Using a serious game to improve both students' motivation and comprehension of Newton's laws

Master thesis (30 ECTS) of Science Education and Communication
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24 July 2016

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Abstract

One goal of physics teaching is to tackle students preconceptions about the laws of motion and promote student comprehension based on physical concepts. An effective way of doing so is by using the problem posing approach: creating situations in which preconceptions are no longer adequate explanations, students will see the need for new theories. By implementing the problem posing approach in a serious game, students can experience the effects of their preconceptions without being bound to our known physical laws. This design-based research aimed to improve both students' comprehension and motivation regarding Newton's laws. To do so a serious game was developed where students had to bring a ball to a finish line. Students were able to set values for forces acting on the ball. A quasi-experimental evaluation conducted in three 3VWO classes (N = 73) followed the design phase. Students worked in pairs. Possible learning effects were measured with a pre- and post-test and students' motivation to engage in the learning activity was also measured in the post-test. The experimental group played the game followed by a classroom discussion. The control group experienced a traditional lesson. In both groups students did not score significantly higher on their post-test than on their pre-test ($p = .287$ and $p = .252$). However students who played the game were more motivated than students who experienced the traditional lesson ($p < .001$, $d = 1.43$). Finally, it is discussed how the experimental lesson can be improved and how the game itself can be improved.

Introduction

The role of preconceptions in physics teaching

On an everyday basis, students encounter different kinds of motion. In many cases, these can be described on a superficial level using a small set of simple ideas in which terms such as energy are not clearly defined. For more complex kinds of motion these ideas lead to wrong predictions (Hestenes, Wells, & Swackhamer, 1992). For instance, students are faced with the following problem: a rocket, drifting sideways in outer space, is subject to no outside forces. At a certain point the rocket's engine starts to produce a constant thrust perpendicular to the previous line of movement. The path of the rocket when the engine is on, is a parabolic path. However, students will predict a straight path. One goal of physics teaching is to tackle these existing ideas about the laws of motion and promote student comprehension based on physical concepts (Clement, 1982). Studies show that an effective way to do so in science education is by giving explicit attention to existing preconceptions (Chi, Slotta, & De Leeuw, 1994; Vosniadou, 1994; Duit & Treagust, 2003). More specifically, giving preconceptions a central role in teaching about the First and Second law of Newton has been shown to yield positive comprehension effects (Muller, Bewes, Sharma, & Reimann, 2008). Also, using preconceptions as a basis for instruction can contribute to building scientific literacy (De Boer, 2000). By creating situations in which preconceptions are no longer sufficient as an explanation, students are exposed to the need to engage in scientific reasoning, such as the development of new hypotheses and theories. In the problem posing approach (Klaassen, 1995), this idea is employed: by creating situations in which preconceptions are no longer adequate explanations, they will see the need for new theories. Students may be able to describe simple motions on a superficial level, however for more complex kinds of motion they have to give a more in depth explanation to describe a motion. Therefore, students need to alter their existing preconceptions and use a formal physical approach to explain more complex kinds of motion. Students will find the need to alter their preconceptions if they are no longer a sufficient explanation, therefore students need to see the behavior of their preconceptions on more complex kinds of motion. However, an important drawback is that teachers are limited to the 'correct' physics situations and problems. In our real world, behavior according to preconceptions cannot be shown, because our world simply behaves according to our known physical laws. If a preconception leads to a certain motion that contradicts the motion according to the physical laws, the motion according to the preconception cannot be shown. To truly show the behavior of students' preconceptions, there is need for an environment that is not bound to the real physical laws. Such an unreal environment is possible; it is a digital one. Students can be put in an unreal world. There they can set their preconceptions and experience their effects, without being bound to the physical limits of this world.

Serious games

A serious game is a computer game with the purpose to facilitate learning on top of the purpose of entertainment. In a serious game the entertainment value of video games is used to influence learners' motivation (Charsky, 2010). Recent studies show that training with serious games can be more effective than training with conventional instructional methods to improve knowledge and cognitive skills (Sitzmann, 2011). The use of a serious game leads to a better retention effect in comparison with conventional instruction methods. Serious games lead to well-structured prior knowledge on which learners can build during their learning career (Wouters, van Nimwegen, Herre, & Spek, 2013). Wouters et al. (2013) argue that it is possible that immediately after learning from conventional instruction, students are able to remember texts or notes given during instruction, leading to no difference between conventional instruction and game conditions. However, after several days students benefit more from game conditions, due to the fact that in a game students process a deeper level of knowledge (Kintsch, 1998). To make practice with serious games more effective than practice with conventional instruction methods, it is important to supplement the game with other instruction methods, such as a class discussion (Wouters, van Nimwegen, Herre, & Spek, 2013). The meta-analysis of Wouters et al. (2013) show that serious games are more effective in combination with other instruction methods in comparison with only playing a serious game. Whilst playing the game, students gain intuitive knowledge, however students are not promoted to verbalize this knowledge and anchor it more profoundly in their knowledge base (Wouters, Paas, & van Merriënboer, 2008).

Motivation

A major reason to use a serious game in a lesson, is that the use of a serious game should influence students motivation. A serious game should be more enjoyable than conventional instruction methods, thus students should be more intrinsically motivated to engage in the learning activity (Charsky, 2010). Intrinsically motivated behavior refers to doing something because it is inherently interesting or enjoyable (Ryan & Deci, 2000). In contrast with intrinsic motivation there is also extrinsic motivation, which refers to behavior that is driven by external rewards (Brown, 2007). Whilst playing a serious game students can also be extrinsically motivated to learn. For example, in a game students' learning can be rewarded with points, thus they are extrinsically motivated. In addition to the two types of motivation Ryan and Deci (2000) developed a taxonomy of human motivation where also different types of external motivation are defined. A distinction is made between external and internal motivation. Internal behavior occurs for example when students identify with the importance of an activity or when an activity is enjoyable Ryan and Deci (2000). In this research the focus lies on internal motivation.

The meta-analysis (Wouters, van Nimwegen, Herre, & Spek, 2013) shows that serious games do not have a positive motivational effect on students, contrary to expectations. In the meta-analysis, Wouters et al. (2013) provide several ideas why current serious games are not more motivating than conventional instructional methods. The first one is that students often lack control over decisions in serious games. Autonomy supports internal motivation (Deci, Vallerand, Pelletier, & Ryan, 1991), thus conditions in the game that limit students' sense of control lead to lower internal motivation. When autonomy is stimulated, students are more internally motivated to engage in the learning activity (Connell & Wellborn, 1991). The second idea is that the connection between entertainment design and instructional design is not a natural one. This means that design choices that are good for instructional purposes, often have a negative effect on the entertainment value (Wouters, van Nimwegen, Herre, & Spek, 2013). For instance, for instructional purposes it is effective to prompt the student to reflect. The designer could use a pop-up screen to do so. However, this pop-up disturbs the flow of the game, which leads to a negative effect on the entertainment value. To tackle the need for flow disturbing messages, it is important that the learning goal and the game goal are intertwined. By doing so, students are learning without the confrontation that they are doing a learning activity. Hence, if the aforementioned ideas are incorporated in a serious game, students should be more internally motivated to engage in the learning activity and therefore positive learning outcomes are expected (Ryan & Deci, 2000). To measure such internal motivation to engage in an activity, specific statements of the Situational Motivation Scale (SIMS) can be used (Guay, Vallerand, & Blanchard, 2000). The SIMS measures different kinds of situational motivation, including situational intrinsic motivation and identified regulation, both belonging to internal motivation. Situational intrinsic motivation is intrinsic motivation that occurs during the engagement in an activity (Guay, Vallerand, & Blanchard, 2000).

Existing games

Several games have been developed with the purpose to improve the comprehension of Newton's laws. Students are often put in an ideal frictionless environment, so that the motion represents the effects of forces in a theoretically ideal form. These serious games show positive learning outcomes (White, 1984; Koops & Hoevenaar, 2011). However, these games did not yield a positive motivational effect. Also, due to the ideal theoretical environment of the games, students are not confronted with their existing ideas, whereas a confrontation with their preconceptions could lead to positive comprehension effects (Chi, Slotta, & De Leeuw, 1994; Vosniadou, 1994; Duit & Treagust, 2003).

Incorporating a problem posing approach in a serious game

By implementing problem posing approach in a serious game, students can actually experience the effects of their preconceptions. Students will find out that some motions are impossible in the world of their own preconceptions.

In a serious game, students are able to set their preconceptions and experience the effects of those preconceptions. For instance, they can see if their preconceptions lead to an unrealistic movement. Confronted with this unrealistic movement, students are encountered with the fact that their preconceptions are apparently no longer a sufficient explanation for realistic movements. Therefore, in the ideal situation, students will find the need to discover new ideas that will lead to a realistic movement. These ideas will give an explanation for realistic movements. Since this need for explanation will come from the students themselves, students are more likely to engage in the learning activity (Vollebregt, Klaassen, Genseberger, & Lijnse, 1999). To evaluate the effectiveness of using the problem posing approach in a serious game, a reflection will be needed.

The case study: Newton's laws

A very suitable subject for the serious game is Newton's laws. Not only are the laws of motion an important part of the secondary school curriculum, there is also a lot of didactical information available about this subject. The preconceptions of students in the field of mechanics are well known (Driver, Squires, Rushworth, & Wood-Robinson, 1994). There is also a valid research instrument available, namely the Force Concept Inventory (Hestenes, Wells, & Swackhamer, 1992). With this information already validated, this research can truly focus on the learning and motivational effects of a developed serious game. Therefore, the aim of this research is to improve both students' comprehension and motivation regarding Newton's laws. This leads to the following research question:

How can the use of a serious game foster both students' comprehension and motivation with respect to learning Newton's laws in comparison with conventional instruction methods?

Method

Research design

The study followed a design-based approach followed by a quasi-experimental evaluation. First design criteria for the serious game were composed and a first version of the game was developed. The practicality of the game was evaluated by observing several students playing the first version and the game was further developed in a second version. This version was evaluated on the content level of the game and improvements were made to develop the final version. A quasi-experiment of the final version evaluated learning effects and motivational effects.

Participants

The participants during the design phase included 30 4VWO students between the ages of 14 and 17. The participants in the quasi- experimental evaluation included 73 3VWO students between the ages of 14 and 16.

Instruments

The developed game consists of seven levels. In each level students need to guide a ball to the finish. They can do this by giving the ball an initial kick, a force (F_{kick}). They also decide if there is another constant force ($F_{constant}$) working on the ball to keep it moving, they can set a value for that force. After the initial kick students can alter the direction of the ball by giving a small kick to the sides of the ball, perpendicular to the direction of motion. The difficulty of the levels slowly increases. Students start on a straight road with no friction. In a later level friction is added and curves occur. Also platforms on the road are added were the ball speeds up or slows down. Students lose a level if the ball falls of the road or if the ball stands still at some point. In each level students are able to collect coins, each worth 10 points, that gives them a score for each level.

Figure 1: *Level overview of the game.*

Figure 2: *An example of the settings at the start of level 4.*

Table 1: An overview of each level in the game. The first three levels and fifth level are introductory levels. At the start of each level students were able to set different forces (F_{kick} or $F_{constant}$). The 2nd column gives an overview if students could set the existence of the force with yes or no or if students could set a value for the force with the use of a scrollbar.

Level	Settings	Friction	Specifications of track
1	F_{kick}: scrollbar	No	Straight and short
2	$F_{constant}$: yes / no	No	Straight and short
3	$F_{constant}$: scrollbar	Yes	Straight and short
4	$F_{constant}$: scrollbar	Yes	Curves, can only finish with realistic physics
5	F_{kick}: scrollbar	No	Introduction of acceleration platforms and deceleration platforms
6	$F_{constant}$: scrollbar	Yes	different roads to finish, curves and platforms, can only finish with realistic physics
7	$F_{constant}$: scrollbar	Yes and no	Different pavements, different roads to finish, curves and platforms, can only finish with realistic physics

The first version of the game was evaluated by observing several students playing the game and in between levels and afterwards the researcher interviewed the students. An observational scheme was used. The observational scheme can be found in appendix I. In this observational scheme the researcher noted per level the settings, whether the student finished the level and if not how and where it went wrong. The researcher also noted the score per level and whether the in-game texts were read. There was also room to note any faults in the level. After each level several interview questions were asked:

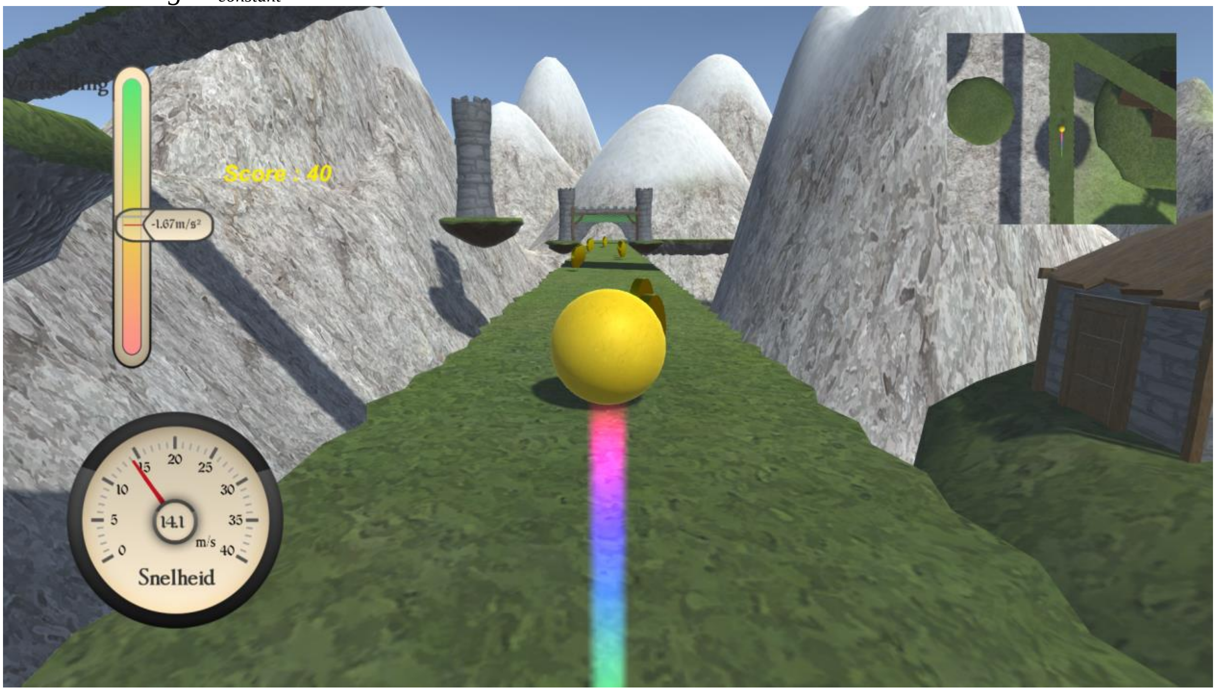
- What do you think about the difficulty level of the level?
- Was there anything unclear in the level?
- What do you think about the length of the level?
- Was the control of the ball intuitive?
- Would you play this level again with different settings?

To evaluate the second version of the game students filled in a post-test directly after playing the game. The post-test included specific items of the Force Concept Inventory (FCI) (Hestenes, Wells, & Swackhamer, 1992). It is advised to use the complete Force Concept Inventory to gain insight on conceptual understanding of mechanics. However, this research focuses on the First and Second law of Newton, not the entire mechanics. The items used in the post-test were items regarding the First and Second law of Newton. For the quasi-experiment a pre- and post-test were used which also included the previously used FCI questions. To evaluate a motivational effect on engaging in the learning activity, statements of The Situational Motivation Scale (SIMS) were implemented in the post-test (Guay, Vallerand, & Blanchard, 2000). The post-test used in the quasi-experiment can be found in appendix II.

Data collection and analysis

To improve the first version of the game, the observations and answers to interview questions were used. The second version was improved, based on the post-test data from 4 VWO students. To evaluate the final version of the game, a quasi-experiment was held in three 3VWO classes. These classes divided naturally in three groups. The first one, the control group, experienced a traditional lesson; they listened to a classroom instruction, they made assignments and revised those assignments. The second group played the game for 25 minutes without any further classroom activities. The last started the lesson with playing the game for 15 minutes and a classroom discussion or 10 minutes followed. This discussion included five images from several levels of the game. A complete overview of the images used during the classroom discussion can be found in appendix III. All groups started with a pre-test and ended the experiment with a post-test. The duration of the experiment in all groups was one lesson of 40 minutes including the pre- and post-test. All experiments were held on the same day.

Figure 3: *An example of an image used during the classroom discussion. This image is made in level 3 with the setting:* $F_{constant} = 0\ N$.



One week after the experiment the class who was previously used as the control group also played the game. Instead of a classroom discussion after playing the game, they got a worksheet with questions they needed to fill in whilst playing the game. The worksheet can be found in appendix IV. At the end of the lesson the motivational effect was measured with statements of the SIMS (Guay, Vallerand, & Blanchard, 2000).

Results

There were several observations and answers to questions during the evaluation of the first version of the game that led to game improvements.

Table 2: The results of the evaluation of the first version of the game and the improvements that were made for the second version.

Observation / answer to question	Improvement for the 2nd version
When the ball falls of the track, it keeps moving	When the ball falls of the track, the ball comes to a standstill and students are able to restart the level
Level 4 and 6 are too difficult	The initial force (F_{kick}) in level 4 and 6 is lowered
The scrollbar did not work properly in the setting	Scrollbar was fixed
In-game text was mostly not read	In-game text was shortened
If in-game text was not read, setting the forces was unclear	In-game text and setting were set in the same pop-up
The deceleration platforms did not work	Deceleration platforms were fixed

The results from the evaluation of the second version of the game led to the final game improvements. In the game a short kick animation is shown, when kicked against the ball, for instance at the start of a level. On the post-test a question was asked if students knew what this animation meant, 92,3% answered correct. 30 4VWO students scored 52% on the FCI questions of the post-test. To give more insight in the game what the influence of a sideways kick on the motion is, a kick animation was added to the sides of the ball when the direction of the ball changes by using the arrows on the keyboard. With these added animations students are more likely to see changes in direction due to a kick, instead of an internal steering system. To give students more insight on the effects of a $F_{constant}$ in comparison with no $F_{constant}$, it was decided that level 2 had to be played twice. One time with a setting that there was a $F_{constant}$ working on the ball and the other time without $F_{constant}$. This way students can see at least one time, the effects of such a force and use this information in the later levels, where a realistic movement has to be made. Most students were not able to finish all levels. In the last level (level 8) students were able to set F_{kick}, $F_{constant}$ and the mass of the ball. This level was deleted in the final version of the game.

Table 3: The results of the pre- and post-test (a minimal value of 0 and a maximal value of 6) and the results of the motivation scale (a minimal value of -2 and a maximal value of 2). Statistical significant differences are indicated with an index. If the indices of two means in a row are different, a and b, the two means significantly differ from each other. If the indices of two means are the same, there is no statistical significant difference between them.

	Control group Mean(SD)	Game group Mean(SD)	Experimental group Mean(SD)
Pre-test	2.40 (1.26)	2.19 (.90)	2.32 (1.04)
Post-test	2.88 (1.30)^a	2.00 (1.02)^b	2.68 (1.17)^a
Motivation	-.030 (.93)^a	.702 (1.06)^b	.977 (.87)^b

A paired samples *t*-test was performed to examine the mean differences between the pre-tests and the post-test of the groups. There was no significant difference in the scores of the control group between the pre-test (M=2.40, SD=1.26) and the post-test (M=2.88, SD=1.30) conditions; t(25)=.755, *p*=.252. There was also no significant difference in the scores of the game group between the pre-test (M=2.19, SD=.90) and the post-test (M=2.00, SD=1.02) conditions; t(24)=-1.174, *p*=.446. For the experimental group also no significant differences were found between the pre-test (M=2.32, SD=1.04) and the post-test (M=2.68, SD=1.17) conditions; t(21)=-1.093, *p*=.287. This means that in all three groups the intervention had no significant effect on the learning results.

A post-hoc analyses (LSD) was performed to examine the mean difference between the post-test. A Bonferroni adjusted alpha level of .017 per test (.05/3) was used to determine significant differences between the groups. The results show that no significant difference can be found at the .017 level between the control group and the game group (*p*=.492). Also no significant difference can be found between the game group and the experimental group (*p*=.678). Between the control group and the experimental group there also were no statistical significant differences found (*p*=.796).

Another post-hoc analyses (LSD) was performed to examine the mean difference between the post-tests. Effect sizes between two groups are calculated using the means and standard deviations of those two groups. The results show that a significant difference can be found at the .017 level between the control group and the game group (*p*=.009). Further, Cohen's effect size value (*d*=-.753) suggested a moderate to large effect. Between the control group and the experimental group no statistical significant differences were found (*p*=.563). Also no significant difference can be found between the game group and the experimental group (*p*=.048). These results show the importance of the embedment of the game in a lesson(series). The final results of the students who only played the game are significantly lower than those of students who experienced a traditional lesson.

Another post-hoc analyses (LSD) was performed to examine the motivational effects. A Bonferroni adjusted alpha level of .017 per test (.05/4) was used to determine significant differences between the groups. The results show that a significant difference can be found at the .013 level between the control group and the game group (*p*<.001). Further, Cohen's effect size value (*d*=1.02) suggested a large effect. Also a significant difference can be found between the control group and the experimental group (*p*<.001).

Further, Cohen's effect size value (*d*=1.43) suggested a large effect. Between the game group and the experimental group no statistical significant differences were found (*p*=.327). These results support the motivational effect of the game, both groups who played the game show a significant motivational effect in comparison with a traditional lesson.

Motivation was also measured when the control group played the game one week after their traditional lesson. Whilst playing the game the students had to fill in a worksheet. Another post-hoc analyses (LSD) was performed to examine the motivational differences between the control group during the traditional lesson and during the lesson where they played the game whilst filling in a worksheet (M=1.42, SD=.22). The results show that a significant difference can be found at the .013 level (*p*<.001). Further, Cohen's effect size value (*d*=2.47) suggested a large effect. The use of a worksheet also significantly differs with the game group (*p*=.012). Further, Cohen's effect size value (*d*=.911) suggested a large effect. However, no significant differences were found in motivation between using the worksheet and a class discussion following the game (*p*=.131).

Conclusions and discussion

The aim of this study was to improve both students' comprehension and motivation regarding Newton's laws. To achieve the research goal the following research question was answered:

How can the use of a serious game foster both students' comprehension and motivation with respect to learning Newton's laws in comparison with conventional instruction methods?

With the current developed game the comprehension of Newton's laws does not improve more in comparison with a traditional lesson. There was no significant difference found between the pre- and post-tests of all three groups. This means that in all groups the learning effects, if any, were low. This could possibly be due to the very short intervention time of 40 minutes. Both pre- and post-test were taken in that time, so the effective intervention time was only 25 minutes. Results show that the traditional lesson is about as effective as the experimental lesson regarding a learning effect. Students completed the post-test directly after the intervention, so no retention effect was measured. That learning effects do not differ between the students who played the game and students who practiced with conventional instruction methods, corresponds with the results of Wouters et al. (2013). To improve comprehension it is important to embed the game in a lesson, students who only played the game scored significantly lower on the post-test than students who participated in the traditional lesson.

Students who played the game as a lesson activity were clearly more motivated than students who received a traditional instruction method. To achieve this motivational effect, several criteria were implemented in the game. Students were able to incorporate their own ideas about motion and forces in the game, they could instantly see the effects of those ideas and come to a conclusion about how realistic their ideas were. Then they could alter their ideas and try to achieve a realistic movement. The learning goal and the game goal are intertwined with each other, there is a direct relation between the two goals. Lastly, students were able to make their own decisions in the game. They can set their own rules for motion and in some levels there are different routes to the finish. To gain a motivational effect, it was expected that is was important not to disturb the flow of the game. However, even when using a worksheet whilst playing the game, a significant motivational effect was found in comparison with a traditional lesson.

Before using the developed game in further research, note that the game itself needs some improvements. With the current game it was possible for students who had some game-experience, to finish the game with the use of nonrealistic physics. This however, should not be possible. Also, in the game before each level short texts appeared with information on how to play the game. However, whilst playing the game students generally did not read those texts, so it took them some time to figure out what they were supposed to do. Lastly, students scored lowest on the questions about direction of motion. The track in all levels of the game is rather narrow, a level with a broader track should be included in the game. With a broader track, students are able to see the influence of a kick on the movement.

To achieve a comprehension effect regarding Newton's laws, several aspects need to be taken into account for further research. It is shown that just playing the game is not an effective learning method. Therefore, the game should be embedded in a lesson series. By doing this, the intervention time also will be lengthened, thus solving the earlier stated problem of the short intervention time. To gain more insight in students' reasoning and comprehension of the subject, their reasoning should be made explicit during or after playing the game. To measure a learning effect, a retention measurement should occur. Wouters et al. (2013) argue that it is possible that immediately after learning from conventional instruction, students are able to remember texts or notes given during instruction, leading to no difference between conventional instruction and game conditions. However, after several days students benefit more from game conditions, due to the fact that in a game students process a deeper level of knowledge (Kintsch, 1998). To improve students comprehension and to achieve a learning effect, students need some guidance whilst playing the game, since they generally did not read in-game texts. A worksheet is one possibility, but are there more effective methods? What should the role of the teacher be in the lesson series? To answer these questions further research is needed.

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Appendix I: Observational scheme

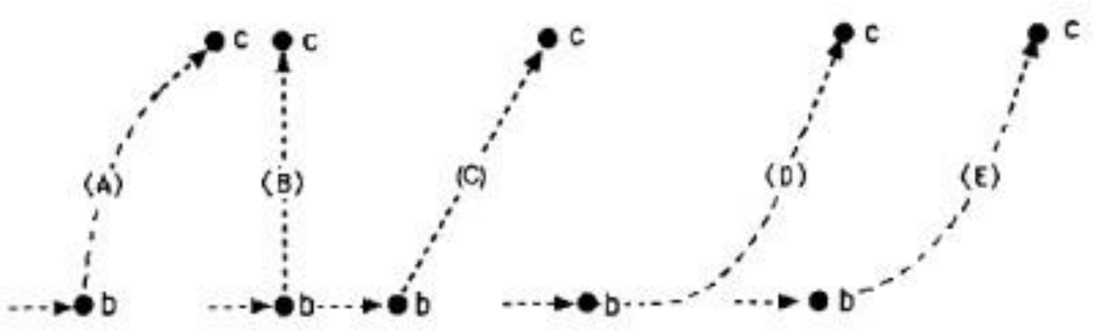
Poging	level					stilstaan	Van baan vallen	Locatie (waar het misgaat)	Level gehaald	Muntjes	Tekst vóór level
	1: Fduw: schuifbalk	groot	midden	klein	0						
1											
2											
3											
	2:Fv: wel/niet	wel	niet								
1											
2											
3											
	3: Fv: schuifbalk	Groter dan Fw	=Fw	Kleiner dan Fw	0						
1											
2											
3											
	4: Fv: schuifbalk	Groter dan Fw	=Fw	Kleiner dan Fw	0						
1											
2											
3											
	5: Fduw: schuifbalk	groot	midden	klein	0						
1											
2											
3											
	6: Fv: schuifbalk	Groter dan Fw	=Fw	Kleiner dan Fw	0						
1											
2											
3											
	7: Fv: schuifbalk	Groter dan Fw	=Fw	Kleiner dan Fw	0						
1											
2											
3											
	8: Fv: schuifbalk	Groter dan Fw	=Fw	Kleiner dan Fw	0						
1											
2											

Appendix II: Post-test

Beantwoord de onderstaande multiplechoicevragen:
Gebruik onderstaande stelling en diagram bij het beantwoorden van de volgende vier vragen.

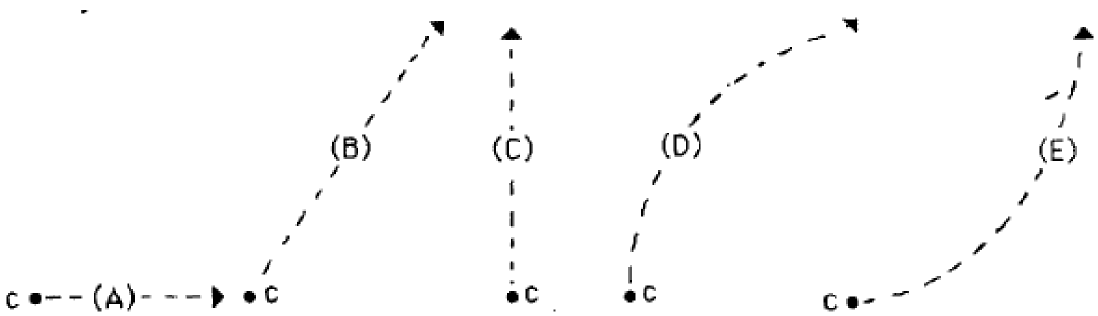
Een raket zweeft zijwaarts in de ruimte van positie ‘a’ naar positie ‘b’. Op de raket werken geen krachten. Op punt ‘b’ begint de motor van de raket een voortsuwingskracht te leveren, loodrecht op de lijn ‘ab’. De motor slaat weer uit wanneer de raket een punt ‘c’ bereikt.

1. Welk pad representeert het beste het pad van de raket tussen ‘b’ en ‘c’?



2. Terwijl de raket van ‘b’ naar ‘c’ beweegt is zijn snelheid:
   A. Constant
   B. Constant aan het versnellen
   C. Constant aan het vertragen
   D. Eerst even aan het versnellen en daarna constant
   E. Eerst even constant en daarna aan het vertragen

3. Bij punt ‘c’ slaat de motor van de raket uit. Welk pad zal de raket volgen na punt ‘c’?



4. Na punt ‘c’ is de snelheid van de raket:
   A. Constant
   B. Constant aan het versnellen
   C. Constant aan het vertragen
   D. Eerst even aan het versnellen en daarna constant
   E. Eerst even constant en daarna aan het vertragen

Z.O.Z. voor de laatste vragen

5. Een grote doos wordt over de vloer geduwd met een constante snelheid van 4,0 m/s. Wat kan je concluderen over de krachten die op de doos werken?

A. Als de kracht die op de doos werkt verdubbeld wordt, zal de constante snelheid toenemen tot 8,0 m/s.
B. De kracht die werkt op de doos om de doos met een constante snelheid te verplaatsen, moet groter zijn dan het gewicht op de doos.
C. De kracht die werkt op de doos om de doos met een constante snelheid te verplaatsen, moet gelijk zijn aan de tegenwerkende krachten.
D. De kracht die werkt op de doos om de doos met een constante snelheid te verplaatsen, moet groter zijn dan de tegenwerkende krachten.
E. Er is een kracht die werkt op de doos, zodat deze beweegt, maar externe krachten zoals wrijving zijn geen ‘echte’ krachten, ze bieden alleen weerstand aan de beweging.

6. Als de kracht die op de doos werkt plotseling stopt dan zal de doos:

A. Meteen stoppen
B. Een korte periode met een constante snelheid verder bewegen en daarna langzaam tot stilstand komen
C. Meteen langzaam tot stilstand komen
D. Doorgaan met een constante snelheid
E. Een korte periode versnellen en daarna langzaam tot stilstand komen

7. Geef per stelling aan in hoeverre je het eens bent met de stelling.

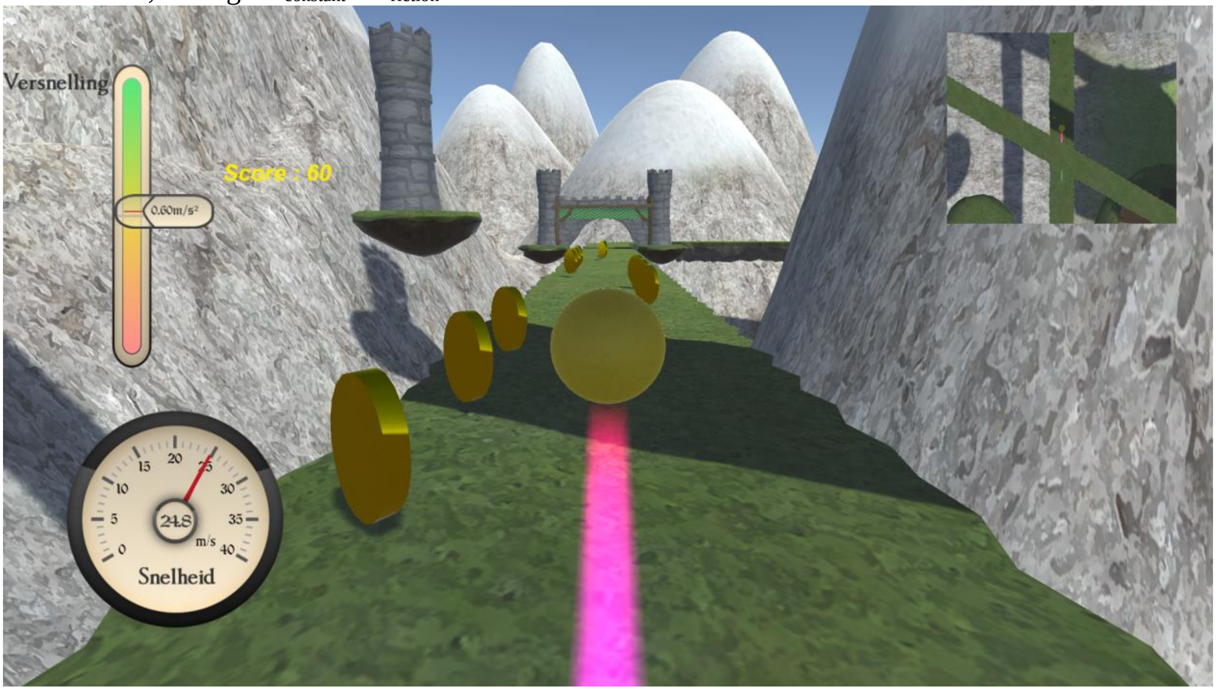
Stelling: Ik heb meegedaan met de lesactiviteit …	Helemaal niet mee eens	Een beetje niet mee eens	Neutraal	Een beetje mee eens	Helemaal mee eens
Omdat ik de activiteit interessant vond					
Omdat er vast wel een goede reden is om mee te doen, maar persoonlijk zie ik die niet					
Omdat het een aangename activiteit was					
Ik heb de activiteit gevolgd, maar ik weet niet zeker of dat het waard was					
Omdat de activiteit leuk was					
Ik weet het niet, ik keek wat de activiteit mij bracht					
Omdat ik me goed voelde wanneer ik bezig was met de activiteit					
Ik heb meegedaan met de activiteit, maar ik weet niet zeker of dat wel een goed idee was					

Appendix III: Images used during the classroom discussion

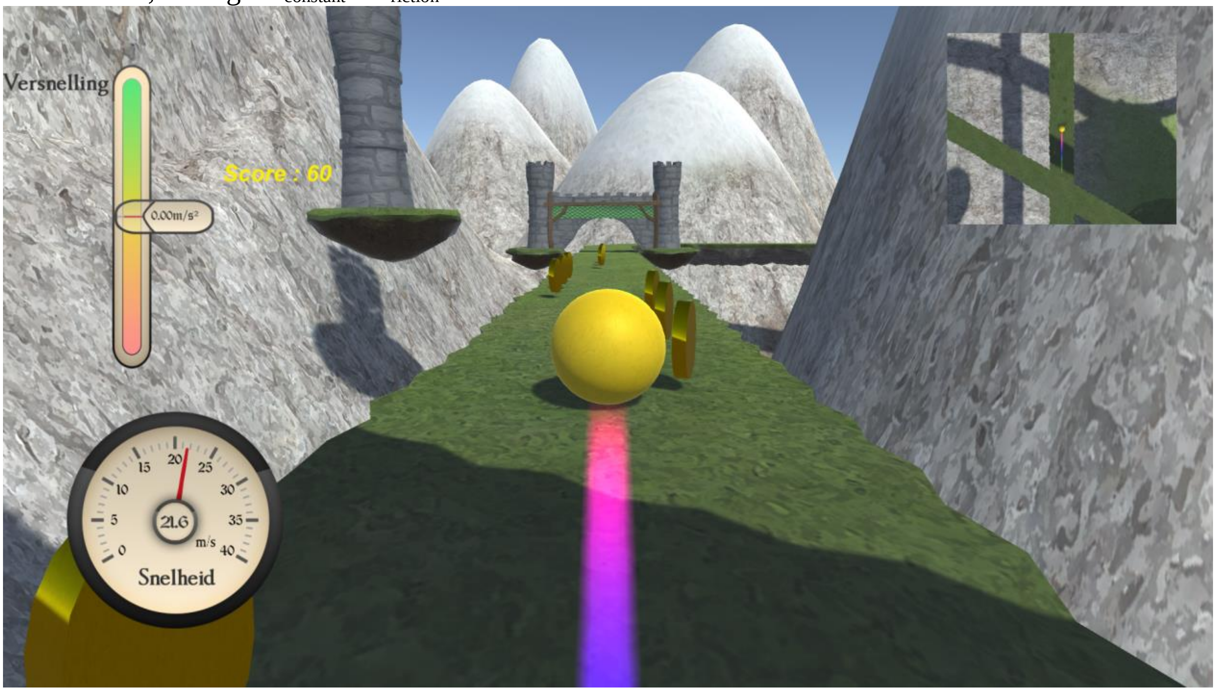
Level 2, settings: $F_{constant}$ = No

Level 2, settings: $F_{constant}$ = Yes

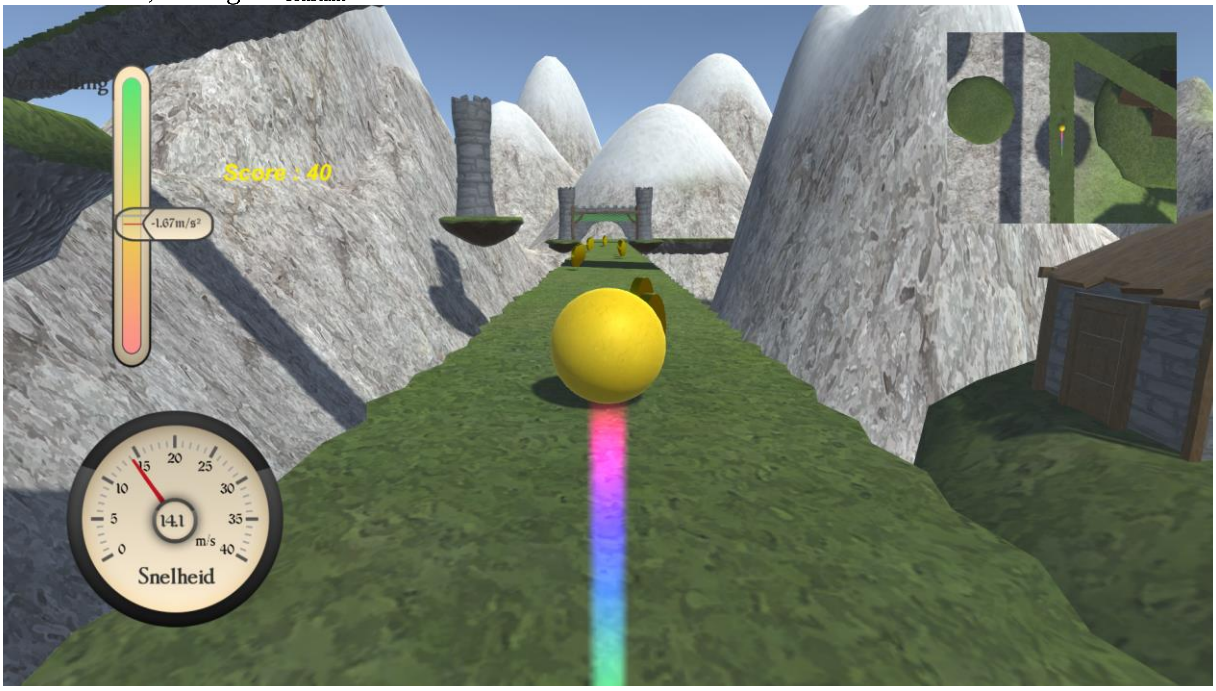
Level 3, settings: $F_{constant} > F_{riction}$



Level 3, settings: $F_{constant} = F_{riction}$



Level 3, settings: $F_{constant}$ = 0 N



Appendix IV: Worksheet

Speel de levels van het spel op chronologische volgorde. Lees de teksten die voor elk level verschijnen. Beantwoord de onderstaande vragen bij de bijbehorende levels.

Level 1:
Er wordt één keer tegen de bal getrapt, tijdens de rest van de beweging werken er geen krachten op de bal. Welke beweging maakt de bal?

A. Versnelling
B. Vertraging
C. Constante snelheid

Level 2:

a. Er wordt één keer tegen de bal getrapt, tijdens de rest van de beweging werkt er een constante voorwaartse kracht op de bal. Welke beweging maakt de bal?
   A. Versnelling
   B. Vertraging
   C. Constante snelheid

b. Is dit een realiste beweging?

Level 3 &4:

a. Er wordt één keer tegen de bal getrapt, de bal rolt over gras. Welke beweging zou de mak moeten maken?
   A. Versnelling
   B. Vertraging
   C. Constante snelheid

b. Als je instelt dat er een constante voorwaartse kracht op de bal werkt, welke beweging maakt de bal dan?
   A. Versnelling
   B. Vertraging
   C. Constante snelheid

c. Welke beweging maakt de bal als die constante voorwaartse kracht precies even groot is als de wrijvingskrachten?
   A. Versnelling
   B. Vertraging
   C. Constante snelheid

d. Je wilt een zo realistisch mogelijke beweging maken. Werkt er dan wel of geen constante voorwaartse kracht op de bal?

Level 5:
Wat is de werking van de groene plateaus? En van de rode?

Level 6 & 7:
Speel deze levels en probeer het einde te halen! Dit is het best te doen als je een zo realistisch mogelijk beweging instelt…