Teaching High School Physics with a Serious Game

Linda Stege[1], Giel van Lankveld[1], and Pieter Spronck[1,2]

[1]Tilburg University / TiCC, [2]Dutch Open University
P.O. Box 90153, NL-5000 LE Tilburg, The Netherlands

l.j.c.stege@uvt.nl, g.lankveld@uvt.nl, p.spronck@gmail.com

Abstract

This study explores the research domain of using serious games to support learning processes. In particular, we examined the effect of a serious game on teaching high school students electrical engineering theory. We compared the abilities of two groups of high school students to answer questions on this subject immediately after they received instructions on it. The first group received its instructions by means of a serious game, the second group by means of a text. We discovered that the group that received its instructions via a serious game performed significantly better than the text group in solving the assignments. Surprisingly, the group that received its instructions via a text indicated that they were better motivated. Further analysis revealed gender differences: males benefitted most from instruction via a serious game, while females were better motivated by a text. From our results we conclude that, at least in our application domain, serious games can be more effective in supporting the learning process than written texts, but that they do not necessarily motivate students better than a textbook.

SERIOUS GAMES, TEXTBOOKS, HIGH SCHOOL PHYSICS

Introduction

The term “edutainment” refers to entertainment games that have the ability to educate players. Such games are also referred to as “serious games”. Similar to serious games are so-called “educational games”. Both types of games are focused on developing the skills and knowledge of their players. However, serious games can be distinguished from educational games in that they are designed to look more like commercial videogames than their counterparts. The educational content of serious games is implicit in the gameplay, rather than an explicit component as found in educational games (Johnson, Vihjalmsson & Marsella, 2005). Winn (2008) states that serious games play as entertainment games, but have been designed to serve a purpose beyond just entertainment.

Some work has been done to investigate the effectiveness of educational games for learning processes (Bourgonjon et al., 2010; Gibbs, 1992; Kim & Chang, 2010; Lieberman, 2006; Pandey & Zimitat, 2007; Squire, 2003; Virvou et al., 2005; Zepp, 2005). Egenfeldt-Nielsen (2007) provides an extensive overview of such research. A general conclusion from this work is that playing games motivates the students, and better motivated students achieve better results. In a literature search we could find some – but not much – work that had examined whether the results achieved for educational games could also be applied to serious games (Van Eck, 2006; Squire, 2005). In general, in educational games knowledge is represented explicitly, while in serious games knowledge is represented implicitly in the game mechanics. Therefore we cannot assume that serious games are as effective in the classroom as educational games. The aim of the present research is to investigate how effective a particular serious game can be in transferring knowledge in comparison with the use of a textbook.

We use the serious game *E and Eve's Electrical Endeavors*, which is designed to instruct high-school students on electrical engineering. We compare the effectiveness of using this game to teach the students about transistors with a textbook that provides the same information. We are interested in the question which students are able to answer questions about electrical engineering more effectively, and in a comparison of the motivational effects of both instruction techniques.

In this paper we first provide brief background information on serious games. We then describe our experiment, discuss the achieved results, and derive our conclusions.

Serious Games

Serious games are games that have a purpose beyond entertainment, e.g., education, training, advertising, or supporting social change (Winn, 2008). Such a combination is no guarantee for success (Van Eck, 2006). Brody (1993) notes that the combination of entertainment and education in computer games has produced some not-very-educational games and some not-very-entertaining learning activities.

For a long time, educators tended to ignore computer games as a source of education (Van Eck, 2006). Nowadays, however, the role of games in education is increasing (Squire, 2003; De Freitas & Oliver, 2006). It is surprising that in general it is assumed that games will have a positive influence on education, but there is very little research that supports that position. One aspect of educational computer games that has been investigated are graphics. Benjamin (2010) showed that realistic graphics in a game are beneficial for the educational value of the game. He concluded that realism in educational games has a positive influence on knowledge transfer, as long as some room for imagination is being left. Bourgonjon et al. (2008) found that games may help students in developing collaboration skills.

A possible reason why serious games are assumed to be beneficial for education, is that students are often motivated to play games. Svinicki (1999) showed that traditional schooling methods do not tend to motivate students. It is generally assumed that well-motivated students learn better. Winn (2008) showed that games are effective at engaging students which makes them active learners. Virvou et al. (2005) showed that certain hard-to-teach students showed improved concentration when playing an educational game. Such results lead to the common assumption that an educational game, which by its nature should motivate, is better at transferring knowledge than the methods used in traditional schooling. Of course, the pitfall is that a game might be a less suitable medium for transferring knowledge, leading to a motivating but ultimately less effective educational experience.

Experimental Setup

To investigate the effect of using a serious game in the classroom, we ran an experiment in which we let a group of high-school students play a game that taught them electrical engineering theory, in particular the use of transistors. A second group of students was given a text which taught exactly the same material, using the traditional method of providing theory using a text, followed by example questions for practicing. We then compared the abilities of both groups in answering questions on transistor theory, and examined their motivation in working with the learning material. We now describe the game that we used, the participants, and the experimental procedure.

Game

The game we used is called *E and Eve's Electrical Endeavors*. It is an online serious game, that was developed by the Eindhoven University of Technology. The purpose of the game is helping players to develop skills and acquire general knowledge about electrical engineering.

The game starts with a brief introduction in which the player is shown that the playable character is trapped in electrical wires. The character has to move through the wires in order to escape. The player has to solve issues with resistances, transistors, and power shares, while moving through the wires (see Figure 1).

After every completed level the issues encountered are explained. The game consists of four chapters with ten levels each (except for the fourth chapter, which consists of only one level). In our experiment the students played only the first two chapters. In the first chapter the player is introduced to the controls and playing techniques. The second chapter teaches the player about transistors.

Figure 1. Screenshot of *E and Eve's Electrical Endeavors*. In the lower middle area of the screen the playable character is moving trough electrical wires. On the left of the screen a transistor is seen.

Participants

In our experiment 187 third-grade Dutch high-school students of two different schools participated. Both these schools were of the highest level of Dutch secondary schooling

(Voortgezet Wetenschappelijk Onderwijs: VWO). 47% of the participants were male, 53% were female. 7 participants did not indicate their gender (see Table 1). The average age of the participants was 14.6 years. 97.8% had the Dutch nationality. 78.7% indicated that they had previous gaming experience. None of the participants was previously instructed at school about transistor theory.

In each repetition of the experiment, the participants were randomly divided into two groups by either the teacher or the investigator. One group was called the “game group”; the students in this group were assigned to play the game. The other group was called the “text group”; the students in this group were assigned to study the text. In total 97 participants (52%) were placed in the game group, and 90 participants (48%) were placed in the text group. Of the game group, 48 participants were male, 44 female, and 5 did not report their gender. Of the text group, 37 participants were male, 51 female, and 2 did not report their gender.

Procedure

The experiment took place in a computer room of the participants’ high school. One classroom had been reserved for this experiment. The experimental procedure followed a schedule that took one hour to complete (see Table 1).

Table 1. Experimental procedure.

phase	**time limit**	**game group**	**text group**
introduction	5 min.	instructions and assigning groups	
learning	20 min.	playing the game	reading the text
testing	20 min.	solving assignments	
survey	10 min.	filling out the survey	
closing	5 min.	powering down computers and leaving the room	
total	60 min.		

The classroom was divided into two sides, and each of the students was randomly assigned to one of the sides. On each desk a computer with an internet connection was installed. It was not previously determined which side of the room would play the computer game and which side would read the text. After the teacher or investigator had randomly decided which side of the room would be the game group, and which side would be the text group, the investigator introduced the purpose of the research and the overall process of the experiment to the participants [introduction].

The students received written instructions. The instructions for both versions were similarly structured, but referred to either the computer game or the text. The printed instructions of the text group were followed by the actual text and training exercises. The students started working after receiving the instructions. The game group played the computer game, and the text group read the prepared text equivalent and worked on the example exercises. None of the students had previously received instructions by their teacher on the subject matter. They were allowed to collaborate with other students in their group during this phase [learning].

After the students had finished playing the game or studying the text, or 20 minutes had passed, the students were asked to stop working on the learning phase. They had to close down the game (game group) or hand in the text (text group), after which they received a set of 6 multiple-choice questions on transistor theory. They had 20 minutes to answer the questions. Two example questions are displayed in Appendix A [testing].

Next, the students completed a short personal survey (see Appendix B), in which they were also asked about their motivation during the experiment. 10 minutes were available for this phase [survey].

Finally, the students were asked to power down their computers and leave the room [closing].

Results

We now discuss our results, in sequence: (1) the effectiveness of the students in the game group and text group in answering questions on the theory; (2) the proclaimed motivation of each of the groups; (3) gender differences; and (4) the students' opinion on the use of serious games in the classroom. An alpha level of .05 was used for all statistical tests.

Acquired knowledge

To measure the difference between the game group and text group in total number of correctly answered questions an independent ANOVA was conducted. The results are displayed in Tables 2 and 3. Note that two participants did not hand in their test results; these were left out of the analysis.

Table 2. Group statistics for total correct answers.

group	***N***	***M***	***SD***	***SE***
game	96	3.31	1.182	0.121
text	89	2.96	1.215	0.129
total	185	3.14	1.208	0.089

Table 3. Results of ANOVA between group and mean of correct answers.

variance	***SS***	***df***	***MS***	***F***	***p***
between groups	5.901	1	5.901	4.115	.044
within groups	262.445	183	1.434		
total	268.346	184			

There was a significant effect of the assigned group on the number of correctly answered questions ($F(1,183) = 4.115$, $p = .044$). These results indicate that, on average, the participants of the game group provide significantly more correct answers on the assignments than their counterparts of the text group.

We wanted to exclude the possibility of the game group containing more students who were doing well at physics anyway, so we measured the difference between the game group and text group's means of their most recent physics grade. We found no significant difference between the groups' means of physics grades ($F(1,183) = .031$, $p = .861$).

Therefore we may conclude that the game we used is better able to transfer knowledge than the corresponding text which provides the same information. It is interesting to note that according to Pearson correlation there was no significant relation between the students' most recent physics grade and the score on our test (r = .127, p = .088), though the significance value indicates that there was a small trend that showed that doing well at physics increases the test score.

Motivation

The participants were asked whether they enjoyed their assigned task (Appendix B, question 3). To measure the difference between the game group and text group in motivation (enjoyment) an independent ANOVA was conducted. The results are displayed in Tables 4 and 5. Note that one participant did not answer this question; this person was left out of the analysis.

Table 4. Group statistics for motivation.

group	***N***	***M***	***SD***	***SE***
game	96	2.82	.833	0.085
text	90	3.12	.776	0.082
total	186	2.97	.818	0.060

Table 5. Results of ANOVA between group and motivation.

variance	***SS***	***df***	***MS***	***F***	***p***
between groups	4.161	1	4.161	6.400	.012
within groups	119.645	184	.650		
total	123.806	185			

There was a significant effect of group on motivation (F(1,184) = 6.400, p = .012). These results indicate that the participants of the text group reported a significantly higher motivation for their assigned task. This result is surprising, as games are assumed to provide higher motivation than texts.

In previous research we noted clear gender differences when computer games are used. We therefore repeated the previous test for the two genders separately. For the male participants, we discovered that there was no significant effect of group on motivation (F(1,82) = .603, p = .440). For the female participants, however, the analysis showed a significant effect of group on motivation (F(1,93) = 3.975, p = .049). Therefore we may conclude that the female students were better motivated by the text than by the game.

Gender differences

Since we already noted gender differences for motivation, we decided to examine gender differences in our experiment in more detail. We started by measuring whether there was an effect of gender on number of correct answers on our test, using an independent ANOVA. The results are displayed in Table 6 and 7. Note that nine participants did not specify gender or did not hand in their test results; these were left out of the analysis.

Table 6. Gender statistics for number of correct answers.

gender	*N*	*M*	*SD*	*SE*
male	84	3.49	1.227	0.134
female	94	2.86	1.142	0.118
total	178	3.16	1.220	0.091

Table 7. Results of ANOVA between gender and number of correct answers.

variance	*SS*	*df*	*MS*	*F*	*p*
between groups	17.405	1	17.405	12.443	.001
within groups	246.190	176	1.399		
total	263.596	177			

There was a significant effect of gender on number of correct answers, indicating that males performed better than females ($F(1,176) = 12.443$, $p = .001$). We also found that males claimed to spend significantly more of their free time on gaming than females ($F(1,177) = 53.008$, $p < .001$; Appendix B, question 7). Considering that the subject matter is physics, these results are rather stereotypical, so not unexpected. However, while the number of males in the game group was close to the number of females, for the text group the number of females was 40% higher than the number of males. As males seem to do better at physics than females, and males reported more game experience, this raises the question whether the better results of the game group on our test can be explained by the ratio of males and females being askew.

We already noted that there was no significant difference between group and mean of last physics grade. But as males do better on our test than females, we decided to measure whether there was a difference between the groups in the number of correct answers that each of the genders gave. The results for males are displayed in Tables 8 and 9.

Table 8: Male group statistics for number of correct answers.

group	*N*	*M*	*SD*	*SE*
game	48	3.73	1.144	0.165
text	36	3.17	1.276	0.213
total	84	3.49	1.227	0.134

Table 9: Results of ANOVA between males of each group and number of correct answers.

variance	*SS*	*df*	*MS*	*F*	*p*
between groups	6.509	1	6.509	4.505	.037
within groups	118.479	82	1.445		
total	124.988	83			

We found that for males, the mean of number of correct answers for the game group was significantly higher than for the text group ($F(1,82) = 4.505$, $p = .037$). For the females, we found no such significant difference ($F(1,92) = .283$, $p = .596$).

We therefore conclude that the serious game we used seemed to teach the male students the theory more effectively than the text, but that the female students gained no benefit from the game over the text.

Games in the classroom

When the participants were asked whether they would like to play serious games in the classroom more often (Appendix B, question 8), 78.7% answered positively. This opinion seems to contradict our conclusions on motivation. There was no significant association between gender and whether or not students would like to play serious games in the classroom ($\chi^2(1) = 1.158$, $p = .282$). However, the text group professed a higher preference for games in the classroom than the game group ($\chi^2(1) = 7.257$, $p = .007$).

Discussion

Our results show that serious games can be a supporting factor in learning processes, though they are not necessarily more motivating than texts. These results contradict previous research conducted by Squire (2005), Virvou (2005), Gibbs (1992) and Mujis and Reynolds (2001). Their studies show that computer games in education do motivate the students better than traditional schooling methods.

Before discussing these results in more detail, we need to point out that this study contained at least three weaknesses in its design. Firstly, no pre-test was done to determine the students' knowledge on transistor theory before they played the game or read the text. While the teachers indicated that transistor theory was a completely new subject for them, we cannot exclude that some of them acquired knowledge about this subject area through other means. Secondly, we did not include a control group that completed the assignments without playing the game or reading the text. Therefore we cannot be sure that the students gained any new knowledge at all, or how much knowledge they gained. Thirdly, for practical reasons we allowed the students to collaborate during the training phase if they wished to do so. Therefore any knowledge gained cannot be attributed to the game or the text with certainty. Because of these weaknesses, our conclusions should be regarded mainly as hints for future research.

We found that the female participants evaluated the computer game as less motivating than the text. We offer two possible explanations for this result. Firstly, the theory concerned electrical engineering, which in The Netherlands is considered typically a male subject. It is possible that a lack of interest in the subject material had an adverse effect on the female students' opinion on the game. Secondly, in general females tend to show less interest in computer games than males (Lucas & Sherry, 2004).

Even though the survey showed that the game did not have a motivational effect on the participants, the investigator who observed the participants during the experiment noticed that the game group immediately started playing the game, while the text group was not motivated to start reading the text at all. The text group had more complaints and asked more questions. Although the participants were randomly divided into the two groups, many students indicated that they would rather play the computer game than read the text (no notice was taken of gender differences in this respect). It should be noted that the behavior of the students in the text group might have influenced their effective learning time negatively.

The results on motivation are so contrasting with other research, that in hindsight it is deplorable that we did not set up our experiments to investigate this variable in more detail, so that we could offer stronger explanations for our findings. In the present research, we just asked one question on the enjoyment of the task (Appendix B, question 3). In future research, we will at least update our survey in this regard.

This study focused on one particular serious game. The research could be extended by studying different serious games. *E and Eve's Electrical Endeavors* is a computer game concerning physics. Serious games concerning language development, training skills (for example for defense) and general knowledge should be examined as well.

In this research only short term memory has been tested. The participants immediately answered the questions after playing the game or reading the text. It would be interesting to compare the effects of a serious game with textbook learning on long term retention of knowledge.

Finally, we wish to stress that we only compared the use of a serious game with the use of a textbook. The teacher was not involved in instructing the students in this experiment. It is very much an open debate whether serious games can approach a teacher's effectiveness in transferring knowledge.

Conclusion

In this research we investigated the difference between teaching high school students electrical engineering theory by means of a serious game and by means of a text. We found that the males who acquired their knowledge through playing the game were more effective in answering questions on the theory than the males who studied the text. For the females, we found no difference between using a game or a text to acquire knowledge. Somewhat surprisingly, the females who played the game indicated that they were less motivated than those who used the text, while the motivational effects of the game and the text were equal for males. Whether this is the result of a lack of female interest in electrical engineering or in computer games in general is an open question. We may cautiously conclude, however, that serious games (at least the one we used in our research) have the potential to be more effective in education than textbooks, in particular for male students.

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Appendix A

These are two of the six questions that the students were to answer after playing the game or studying the text (translated from Dutch). Both questions concern Figure 2.

Q1: If the transistor is 'closed' (current flows in the right side of the diagram), what would happen if resistance R_2 decreases very much?

A. The situation remains the same, the transistor remains 'closed'.
B. The transistor will open so that the current in the right side of the diagram gets interrupted.
C. The situation depends on resistance R_3.

Q2: The transistor is 'closed', so current flows in the right side of the diagram. What will happen to the current in the right side of the diagram when resistance R_3 decreases?

A. The current in the right side will increase.
B. There will still be current in the right side, but weaker.
C. The current will no longer flow in the right side.

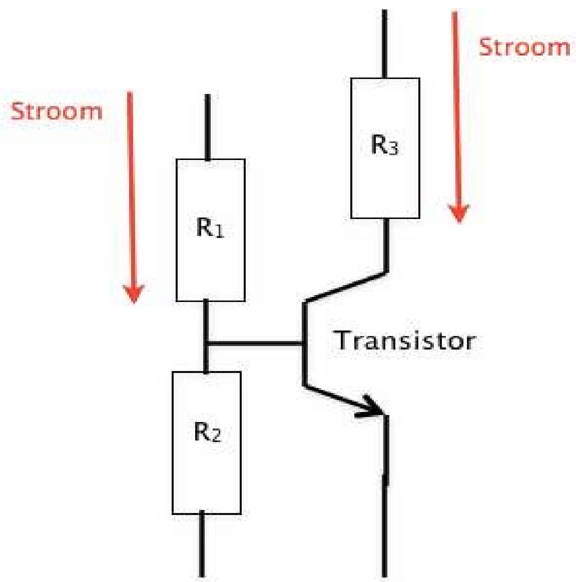

Figure 2: Schematic representation of 3 resistances and 1 transistor. The arrows indicate the flow of the current.

The answers are: Q1:B, Q2:A.

Appendix B

The students completed a short survey. The survey asked the particpants to enter their gender (male/female), date of birth, and nationality, and to answer the following eight questions (translated from Dutch; where indicated, the students got a version with "game" or "text" appropriate to the group that they were assigned):

Below we ask several questions about physics as taught in school.

1. In comparison with other subjects, I consider physics:
   no fun at all   no fun   average fun   fun   a lot of fun
   (please circle your answer)
2. What grade did you receive for your last physics test (for which you received a grade):
   0   1   2   3   4   5   6   7   8   9   10
   (please circle your answer)

Below we ask several questions about the [game you just played / text you just read] and the assignments.

3. I consider the [playing of this game / reading of this text]:
   no fun at all   no fun   average fun   fun   a lot of fun
   (please circle your answer)
4. I consider this [game / text]:
   very hard to understand   hard to understand   understandable   easy to understand   very easy to understand
   (please circle your answer)
5. Can you indicate why you did or did not find the [game / text] understandable?
   (open question)
6. If you could change anything about the [game you just played / text you just read], what would it be?
   (open question)
7. How many hours per day do you play computer games?
   I never play computer games   0 to 1   1 to 2   2 to 4   more than 4
   (please circle your answer)
8. Would you like to get physics theory explained using computer games more often?
   □ Yes, because...
   □ No, because...
   (please check your answer)

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