassen, C. W. J. M. (1995). *A problem-posing approach to teaching the topic of radioactivity.*

17. De Jong, O., Van Roon, P. H., & De Vos, W. (1995). *Perspectives on research in chemical education.*

16. Van Keulen, H. (1995). *Making sense – Simulation-of-research in organic chemistry education.*

15. Doorman, L. M., Drijvers, P. & Kindt, M. (1994). *De grafische rekenmachine in het wiskundeonderwijs.*

14. Gravemeijer, K. (1994). *Realistic mathematics education*.

13. Lijnse, P. L. (Ed.) (1993). *European research in science education*.

12. Zuidema, J., & Van der Gaag, L. (1993). *De volgende opgave van de computer*.

11. Gravemeijer, K., Van den Heuvel-Panhuizen, M., Van Donselaar, G., Ruesink, N., Streefland, L., Vermeulen, W., Te Woerd, E., & Van der Ploeg, D. (1993). *Methoden in het reken-wiskundeonderwijs, een rijke context voor vergelijkend onderzoek*.

10. Van der Valk, A. E. (1992). *Ontwikkeling in energieonderwijs*.

9. Streefland, L. (Ed.) (1991). *Realistic mathematics education in primary schools*.

8. Van Galen, F., Dolk, M., Feijs, E., & Jonker, V. (1991). *Interactieve video in de nascholing reken-wiskunde.*

7. Elzenga, H. E. (1991). *Kwaliteit van kwantiteit*.

6. Lijnse, P. L., Licht, P., De Vos, W., & Waarlo, A. J. (Eds.) (1990). *Relating macroscopic phenomena to microscopic particles: a central problem in secondary science education.*
5. Van Driel, J. H. (1990). *Betrokken bij evenwicht*.
4. Vogelezang, M. J. (1990). *Een onverdeelbare eenheid*.
3. Wierstra, R. F. A. (1990). *Natuurkunde-onderwijs tussen leefwereld en vakstructuur*.
2. Eijkelhof, H. M. C. (1990). *Radiation and risk in physics education*.
1. Lijnse, P. L., & De Vos, W. (Eds.) (1990). *Didactiek in perspectief*.

Utrecht
University

Faculty of Science
Freudenthal Institute

It has long been a coveted idea to combine the motivational aspects of games with learning in formal education. Digital educational games have indeed shown potential in this respect. However, individual educational games demonstrate large variations in (learning) outcomes. Ensuring that learning and gameplay are integrated with each other appears to be the key to obtaining higher learning outcomes. This is referred to as intrinsic integration. This dissertation adds to the body of knowledge on the characteristics that make educational games effective, realizing that no easy fix exists. To use a game in formal education, students should be able to transfer their acquired conceptual knowledge from the game context to other scenarios. This is possible by embedding the game in other learning activities. This dissertation describes four studies that were conducted to answer the main research question: *How can a digital intrinsically integrated game be designed and implemented in a lesson fostering conceptual knowledge and transfer regarding Newtonian mechanics*? Findings of our studies provide more insight on how students learn using a digital educational game. We developed a guiding frame for designing an intrinsically integrated game. Our studies demonstrate the benefits of embedding an educational game within other learning activities. Based on our findings, we give practical recommendations for such learning activities. Our studies provide an in-depth analysis, giving more insight on students' learning and providing recommendations for others who want to venture into the wonderful world of game didactics.

https://doi.org/10.33540/2340