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Digital Games, Gender and Learning in Engineering: Do Females Benefit as Much as Males?

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Abstract The aim of this paper was to explore whether there is a gender difference in the beneficial effects of Racing Academy, which is a video game used to support undergraduate students learning of Mechanical Engineering. One hundred and thirty-eight undergraduate students (15 females and 123 males) participated in the study. The students completed a pre-test a week before they started using Racing Academy. The pre-test consisted of a test of students' knowledge of engineering, and a measure of students' motivation towards studying engineering. A week after using Racing Academy the students completed a post-test which was identical to the pre-test, except it also included a measure of how frequently they used Racing Academy and how motivating the students found playing Racing Academy. We found that after playing Racing Academy the students learnt more about engineering and there was no gender difference in the beneficial effect of Racing Academy, however there is some evidence that, female students found Racing Academy more motivating than male students. The implications for the use and design of video games for supporting learning for both males and females are discussed.

Keywords Digital games · Gender · Learning · Engineering

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Introduction

Both the USA and the UK have recently stressed the importance of science, technology engineering and mathematics (STEM) for their long term economic futures (DfEL 2009; Engineering UK 2009; USA NSB 2007). In pursuit of this aim, there has been considerable interest in the use of video games for supporting STEM education. For example, in the USA in the last 5 years, there have been two committees set up to discuss the role of digital games in science and engineering education. The first was held by the Federation of American Scientists held in 2005 entitled 'Harnessing the power of video games for learning' and even more recently in 2009 the National Academies Board on Science Education held a committee on computer games, simulations, and education in learning science. In fact the Journal of Science Education and Technology, has published two special issues which discussed the role of video games in learning (Barab and Dede 2007; Dede and Barab 2009).

There are a number of important reasons for all this interest in using video games in STEM education. The first is that a number of reports have shown that video games have become an integral part of life for children and adolescents. In a recent survey of USA adolescents, 98% of teenagers played video games (Lenhart et al. 2008) regularly at least once a week.

Second, well designed video games can provide powerful learning environments (Gee 2005; FAS 2006; Mayo 2007, 2009). The Federation of American Scientists (2006) identifies the following reasons why video games could facilitate students' learning in STEM.

- They are highly motivating (Kafai 2001) and research has consistently shown that high levels of motivation leads to high learning outcomes.
- They provide clear learning goals and players know why they are learning something.
- Players are presented with a range of experiences and practice opportunities.
- They are learning in a complex challenging simulated world rather than learning a set of abstract facts devoid of real world context.
- The lessons can be practiced over and over again.
- Video games continually monitor player's progress and provide feedback which is clear and often immediate.
- Video games move at a rate that keeps players at the edge of his or her capabilities moving to higher challenges when mastery is acquired.
- They are infinitely patient and can offer scaffolding, providing learners with cues, prompts, hints and partial solutions to keep them progressing through learning until they are capable of directing and controlling their own learning path.
- They encourage inquiry and questions and respond with answers that are appropriate to the leaner and context.

Furthermore, Gee (2003, 2005) and Shaffer et al. (2005) both argue that video games have the potential of placing students in simulated environments where they face authentic, open ended challenges similar to those faced by actual professionals. Gee (2005) argues that when individuals play these type of video games they experience first hand how members of a profession think, behave and solve problems, thus they are engaged in a deep, meaningful learning experience. Shaffer et al. (2005) argue that too much of classroom learning is about understanding symbols divorced from the concrete reality of those symbols. In the virtual worlds of games learners experience the concrete realities of what those words and symbols represent. They can understand complex concepts without losing the connection between the abstract ideas and the real problems they can be used to solve. Shaffer et al. (2005) conclude that one reason computer games are powerful learning environments is because they make it possible to develop situated understanding.

Recent research appears to confirm the benefits of video games for supporting situated learning. Coller and Scott (2009) developed a racing car game which they used to support students learning of numerical methods in an undergraduate mechanical engineering course. They found that students taking the game based course spend roughly twice as much time, outside of class, on their course work. They showed greater depth of understanding of the relationship between concepts and they were very interested in a further follow up course. Mayo (2009) reports that video games can increase learning in STEM between 7 and 40% compared to traditional lecture based courses.

Gender and Video Games

Unfortunately, students who do not have access to or who are not interested in video games are believed to be disadvantaged compared to their peers who are interested and have exposure to video games. One group that is of particular concern is girls (Cassell and Jenkins 1998; Winn and Heeter 2009). For a long time video games were thought to be 'boys toys'. Early research supported this conclusion, showing that boys were more likely to have access to video games (Dominick 1984; Loftus and Loftus 1983; Kaplan 1983), played video games for longer (Dominick 1984) and preferred video games more than girls (Funk and Buchman 1996; Bamett et al. 1997). Roberts et al. (2005) concluded from a large scale survey of over 3,000 children in the USA aged between 2 and 18 'that interactive games are male media—many more boys than girls play them, and they play them for substantially longer periods of time' p. 26.

More recent research suggests that the amount of female game playing is on the increase (Bryce and Rutter 2002; Jenkins 1998). Entertainment Software Association (2009) report that 40% of video gamers are female. Furthermore, in a recent survey of American teenagers, Lenhart et al. (2008) found that 99% of boys played video games and 94% of girls played video games. In fact there is some evidence to suggest that females play casual computer games more than males (Popcap games, 2006, cited in Winn and Heeter 2009). Moreover, in Whyville, a virtual world with over 1.2 million registered users, 68% are female (Kafai 2010). However, behind all these headline figures, there are still sizable gender differences in the amount and type of video game experience, which are consistently observed across different age groups and in different countries. Rideout et al. (2005) in a survey of 2,032 children from the USA aged between 8 and 18 found that boys play video games on average 1 h 34 min per day compared to 40 min a day for girls. Lee et al. (2009) reported a nationally representative sample of 1,354 children from the USA. They surveyed these children in 1997 and then 5 years later in 2002. They reported gender was the strongest predictor of time spent playing video games. Boys spent more time playing video games than girls in all age groups except for very young children aged between 0 and 4. Lenhart et al. (2008) reported that American teenage boys are twice as likely to play video games for 2 h or more each day than teenage girls. Greenberg et al. (2010) found male high school and college students played video games for 19 h a week compared to 8 h a week for females. This finding was replicated by Winn and Heeter (2009). Similar findings have been reported outside of the USA. In the UK, McFarlane et al. (2002) reported a survey of children aged between 7 and 16 and reported that 57% of boys were still playing video games for up to 2 h or more a day, whereas 80% of girls reported playing video games up to 1 h or less. Chou and Tsai (2007) reported a survey from Taiwan. She found that on average male students played video games for 4.7 h per week compared to females 2.9 h per week. Heeter and Winn (2008) argue that by the time students reach college a male student has logged on average thousands more hours of video game play than a female student, which potentially could put female students at a disadvantage if video games were widely introduced in STEM education.

Gender and STEM

It would be particularly worrying if the above was true given the large gender gaps that have been reported in science, technology, engineering and mathematics (STEM) areas. In the USA, a recent a report by the National Science Foundation (2009), showed that only 19% of those enrolled on a bachelor degree in computer science degree in 2007 were female and 19% of students enrolled in bachelor degrees in engineering were female. A similar picture emerges in the UK, a recent UK government report on STEM education (DfEL 2009) found that women were under represented in STEM subjects, in particularly mathematics, engineering and technology. Only 27% of undergraduate students studying mathematics and technology in the UK were female and in engineering the picture was even worse with only 15% of undergraduate students studying engineering were female. The under representation of females in STEM subjects is a world wide phenomena, with females consisting of 34% of undergraduate students studying mathematics and technology and 19% undergraduates studying engineering. Unfortunately even the female students who take engineering at undergraduate level are less likely to continue into the STEM workforce than their male counterparts. Engineering UK (2009) identified that of women who graduate with a first degree in science, engineering or technology; only 27% pursue a career in these fields compared with 54% of male graduates. The report concludes that.

> ‘Gender bias is a problem shared across most developed economies and considerable female talent is being lost from the STEM artery. This is ultimately leading to low female representation in the STEM workforce, with Engineering attracting the lowest percentage of STEM women professionals’ p. 40.

Gender and Digital Game-Based Learning in STEM

Thus, it is important to investigate whether the introduction of digital game based learning in STEM and in engineering in particular will have a detrimental effect on female students. There have been recently a number of papers which have investigated the impact of gender on students’ performance when using digital games. They have mainly involved multi-user virtual environments (MUVE). A number of studies appear to show that these MUVEs are at the very least equally supportive of girls and boys learning. Bruckman et al. (2000) in her study of Learning in the MOOSE Crossing virtual environment found no gender differences in programming achievement. In a later study Bruckman et al. (2002), found that girls spent significantly more time communicating than boys in the virtual environment. Barab et al. (2007) reported similar findings in their study of Quest Atlantis. There was no gender difference in pre-test to post-test gains and no gender difference in overall participation rates between boys and girls, however girls used online chat more than boys in Quest Atlantis. They also wrote more in their online notebooks when completing quests and engaged in longer reflections about their work in the MUVE. These findings were replicated by Dede et al. (2004) in their study of River City. They found no gender differences in learning outcomes, motivation or self efficacy towards science (Dede et al. 2004). In more recent studies of River City which included a reflective guidance system, girls were more likely to view more guidance messages than boys and girls had larger gain scores (Nelson 2007).

These studies on MUVEs are promising, however it is important to look at other types of digital games and investigate whether they have a differential impact on girls and boys achievement and motivation in STEM. The aim of this paper is to explore whether there is a gender difference in the beneficial effects of a racing car simulation game, called Racing Academy, which was used to support undergraduate students learning of mechanical engineering. It examines not only whether it benefits students learning but also whether it impacts on their motivation towards engineering.

Racing Academy

Racing academy is based on a real-time vehicle dynamics simulation system, which is capable of recreating the experience of driving any automobile. It accurately models in real-time how cars behave and react. The games engine has the capacity to allow users to manipulate over 1,000 parameters of their vehicles. This is particularly important as it will enable the students to change the vehicle parameters (such as the engine, transmission, tires and suspension) in order to optimize vehicle performance and get a better understanding of the system dynamics that influence behavior. Players must engage with the underlying physics and work as a member of a team where practice arises out of real physics and involves the social negotiation of understanding.

The game has three levels and a race level. In the first three levels, players race a computer controlled opponent ("the AI driver") along a quarter mile drag strip (see Fig. 1). Every time they beat the AI driver they move onto the next level and the races typically last between 11 and 15 s.

In level 1 the player is given the choice of changing the controls, changing the color of the car and a choice of one of six engines. In level 2 the players have a choice of tires and in level 3 the players can change the gear ratios. After level 3, the students can access the Race level, which has a test circuit. At this level, the students can change 12 different characteristics of the car. On the test circuit, they compete against themselves to obtain the quickest time around the test circuit.

Racing Academy can be downloaded free from the following website http://www.lateralvisions.com/Racing_Academy/JISC_Prototype.aspx. The aim of this paper was to explore whether there was a gender difference in the beneficial effects of Racing Academy, both in terms of learning mechanical engineering and in terms of their motivation towards engineering.

Fig. 1 Drag strip

Method

Participants

One hundred and fifty-eight students (143 males and 15 females) participated in the study, with an average age of 18.5 years (SD = 0.9). They were from a first year undergraduate course in the Department of Mechanical Engineering at the University of Bath, which is a university in the south west of England.

Procedure

The students completed a pre-test a week before they started using Racing Academy, which consisted of a test of students' knowledge of engineering, a measure of their experience with digital games and a measure of students' motivation towards studying engineering.

While the students were using Racing Academy, the students were organized into teams of 3 or 4 students. The team had 2 weeks to design the fastest car they could to race in a competition against the other teams in their course. Each team has its own online discussion forum which they could use to discuss issues concerning the design of the car. There was also a general discussion forum, where students could ask an expert general engineering questions.

A week after using Racing Academy the students completed a post-test which was identical to the pre-test, except we also asked them how much they used Racing Academy and how motivating the students found playing Racing Academy.

Materials

The pre-test contained a measure of their experience of playing digital games. We asked them how frequently they played digital games during the week; how frequently they played at the weekend and finally what type of digital games they played.

In the pre and post-test, we assessed three different aspects of motivation towards engineering which were enjoyment of engineering, perceived competence in engineering and how important engineering was to them personally. Students answered the questions using a five point Likert scale ranging from strongly disagree to extremely agree. These questionnaires were based on standard psychological measures (e.g., Deci and Ryan 1985; Ryan 1982). Cronbach's alpha for these three measures ranged from 0.70 to 0.85.

In the post-test we assessed how motivating the students found playing Racing Academy by measuring how much they enjoyed playing Racing Academy, how good they were at playing Racing Academy, how much effort they put into playing Racing Academy and how valuable playing Racing Academy was. The students answered it using a five point Likert scales, ranging from 1 strongly disagree to 5 extremely agree. These scales were based on standard psychological measures (e.g., Deci and Ryan 1985; Ryan 1982). Cronbach's alpha for these four measures were as follows alpha ranged from 0.84 to 0.87.

Finally we asked the students how often in the previous week they had played Racing Academy, how often they read the message boards and how frequently they posted messages on the message boards. The students answered this with a five point scale ranging from, never to several times a day.

Results

Non-parametric statistics were employed throughout the analysis because of the large difference in sample size between males and females and because most of the data was not interval ratio. There were a number of significant gender differences in terms of digital game playing experience. Males played digital games longer than females both during the week (Mann–Whitney, $z = 4.3$, $p < 0.01$) and at the weekend (Mann–Whitney, $z = 3.4$, $p < 0.01$). During the week the average length of a digital playing games session for males was 1.4 h during the week and 2.1 h at the weekend compared to females 0.3 h during the week and 0.6 h at the weekend. In fact most females in this sample did not play digital games during an average week. Seventy-four percent of females did not play digital games during the week compared to only 15% of males and 68% of females did not play digital games during the weekend compared to only 12% of females. Males on average were playing digital games for 3.5 h a week compared to 0.9 h per week for females.

There were gender differences in terms of the types of games males and females played (see Table 1).

Males were significantly more likely to have played action, fighting, sports and strategy games than females, whereas females were more likely to have played puzzle games than males.

There were no gender differences in terms of the students self reported use of Racing Academy. Sixty-eight percent of males played Racing Academy several times a week compared to 79% of females (Mann–Whitney, $z = 0.4$, $p > 0.05$). Forty-two percent of males read the message boards once a week compared to 50% of females (Mann–Whitney, $z = 1.0$, $p > 0.05$). Sixty-one percent of males did not post any messages on the message board compared to 79% of female students (Mann–Whitney, $z = 1.4$, $p > 0.05$).

Table 1 Gender differences in types of game played

	Males		Females		Chi squared
	N	%	N	%	
Action	99	81.1	1	7.1	35.3*
Sports	75	62	3	21.4	8.4*
Fighting	45	36.9	1	7.1	5*
Strategy	70	57.4	4	28.6	4.2*
Adventure	37	30.3	3	21.4	0.5
Simulation games	52	42.6	5	35.7	0.2
Role playing games	32	26.4	3	31.4	0.2
Puzzle	49	40.2	10	71.4	5*

*$p < 0.05$

Table 2 shows the scores for students' mean motivation towards engineering. Engineering motivation for both males and females was extremely high both in the pre-test and the post-test. Males have a significantly higher perceived engineering competence than females in the pre-test (Mann–Whitney, $z = 2.0$, $p < 0.05$) and the post-test (Mann–Whitney, $z = 2.8$, $p < 0.05$). However, there were no significant gender differences in terms of changes in motivation towards engineering after playing with Racing Academy. Males and females motivation towards engineering did not change after playing Racing Academy, which is understandable given how highly motivated they were to begin with.

Table 3 presents the scores the students obtained in the pre-test and the post-test. Overall students improved on all aspects of the test. There was a significant improvement in their general physics knowledge (Wilcoxan, $z = 2.2$, $p < 0.05$), knowledge of engines (Wilcoxan, $z = 4.9$,

Table 2 Gender differences in motivation towards engineering

	Male		Female		z
	M	SD	M	SD	
Pre-test					
Engineering motivation	4.2	0.4	4.2	0.5	0.6
Importance to self	4.0	0.5	4.1	0.6	0.1
Perceived competence	3.7	0.5	3.4	0.7	2.0*
Post-test					
Engineering motivation	4.1	0.4	4.2	0.5	0.4
Importance to self	4.0	0.5	4.0	0.5	0.1
Perceived competence	3.6	0.5	3.3	0.4	2.8*
Difference between pre-test and post-test					
Engineering motivation	−0.1	0.3	−0.1	0.5	0.1
Importance to self	−0.0	0.4	−0.1	0.3	0.8
Perceived competence	0.0	0.4	−0.1	0.6	0.0

*$p < 0.05$

Table 3 Gender differences in pre-test scores

	Males		Females		Mann–Whitney
	M	SD	M	SD	z
Pre-test					
General	3.6	0.8	3.2	0.8	1.6
Engines	1.3	0.8	0.9	0.9	1.6
Tires	1.3	0.8	0.7	0.8	2.4*
Gears	1.7	1.1	0.5	0.8	3.7*
Total	7.9	2.4	5.3	2.2	3.6*
Post-test					
General	3.8	0.8	3.1	0.8	3.0*
Engines	1.7	0.8	1.6	0.8	0.8
Tires	1.8	1.0	1.4	1.1	1.4
Gears	2.0	1.0	1.3	1.2	2.3*
Total	9.4	2.7	7.4	2.6	2.6*
Difference between pre-test and post-test					
General	0.2	0.9	−0.1	0.6	0.1
Engines	0.4	1.0	0.7	1.1	0.5
Tires	0.5	0.8	0.8	1.1	0.6
Gears	0.4	1.0	0.8	1.1	1.4
Total	1.5	2.0	2.1	2.1	0.8

*$p < 0.05$

$p < 0.05$), tires (Wilcoxan, $z = 6.5$, $p < 0.05$), gear boxes (Wilcoxan, $z = 4.0$, $p < 0.05$) and overall performance (Wilcoxan, $z = 2.2$, $p < 0.05$). There were a number of significant gender differences in the pre-test scores. Males scored higher than females on the tire pre-tests (Mann–Whitney, $z = 2.4$, $p < 0.05$), gears pre-test (Mann–Whitney, $z = 3.7$, $p < 0.05$) and their overall score (Mann–Whitney, $z = 3.6$, $p < 0.05$). Similar differences were found in their post-test scores. Females score lower than males on general physics (Mann–Whitney, $z = 3.7$, $p < 0.05$), gears (Mann–Whitney, $z = 2.3$, $p < 0.05$) and overall score (Mann–Whitney, $z = 2.6$, $p < 0.05$). There were no gender differences in terms of their improvement, although females on all but one of the measures were improving more than males. For example in the test concerned with gears, females scores improved on average by 0.8 compared to an improvement in the males scores of 0.4.

Finally, we examined if there were any gender differences in how motivated the students were playing Racing Academy. There were no gender differences in terms of how much males and females enjoyed playing Racing Academy; how good they were at playing Racing Academy and how valuable playing Racing Academy was to their course. Interestingly, females thought Racing Academy was worth the effort of playing, when compared to males (females, M = 3.5, SD = 0.6; males, M = 3.1, SD = 0.7; Mann–Whitney, $z = 2.5$, $p < 0.05$).

Discussion

The aim of the study was to investigate whether female undergraduate students benefited as much as male undergraduate students when playing Racing Academy to support their learning of engineering. We found that there was significant improvement in students learning after playing with Racing Academy and female students benefited as much as male students. Furthermore, female students motivation towards engineering was not detrimentally impacted by playing Racing Academy compared to male students. Moreover, there were no differences in terms of participation rates between male and female students. Male and female students played Racing Academy for equal amounts of time and there were equal rates of participation in the online forums. Finally, there was some evidence that female undergraduate students found Racing Academy more motivating than male students.

These findings are in line with previous research on MUVEs (Barab et al. 2007; Dede et al. 2004) which have also reported that female students learn as much as male students from playing in MUVEs. The slight difference between the current findings and previous research concerned the level of participation in the online discussion forum. Previous research has found that female students participate more in online chat than male students (Barab et al. 2007; Bruckman, et al. 2002). We found no difference between male and female students in terms of posting or reading messages in the online forums. However, overall the level of participation with the online forums in our study was very low compared to previous research. In Racing Academy, only 39% of males and 21% of females posted messages on the Racing Academy Online Forums. One possible reason for this low participation was because Racing Academy was not a MUVE and that the online forums were not the only means of communication. The students lived on campus and had their classes on campus. Thus they could meet up face to face rather than use the online forums. In addition the Racing Academy competition took place within 2 weeks of arrival at university and the Moodle based forum would not have been familiar to the majority of participants.

The finding that both male and female students benefited equally is very encouraging for digital game based learning and suggests that females will benefit as equally as males regardless of the type and design of the digital game. However, previous research suggests that this is not the always the case. Littleton et al. (1992) conducted a series of studies which investigated how differences in the design of computer games influence boys and girls performance. They compared girls and boys performance on a computer game called the King Crown, which was a male stereotyped computer game, with their performance on the Honeybears, which was designed to be gender neutral. The underlying problem structure and interface of these computer games were identical. They found a significant male superiority on the male stereotyped version of the computer game and no gender difference on the gender neutral version of the game. The boys were performing at the similar levels regardless of the version of the computer game, whereas the girls performance was significantly higher when they played the Honeybears and in fact was slightly higher than the boys performance. This study clearly shows how important design features in the game are for girls and boys performance. Therefore it is important to explore how differences in design and context may have a differential effect on male and female students.

One importance difference, which could have implications for the design of digital game based learning, is gender differences in available leisure time. Winn and Heeter (2009) reported a study where they their explored this issue and how it impacts on the time male and female students spent playing digital games. They found women have less free time than men and that their free time is available in smaller chunks and they play digital games for shorter periods of time than men. This finding and explanation is consistent with the recent reports that females play more causal games than males (Information Solutions Group 2006) because they are well suited to the leisure time constraints of women. It has important implications in the design of digital games in general and the design of digital based learning in particular. Digital game based learning should be designed to be played for short periods of time and designed so players can control exactly when the play session will end, in order to facilitate time management and to permit temporary concentration on the gaming experience without worry of being sure to stop on time. It also points to the advantages of using mobile causal games in supporting learning. They can be played anywhere, for short periods of time and in those periods of dead time (e.g. waiting for a bus or train). Future research should examine the potential of a mobile version of Racing Academy and how that might impact on male and females learning experience.

Further research is also need to explore whether the use of digital games could have a detrimental impact on the recruitment of female students onto STEM courses. As already mentioned in the introduction, the under representation of females in STEM subjects is a world wide phenomena and it is important to explore whether digital games, like Racing Academy, may have a negative impact on the recruitment of female students on STEM courses. We are currently using Racing Academy as a means of encouraging students to apply for STEM courses and research is exploring whether this has a negative impact on female student recruitment.

In conclusion this study investigated whether ether were any gender differences in the beneficial effects of using a digital game to support students learning of mechanical engineering. We found there was no gender difference in the beneficial effect of Racing Academy, however there was some evidence that, female students found Racing Academy more motivating than male students.

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