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Conceptual Change During a Serious Game: Using a Lemniscate Model to Compare Strategies in a Physics Game

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Abstract

In our research, we used two different versions of a serious game to realize conceptual change regarding classical Newtonian mechanics. We propose the Serious Gaming Lemniscate Model (SGLM). It states that in an educational game, a player is either in a gaming state, intuitively acting on the feedback in the game, or in a learning state, rationally reflecting on the gaming experience. To test our model, we moved the student from the gaming state to the learning state. Next, we investigated whether this shift was effective in changing the student's concepts. We did so by suddenly increasing the complexity of the game between consecutive levels, generating authentic learning questions. We compared the learning gain of students who are forced out of the game state to students who played the game through without the sudden increases in difficulty. Both strategies were benchmarked against a control group where no game was used. We developed a physics game to challenge the conceptual knowledge of third-grade secondary school students regarding Newtonian mechanics. We found that students who played the game as part of the physics classes experienced an increase in perceptual knowledge. However, the effect of interrupting the game state to initiate a learning state did not add to the conceptual change compared with the group who played the game through without interruptions.

Keywords

conceptual change, Force Concept Inventory, game cycle, Kolb, learning cycle, learning gain, Lemniscate Model SGLM, Newtonian mechanics, reflection, serious game, Serious Gaming Lemniscate Model, Vygotsky

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Debriefing, reflection on a game experience, is a crucial step in serious gaming (Lederman, 1992). This is especially true when it comes to correcting misconceptions that are "known to be resistant against education" (Eryilmaz, 2002). Misconceptions are preexisting intuitive concepts arising from everyday experiences in the real world. It is hard to correct them by explanations or standard lessons. It is important to offer alternative experiences to the students. These alternative experiences can be used to trigger cognitive conflicts, creating the basis for conceptual change (Scott, Asoko, & Leach, 2007). Conceptual change indicates a change in conceptual knowledge, from misconceptions to correct scientific concepts. Serious games offer students new experiences and the opportunity to reflect on those experiences.

Unlike computer simulations or applets, serious games are likely to trigger a flow experience (Csikszentmihalyi, 1991). This flow experience drives intrinsic motivation (Kearney & Pivec, 2007), which is why serious games seem to be so suitable for educational purposes. It is not clear, however, how this flow experience is related to the effectiveness of the learning experience. It may hamper a deeper reflection, since the player may only be interested in playing the game on a superficial level; conceptual learning does not automatically fit in this activity (Paras & Bizzocchi, 2005). Kearney and Pivec (2007) prefer the student to be in the flow state, since this drives motivation. Yet Appelman (2007) states, "The confusion in a serious game is whether or not the flow is synonymous with engagement in learning or just deep concentration on gameplay and fun" (p. 1). Rieber and Noah (2008) find that "the gaming activity did not promote reflective cognition. In fact it actually interfered with explicit learning" (p. 89). Leemkuil and de Jong (2011) review different guidance mechanisms used in educational games, helping the student reflect on the experiences encountered in the game.

We developed the Serious Gaming Lemniscate Model (SGLM) to reflect two mental states involved in experiential learning by serious games (Koops, 2010). This model has a game cycle in which a student can evolve and discover the rules of the game intuitively. The model also has a learning cycle in which a student can systematically reflect, analyze, and investigate the in-game experience. In the game cycle, the student acquires spontaneous (game induced) conceptual knowledge, which is only applicable within the game context. In the learning cycle, the student gains a more formal (scientific) conceptual understanding of what happens in the game and decides how to apply this knowledge, either within the context of the game or in a completely different context. According to the SGLM, it is important to make the transition from the game cycle to the learning cycle. In this research, we investigated whether we could effectively initiate this transition by forcing the student out of the game cycle, using sudden increasing difficulty to effect the shift. We explored how this shift affected students' concepts.

We have set up an experiment using two slightly different versions of the same game. For this research, we developed a simple serious game (SPACE CHALLENGE) that offers an alternative experience regarding Newtonian mechanics. The game is about a spaceship in a frictionless environment. This game allows the player to explore the concepts of Newtonian mechanics in a powerful way, offering a contrast to everyday experiences.

The central question in this research is, “Does a forced switch between game cycle and learning cycle lead to more conceptual change?”

The SGLM

The SGLM basically consists of a game cycle and a learning cycle, which are mutually interconnected. The word lemniscate comes from the Greek word *lemniskos* for ribbon. Mathematicians use it as the symbol for infinity. The symbol does not have a start or an end, and connects two different cycles at the turnover point in the middle. We have chosen the lemniscate since it provides a nice metaphor for the two levels of intuitive and scientific learning, as will be explained below.

Other serious game models consist of a combination of learning cycles, often accompanied by transfer steps taken in a separate debriefing afterward. Garris, Ahlers, and Driskell (2002) describe the gameplay as a process, fed by the designer with content and rules that are executed and experienced by the player. Afterward, the teacher takes care of the transformation of implicit knowledge into explicit knowledge, usually in a debriefing phase. Pivec and Pivec (2009) present a model that describes how a student gains declarative, procedural and strategic knowledge by reflection-in-action during the game cycles. They explain that the reflection-on-action in the teacher-led debriefing is only necessary for affective learning outcomes. Kiili and Ketamo (2007) present a single loop/double loop learning model describing a “cyclic process through direct experience in the game world.” According to this model, no debriefing is necessary. They find a positive learning gain in the domain of geometry. Kiili (2005) stresses that the feedback of the game should support reflective thinking. However, no suggestion is made on how and when to organize this reflection.

In the SGLM the intuitive learning and the scientific learning are presented in the game cycle and the learning cycle as two different types of learning. According to the SGLM a student is either intuitively acting in the game cycle or rationally reflecting in the learning cycle. No scientific knowledge can be realized without reflection in the learning cycle.

The lemniscate representation of the SGLM is inspired by the Experience-Based Tacit-Explicit Knowledge Interaction Model that Medeni and Medeni (2004) developed for knowledge management purposes.

The learning cycle reflects the experiential learning cycle (D. A. Kolb, 1984), where the student may start from a concrete experience. The student then reflects on this experience in an observation, thinks about the reflection and develops a formal conceptual understanding during the abstract conceptualization. Finally, she tests the newly developed concept in an active experimentation (Figure 1). In our case, the student experiences frictionless motion in the game (concrete experience). The differences with everyday experience are observed: Motion does not stop by itself (reflective observation). The concept is explained, possibly with help of the teacher (abstract conceptualization). Finally, the student can figure out and plan a strategy for the next attempt in the game (active experimentation).

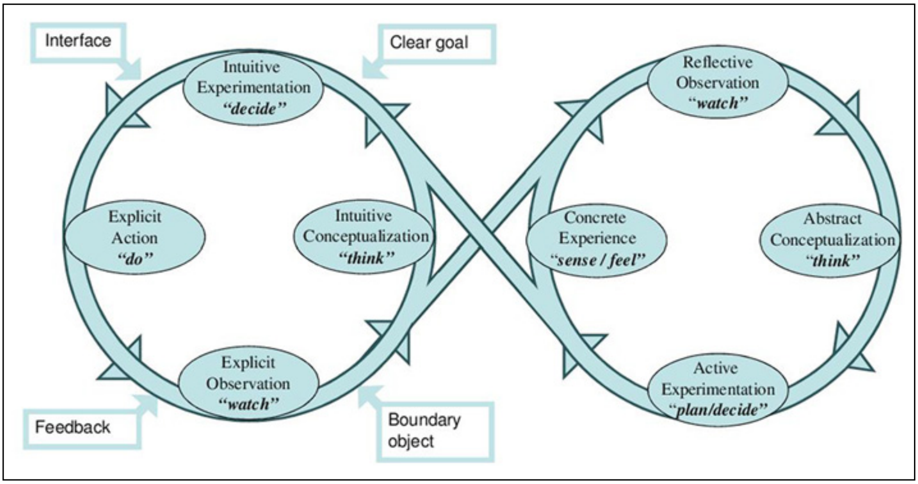

Figure 1. The Serious Gaming Lemniscate Model.

The game cycle is a representation of a similar cycle, now reflecting the intuitive state of the gamer. The game cycle describes the creation of spontaneous conceptual knowledge (Egenfeldt-Nielsen, 2005; Vygotsky, 1986). The game cycle invites the student to start an intuitive experimentation by performing an explicit action. The student recognizes the game goal and takes action in an attempt to reach it. The student's action triggers the game to generate feedback for explicit observation. Finally, the student creates an intuitive concept to relate the feedback to the action (Figure 1). Depending on the type of game being played, a single game cycle may last a very short amount of time and can be cycled through many times, gradually building up the spontaneous conceptual knowledge.

Two Types of Reflection in the SGLM

Schön (1983) describes how a professional can learn in two different modes by differentiating reflection-in-action and reflection-on-action. When reflecting-in-action, a professional reflects during the action itself. This reflection mode is observed with experienced professionals who can rely on a large repertoire of experience and a solid conceptual foundation. The reflection-on-action takes place after the action is finished and the professional looks back on the completed task. When a professional gets enough opportunities to reflect-on-action, the ability to consciously and systematically reflect will develop. In an educational setting, this ability is trained during practicum. Shaffer (2007) argues that the reflection-on-action often takes place with the help of peers. The two essentially different types of reflection are acknowledged by the SGLM. Reflection-in-action takes place in the game cycle and reflection-on-action is situated in the learning cycle.

Switch From Game Cycle to Learning Cycle

In a serious game, the student figures out the implicit rules of the underlying theoretical model on which the game is based. Having a clear goal, the student, preferably in a flow state (Csikszentmihalyi, 1991), develops an intuitive "sense" for the interaction (and thus the underlying rule set of the game), often by a trial and error approach (Kiili, 2005). The student develops a spontaneous concept (Egenfeldt-Nielsen, 2005; Vygotsky, 1978). This spontaneous concept is different from the formal concepts that are applicable within a wider range of (school) contexts. Intuitive knowledge is attained by experiential involvement in a practical or mental activity (Rieber & Noah, 2008; Swaak & de Jong, 2001). It is not a formal concept, and it cannot yet be applied to a different situation or context. To transform this spontaneous concept into a formal concept, the student must go through the experiential learning cycle (D. A. Kolb, 1984). Previous studies have examined serious gaming by applying experiential learning theories (see, for example, Egenfeldt-Nielsen, 2005; Garris et al., 2002; Kearney & Pivec, 2007; Leemkuil & de Jong, 2011; Ulrich, 1997).

The experience gained in a serious game can be taken as a starting point in the learning cycle (Van Eck, 2006). From here, additional educational interventions must be performed to translate spontaneous conceptual knowledge to formal conceptual knowledge. The interventions are needed to transform a spontaneous concept created by the experimenting student (and only applicable within the game context) into a formal scientific (generally applicable) concept (Egenfeldt-Nielsen, 2005). To realize transfer of game experience to real-life situations, a debriefing to reflect on the experience is crucial (Crookall, 1995; Crookall & Thorngate, 2009; Freitas & Neumann, 2009).

A student is very unlikely to reflect rationally on the experience while in the game cycle. Egenfeldt-Nielsen (2005) states,

> Students will, of course, acquire a number of experiences immersed in the game universe, but these will primarily be ordered as spontaneous concepts and not scientific concepts that can help students see the experiences in a broader perspective. (p. 128)

In the game cycle, the student will intuitively "reflect" on the experience and decide on new actions on the fly (Garris et al., 2002). A. Y. Kolb and Kolb (2009) emphasize the need for reflection and describe how learning at the object level of direct concrete experience should be considered at the abstract meta-level with a learning model that includes ideas like learning demands. For this, the student must reflect-on-action (Schön, 1983), and we must pull the student from the game cycle into the learning cycle. We cannot ask a student who is concentrating on collecting diamonds in a videogame to take part in a scientific discussion on Newtonian mechanics at the same time. We need a mechanism to pull the student out of the game, while stimulating interest in the scientific reflection on the experience.

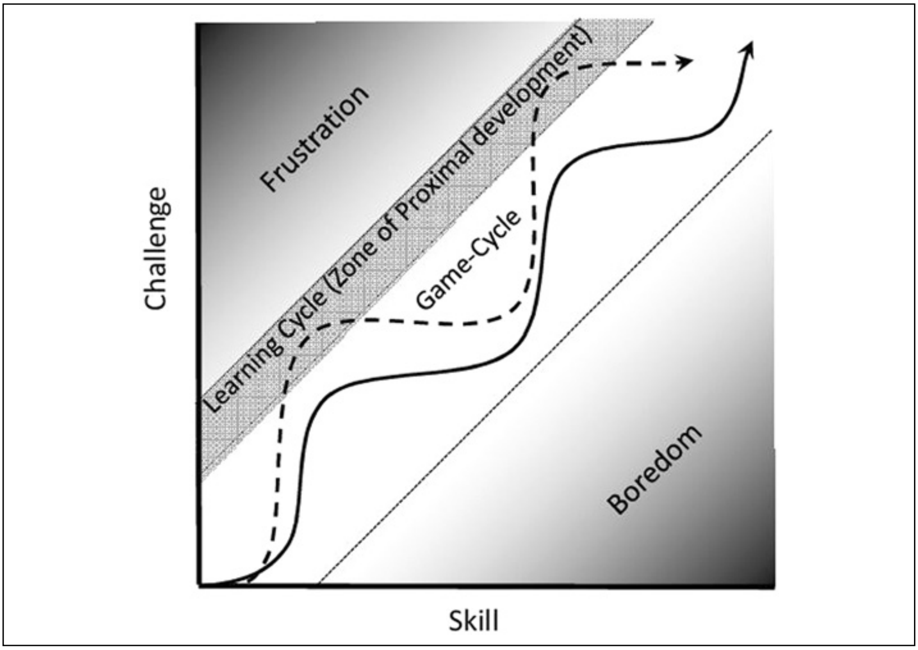

Figure 2. Here is indicated how a bit of frustration can force a player out of the Game Cycle into the Learning Cycle.
Note: By frustrating a student out of the game cycle, we can get in the Zone of Proximal Development to guide the student through the learning cycle, preparing for the next game experience.

Why would the student have an intrinsic interest in the scientific discussion? Why would the player happily engage in a discussion just after playing a game? The challenge with a serious game experience, according to the SGLM, is to lure the student out of the game cycle in order to willingly and rationally reflect on a scientific level.

Working the Junction

Mercedes and Rodrigo (2011) found that confusion is a desirable state in gaming. Students who are confused are not likely to stay confused, but will transition into engagement. We believe that confusion or frustration may be a suitable instrument to work the central junction in the SGLM. In one of the versions of the game we designed, the challenge increases substantially when a new underlying concept is introduced. The student might fail quickly and fall out of the game cycle as he is confronted with a game-over screen. The student will look for assistance to get back into the game cycle, originating from the intrinsic motivation to succeed within the game. While the student is no longer in the game cycle, teachers are able to communicate on a conscious and cognitive level, helping the student understand the reason behind the failure. We need this communication to fully make use of the zone of proximal development (Vygotsky, 1978; Figure 2). We (or advanced peers) are now able to explain scientific concepts, answer

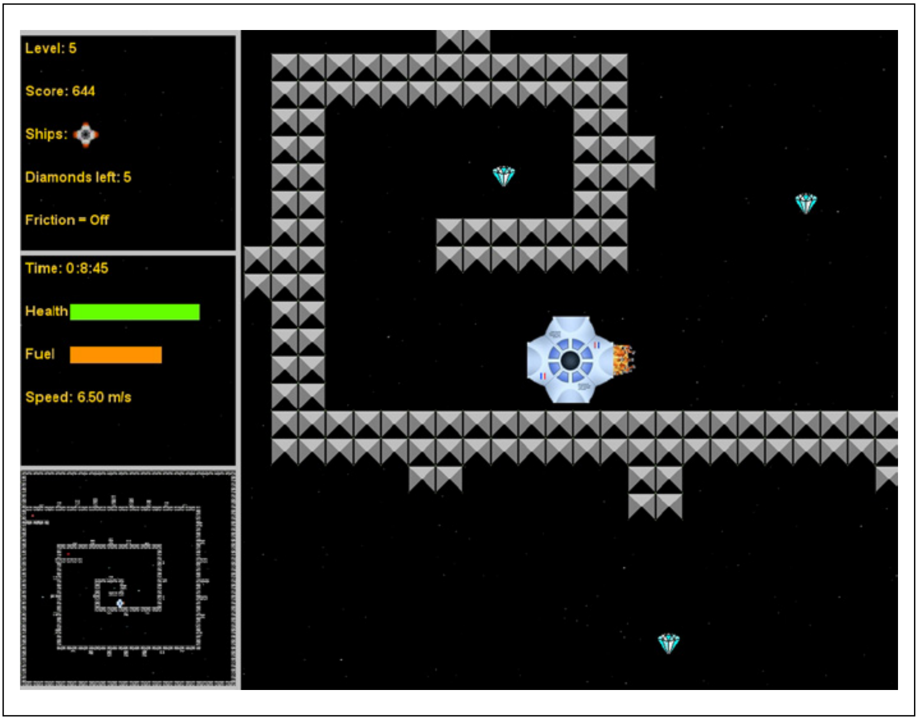

Figure 3. SPACE CHALLENGE.

specific questions, or assist with instructions and experimentation hints (de Jong & van Joolingen, 1998). Based on the scientific knowledge we provide, the students may find more appropriate strategies for future attempts. Once a scientific hypothesis is formed, new game strategies can be devised (based on these formal scientific concepts), and the student can switch back to the game cycle to once again tackle the game. Repeating this process is expected to result in a student who will transfer spontaneous conceptual knowledge to formal conceptual knowledge, and then put this formal conceptual knowledge to good use within the game context (and other contexts as well).

In Figure 3 the solid line represents a learning curve of a student in the game cycle during the whole process. Skill and challenge are balanced all the time, and scientific reflection on the actions taken is not necessary to accomplish the game goals. The broken line shows a learning process where every now and then the challenge increases to exceed the students' capabilities, pushing the student out of the game cycle and into the learning cycle.

The Experiment

In a previous article (Koops, 2010), we showed how the SGLM explains results from previous research. In this experiment, we used the SGLM to design a game and to measure the conceptual gain it achieved. We measured the conceptual gain in three different groups. To investigate the effect of the forced switching between game cycle and learning cycle, we implemented two different strategies. A third group served as the benchmark group. In one strategy, we let the students play the game through before debriefing the experience. In the other strategy, we triggered the switch from the game cycle to the learning cycle. The trigger mechanism we developed is the sudden and substantial increase in the difficulty of the game whenever any new concepts are introduced. The learning curve is therefore quite steep. The levels can only be solved when an optimal solution is chosen. Little room exists for error, and a trial-and-error-based approach to finish the game is nearly impossible. After the gaming session, the students are debriefed in a similar fashion as the first strategy.

We wanted to find out which of the two strategies is the most effective. We determined the effectiveness by measuring the conceptual gain of the students. For this research, we specifically created two slightly different versions of the serious game called "SPACE CHALLENGE."

SPACE CHALLENGE Design Based on SGML Principles

In SPACE CHALLENGE, the student maneuvers a spaceship through a 2D maze. The mission is to collect all diamonds in each level. Each level can be finished by hovering completely still over a final stop sign. Walls, mines, and debris, which are present in some of the levels, have to be avoided. The game does not look like a serious game at first glance. It seems like a common arcade game. At a closer look, essential features of the SGLM are obvious. These essential features, such as a clear goal, an intuitive interface, immediate feedback and boundary objects, are indicated in the square outlines in Figure 1. The arrows in the game cycle (Figure 1) show the specific order in which these must be presented to the student (Koops, 2010). It is the careful implementation of all these features, developed for specific learning goals, that makes this game a serious game. These features organize the concrete experience of the student; it is on these experiences that the scientific reflection will be based. For the student to be able to act intuitively, a clear goal is required in the game, preferably related to the target concepts in some way, thus making the transfer easier (Kiili, 2005; Rieber & Noah, 2008; White, 1984).

In SPACE CHALLENGE, the goal is to maneuver the spaceship skillfully, collect diamonds, hover over the stop signs, avoid crashing, maintain fuel and stay within the time limit (Figure 3). The information panes at the left side of the screen indicate the current level, the number of ships that are left, whether friction exists in the level and the remaining time. Fuel and health indicators are placed here, next to a speed indicator. In the bottom field is a mini map of the maze in the current level.

Since the goal is clear, the student is ready for action. A simple and intuitive interface is essential for the student to easily control the game, sustaining the trial and error approach (Kiili, 2005; White, 1984). The interface should faithfully represent the target concepts by influencing the value of essential model quantities in an unambiguous way

(White, 1984). This is realized by simply using the cursor keys to control the thrust engines of the spaceship. The student can only choose four well-defined directions, since only four cursor keys are available. The engine thrust (force) is set to a default value. The student can only vary the thrust time by pressing for longer or shorter periods of time on the cursor keys. By keeping the thrust value constant, we do not implement the force as a variable. This helps to keep the focus on the key target concepts of the game. In education, it is good practice to focus on the learning goals and remove noise and irrelevant features. We believe that this should also be kept in mind when it comes to serious games. Entertainment games may benefit from many degrees of freedom, as these offer opportunities for the player to investigate. In serious games, we want to keep a clear focus on the learning goals, by restricting the number of variables (at least in the lower levels of the game) while still maintaining enough freedom for fun gameplay. The feedback is provided by the ship's velocity, which instantly adjusts as the thrust engines are fired. Flames are visible, and a "thrust-sound" is heard when the engine is active (Figure 3). Furthermore, the amount of fuel decreases as the engines are being used. Whenever a wall or a mine is hit, sound effects and a reduction on the health indicator inform the students of the severity of the damage. These properties allow the student to evaluate specific events in the game. The representation of these properties in the virtual environment also relates to the scientific context (White, 1984). In SPACE CHALLENGE, the engine's exhaust flames are indicative of the direction of force applied to the spaceship and its subsequent change in velocity, allowing the student to get involved in a qualitative reflection. Such properties can be identified as boundary objects.

A boundary object is an idea, introduced by Star and Griesemer (1989), that originates from sociology and is adopted in other fields as well (Trompette & Vinck, 2009). We use it for an object that has a natural relevance in two different contexts; in this case in the game cycle as well as in the learning cycle. The flames are identified as boundary objects, as they have a natural meaning within the game, and during the reflection and debriefing they are a metaphor for the force exerted on the spaceship. In some levels, where friction is active, this is represented with a blue background (indicating the presence of air, and thus friction). This allows for a direct experiential comparison between motion with and without friction.

The levels in the game increase in difficulty, similar to a normal lesson series in Newtonian mechanics. In Levels 1 and 2, the students must accelerate and stop along a straight line, both with and without friction. Levels 3 and 4 involve maneuvering the spaceship along a curved path, both with and without friction. Levels 5 and 6 incorporate more complex maneuvers and narrow pathways. Level 7 combines these basic movements in a more complex environment with an increasing number of obstacles. The increase in difficulty is maintained throughout consecutive levels.

Implementing the Game in the Lessons

In SPACE CHALLENGE, we offered the student a concrete experience in the game cycle, after which we invited the student to reflect on this experience in the learning cycle. As teachers, we facilitated this reflection, providing support by asking questions, proposing scientific concepts, or suggesting experiments or game strategies. The game was incorporated in a lesson series on Newtonian mechanics. In our research, the game cycle started by providing the student with a clear game goal: Collect diamonds using a spaceship without crashing into obstacles.

The interface of the game is very simple and intuitive, so the student can focus on game strategies and immediately perform meaningful explicit actions, rather than wasting cognitive capacity trying to figure out how to handle the spaceship. By observing the spaceship moving on-screen, the student gets immediate feedback on the performed action. Based on this feedback, the student might adjust the game strategy in a next attempt. In this way, the student moves around within the game cycle and gains experience in an alternative virtual world without friction. The player will notice sooner or later that a movement, once started, will not stop unless an opposing (breaking) force is applied. The player will get used to the fact that accelerating and breaking only happen when a force is applied to the spaceship. A constant motion can only exist when no force is applied. At this stage, the knowledge gained by the student is not (yet) explicit, because no reflection on the experience has taken place. The in-game experiences add to the spontaneous conceptual framework of the student. In order to make the student think of these experiences in a more formal manner, based on scientific concepts (which are applicable in other contexts as well), we needed to stimulate the student to rationally and systematically reflect on the experiences. After the student had stopped playing the game, we had the opportunity to ask about the observations made during the game: "Did you notice what happened when you did not apply any force?" "What was your strategy when you had to move around with little fuel/time left?" and "How do you effectively go through a corner?" After starting a discussion this way, we helped the student formulate the experience and observations in a scientific manner, stimulating the transfer from spontaneous conceptual knowledge to formal conceptual knowledge.

Measuring the Conceptual Gain Using the Force Concept Inventory (FCI)

Traditional tests to measure the students' progression in secondary school rarely reflect their conceptual knowledge, but rather the ability to calculate a correct answer using standard formulas in standard situations. These problem-solving abilities are very different from conceptual knowledge (Ates & Cataloglu, 2007). Therefore, traditional tests do not detect conceptual discrepancies, which might cause students to cope with the subject by memorization of isolated fragments or formulas and by carrying out calculations that do not contain any meaning in themselves (Hestenes, Wells, & Swackhamer, 1992; Krause, 2008).

In our experiment, the conceptual gain was measured using the FCI. The FCI is a multiple choice test. It forces the student to choose between the correct scientific answers and many common intuitive alternatives. It has proven to be a valid and reliable instrument for measuring conceptual knowledge regarding Newtonian mechanics (Hestenes et al., 1992; Krause, 2008; Muller, Bewes, Sharma, & Reimann, 2008). For this research, the FCI was translated into the Dutch language without any modifications. Note that the FCI exclusively measures conceptual knowledge. It does not predict how well a student will score on a calculus-based test where mostly problem-solving capabilities are tested.

Method

To investigate the effect of forcing a student out of the game cycle, we measured the conceptual gain of students for three different groups of students by comparing pretest and posttest scores from the FCI. We wanted to see how the conceptual gain was influenced by the forced interruption of the game cycle. To benchmark the effectiveness of the game against a traditional class, we also measured the conceptual gain for a control group.

Two slightly different versions of SPACE CHALLENGE have been developed for this research. The differences between the two versions are the difficulty level and the steepness of the learning curve throughout the game. In the "switch" version, a student can only complete a level when she chooses the optimal solution. The difficulty is high since the player has just enough time and fuel to complete each level. The student is quickly kicked out of the game cycle by a game-over screen whenever a suboptimal solution is chosen regarding fuel consumption or time constraints. In the "game" version, enough time and fuel is available to explore in-game causal effects of their actions (trial and error), without immediately being confronted with a game-over screen. We randomly assigned each of three high school classes of athenaeum, the Dutch pre-university education, to a group. The students' age varied from 15 to 16. A class of 10 students (5 boys and 5 girls) played the "switch" version of the game that frequently forces them out of the game cycle. This group will be referred to as Switch Group (SG). A class of 14 students (8 boys and 6 girls) played the "game" version that does not interrupt the game cycle. This group will be referred to as Game Group (GG). A class of 17 students (9 boys, 8 girls) constituted the Control Group (CG). This CG was taught by a different teacher and received the standard lessons, consisting of discussing the homework, introduction of new concepts, and working on problems, while the teacher was there to answer questions. In the CG, no game was played at all.

Gaming Observations

In GG, the gaming session was peaceful. The students played the game in great concentration, and the teacher incidentally answered a question. In SG, the first students already started to raise their hands in need of assistance after a few minutes of gameplay.

For the different levels, we observed different types of questions. Most help was needed with Levels 1 and 3, where the students are confronted with the frictionless environment. Initial remarks were that the game was too hard: "I don't have enough time," "This is too difficult," "It seems impossible" (remarks are translated from Dutch). The teacher encouraged the students to go on. Following questions in this phase expressed need for procedural help. For instance, "Can you show me once how to do it?" and "How do I proceed?" The teacher provided hints, referring to typical game features like "Watch your time and fuel, do not use more fuel on accelerating than on decelerating." Other conceptual questions were "The bend takes too much time, how can I solve that problem?" The teacher suggested starting to move downward before the horizontal speed is zero: "You could try to combine the horizontal and vertical motions." "I have either not enough time or not enough fuel, what should I do?" The teacher again referred to game features, suggesting investigating the trade-off between high speed and high fuel costs against low speed and long travel time.

On the Levels 2 and 4, where friction is present, as in the real world, students were observed asking each other for help. On these levels, the teacher was hardly consulted during our observation. After the first four levels, no more questions were asked. We saw students get into trouble in Levels 6 and 7, where the path narrows, and precise navigation is important. Students replayed the level until they mastered it by practice, without asking additional support from peers or the teacher.

The teacher was not able to address all questions simultaneously. Therefore, students started discussing with each other, trying again and again, with some students finally giving up after a while. The teacher offered assistance as much as possible. However, the atmosphere in the classroom remained chaotic so that the teacher was unable to offer everyone assistance in time. The unstructured observation was performed by the teacher. He made notes while helping students.

Lesson Series

All three groups were presented a series of six lessons on Newtonian mechanics. The duration of each lesson was 50 minutes. The first lesson for all three groups was used to fill out the FCI, and no homework was assigned. In the next lesson, both SG and GG played SPACE CHALLENGE for the duration of the lesson. The CG received a standard lesson on Newtonian mechanics instead. Lessons 3, 4, and 5 were similar for all three groups, the only difference being that for SG and GG, the teacher referred to in-game experiences when appropriate. In the last lesson, before the final test, all three groups again filled out the FCI.

Debriefing

In lessons 3, 4, and 5, the teacher of both the "switch" group and the "game" groups reflected on the game experience. The teacher explained that without friction, the student will need to exert a force in order to accelerate or slow down, as well as the fact that the time needed for acceleration equals the time to slow down (if the force remains a constant). To illustrate this, the teacher referred to the first and the third game level, where no friction is present and motion will continue without a braking force. Students remembered these features form their in-game experiences. Reference to these levels was also made when the formula of Newton's first law was broken down in the lessons. To illustrate Newton's third law, the teacher mentioned the effect of action and reaction

Table 1. FCI Scores.

	Pre test		Post test	
Teaching technique	*M*	*SD*	*M*	*SD*
GG	9.3	4.6	13.4	6.0
SG	8.4	1.6	10.7	2.3
CG	7.9	3.1	8.3	3.9

Note: FCI = Force Concept Inventory; GG = Game Group; SG = Switch Group; CG = Control Group.

forces between a spaceship and the gasses it "throws away" (the relevant boundary object being the flames). The teacher related the effect of friction as a decelerating force to the Levels 2 and 4, where air friction is included in the game (the relevant boundary object being the presence of visible blue air). The fact that levels with friction were relatively easy corresponds to students' real-life everyday experiences regarding movement on earth (e.g., bicycling), where friction is always present.

In the CG, no debriefing took place, since this group did not play the game.

Results

Both SG and GG increased their conceptual knowledge (Table 1). Comparing the pretest and posttest FCI scores, one can see how CG hardly improved on conceptual knowledge regarding Newtonian mechanics.

In a one way independent ANOVA, we find a significant difference between pretest and posttest FCI scores, $F(2,38) = 11.33$, $p < .001$, $\omega = 058$. A Games-Howell post hoc test reveals that the significant differences are between GG and CG. Planned contrasts revealed that playing a game (SG or GG) significantly contributes to the FCI scores, $t(38) = 4.08$, $p < .001$, $r = .55$. We find no significant difference between SG and GG.

Discussion

Our main interest in this research was the effect of the forced game cycle interruption on conceptual gain. While the conceptual gain seems to be smaller for SG than for GG, this difference is not significant (Figure 4). This means that we cannot state that forced game cycle interruption improves conceptual learning. The CG shows no conceptual change. This is not surprising because misconceptions are resistant to traditional education. When students have not experienced frictionless motion, it is hard for them to really understand this concept.

The conceptual gain of GG does show a significant better result than CG, which indicates that the game itself (whose design was specifically based on SGLM principles) does improve conceptual learning. This is a good result in itself, especially when we consider that SPACE CHALLENGE was only played for approximately 50

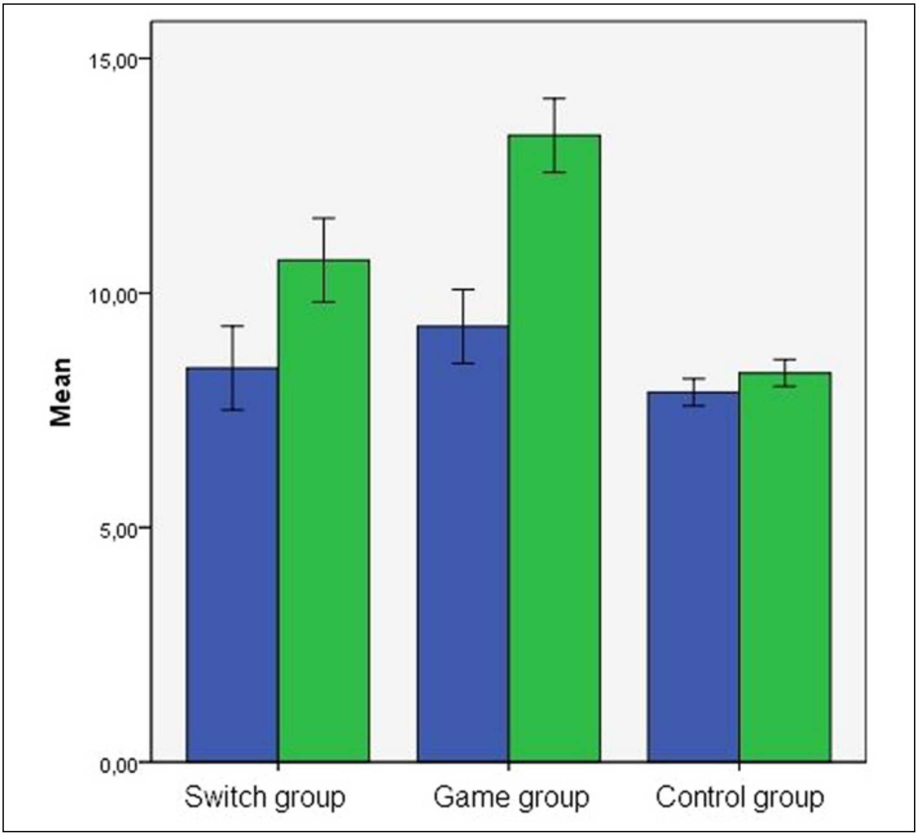

Figure 4. FCI gain.
Note: FCI = Force Concept Inventory. Blue bars represent pretest FCI and green bars represent posttest FCI.

minutes. The debriefing, based on the in-game experiences, was apparently sufficient to realize transfer of spontaneous game concepts to formal scientific concepts.

We have seen from observations that the strategy to force the student out of the game cycle did function as planned. As a consequence, a rather chaotic atmosphere arose, where many students required assistance simultaneously while the teacher was not able to provide this to the majority of students. As a result, many students could not continue the game as planned, and thus lost valuable time instead of gaining in-game experiences. The SGLM requirement of sufficient support, guiding the students through the learning cycle, was not met. Therefore, the potential advantage of the students turned into a disadvantage, as the support could not be delivered in time.

We consider, for future research, to make the increase in difficulty less extreme. To counter the chaotic atmosphere, where many students actively seek assistance from the teacher, we will put more emphasis on creating support material in advance, like frequently asked questions, level-guides, short movies, mind maps, and so on. This way, students can actively seek support in the learning cycle without the immediate attention of a teacher.

We conclude that SPACE CHALLENGE is an effective tool in physics education, aiming to improve conceptual knowledge on Newtonian mechanics. Since the development of the game was fully based on the principles set by the SGLM, we can conclude that the model provides a valid set of development guidelines.

We cannot yet conclude that all scientific learning took place in the learning cycle. It is possible that the students in the GG did intuitively construct some scientific concepts. We believe, however, that these were formed in the debriefing in the lessons after the game.

Further research is planned to investigate how we can further increase the conceptual gain by providing sufficient scaffolding in the learning cycle. Since we have noticed that forced game cycle interruption is not significantly harmful in itself, we believe that we can use this method as a tool to enter the learning cycle. We believe that by providing sufficient scaffolding for the student to get back into the game cycle, we could further improve the conceptual gain using SPACE CHALLENGE, beyond the results of GG.

We are currently involved in an experiment to measure the conceptual gain as well as the flow state in different types of serious games, in an effort to study the possible relation between flow and conceptual gain.

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