A serious game for interactive teaching of Newton's laws

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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. In this study, we used a serious 3D immersive game to put students in situations in which their preconceptions are no longer adequate explanations. The expectation is that students will see the need for new theories. This design-based study aims to improve both students' comprehension and motivation regarding Newton's laws. In the game 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 grade 9 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).

Keywords: Science Education, Serious Games, Simulation; inquiry-based learning; modeling

Concepts: • **Applied Computing** → Interactive learning environments

1 Introduction

Understanding the laws of Newton is the basic of every mechanics course. One common problem in teaching these laws is that they seem to be in contrast with everyday experience. This leads to misconceptions such as the idea that for every motion a force is required. For more complex kinds of motion these ideas lead to wrong predictions (Hestenes, Wells, & Swackhamer, 1992). One goal of physics teaching is to address such 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). For complex types of motion, students need to alter their existing preconceptions and use a formal physical approach to explain more complex kinds of motion.

In this study we aimed to make students aware of the limitations of their conceptions using a serious game. 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). Serious games lead to well-structured 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). 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. Another major reason to use a serious game in a teaching, is that the use of a serious game could increase influence students' motivation. Intrinsically motivated behavior refers to doing something because it is inherently interesting or enjoyable (Ryan & Deci, 2000).

2 Method

The study followed a design-based approach followed by a quasi-experimental evaluation. The game was iteratively developed and fine-tuned to reach a final version. A quasi-experiment using the final version evaluated learning effects and motivational effects. The participants during the design phase included 30 10^{th} grade students between. The participants in the quasi- experimental evaluation included 73 9^{th} grade students.

2.1 The game

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 (Fkick). They also decide if there is another constant force (Fconstant) 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

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each level students are able to collect coins, each worth 10 points, that gives them a score for each level.

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. 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 final 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). 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).

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 without any further classroom activities. The last started the lesson with playing the game and a classroom discussion followed. This discussion included images from several levels of the game. 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 data were collected on the same day.

3 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 1: 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	Improvement for the 2nd
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 (Fkick) 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 resulting final version was used in the quasi experimental evaluation. Table 2 below provides the scores on the pre- and post-test as well as for the motivational test administered afterwards. In all three groups the intervention had no significant effect on the learning results. Remarkable is that the game-only even scored lower on the post-test, although not significantly.

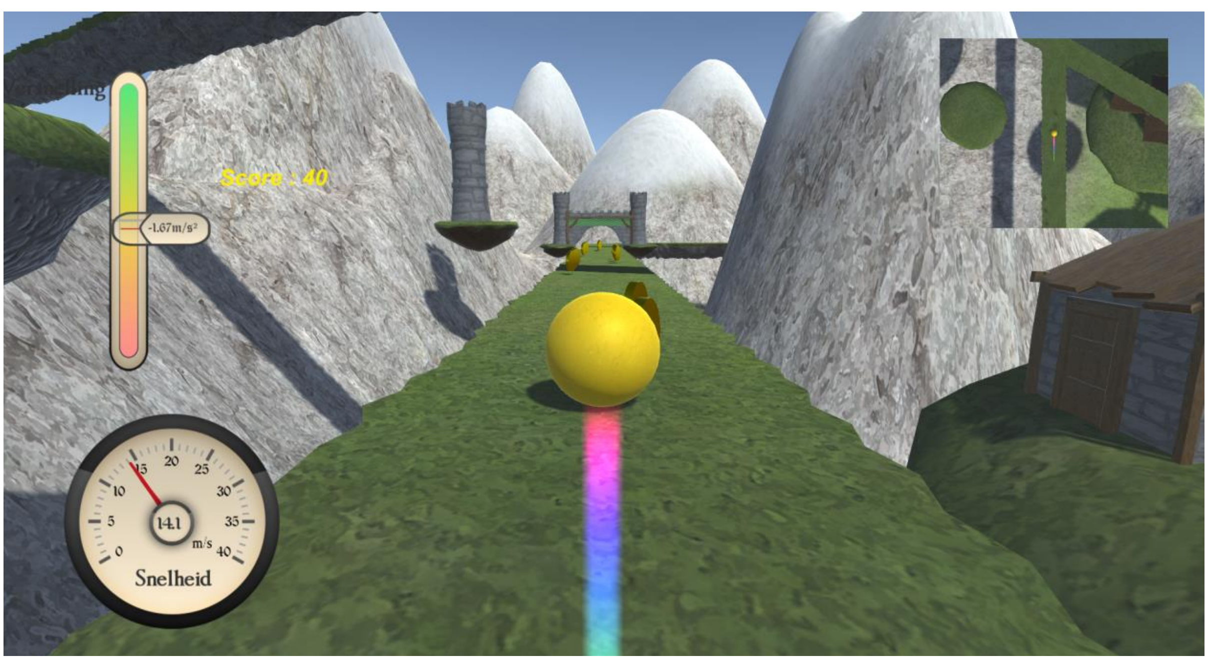

Figure 1. Screenshot of the game. Visible is the ball as well as the controls for the learner to influence the ball's course

Table 2. Mean scores and standard deviations for the three groups on pre-test, post-test and Situational Motivational Scale

	Control	Game only	Game + discussion
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]
SIMS	-.31 (.93)[a]	.70 (1.06)[b]	.98 (.87)[b]

A 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 .017 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.

4 Conclusions

We were unable to show that the game actually contributed to learning Newton's laws. This can be ascribed to the short duration of the intervention, effective intervention time was only 25 minutes. However, 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.
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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