

An Investigation of Self-Efficacy using Educational Video Games Developed by the GK-12 STEAM Project

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Abstract: Educational video games can be used affectingly when teaching science in the classroom. The Science and Technology Enrichment for Appalachian Middle-schoolers (STEAM) project has developed a variety of educational content using different technology platforms such as Flash and Second Life. Initial evidence suggests that students learn significantly more from games developed in 3D virtual worlds than 2D ones. One explanation of this phenomenon is that 2D games max a larger cognitive load from participants. Larger cognitive loads decrease the effectiveness of the educational content taught in games. The primary focus of this research is to investigate this phenomenon further by disseminating self-efficacy levels of participants playing the educational games developed by STEAM. This paper describes how self-efficacy and cognitive loading relates to the proposed methodology of teaching through 2D and 3D games.

Introduction

Seamlessly integrating technology in the classroom can be a very difficult task (Bitner & Bitner, 2002). In doing so, it can serve as a great medium to teach difficult scientific material to students. Science and Technology Enrichment for Appalachian Middle-schoolers (STEAM) is a multi-year project funded by the National Science Foundation (NSF) GK-12 program. STEAM consists of a diverse set of science and engineering graduate students, which are lead by faculty from the Colleges of Education, and Electrical Engineering and Computer Science at Ohio University. This university-managed project has two primary goals. The first goal is to broaden graduate education by graduate students becoming directly involved with developing educational games and helping middle school teachers in teaching the science content to middle-schoolers in Appalachian Ohio. The second goal of the project is to increase middle school students' content knowledge found in the Ohio's Academic Content Standard for science. This is significant because there are several disadvantages that schools in the Appalachian region must face and overcome. The focal point of this paper is to review some of the design challenges that are faced by STEAM when developing educational games and to support the hypotheses that students learn more efficiently when playing games developed in 3D virtual environments rather than 2D ones.

The world's first video game, *Spacewar*, was created by Steve Russell in 1961. The video game industry has grown tremendously since Russell's initial multi-player game. In 2007, the revenue generated by the video game industry in the United States has been estimated to nearly-reach \$19 billion dollars (The NPD Group Inc., 2008). With such large yearly revenues, it is not a surprise that nearly all of America's teenagers play video games in some fashion. In a large-scale study that investigated the use of video games and civic engagement found that 97% of teens 12 to 17 years of age play games regardless of gender, age, or socioeconomic status (PEW Internet & American Life Project, 2008). With so many of our youth playing games, it is important to know how they are playing and how educators can take advantage of this widespread use of digital media. This study also reported that 86% of gamers play on consoles like Microsoft's Xbox, Sony's Playstation, and Nintendo's Wii. Of this sample population, the distribution of females playing console games is significantly dominated by males. According to PEW, most gamers own multiple gaming devices. The second most widely used gaming medium is personal computers. Personal computers are used nearly equally by females and males, where little variation between the two genders is found. In full, 85% of teenagers who own a personal computer say they play games on it.

The gaming survey conducted by the PEW Project also revealed several differences in the types of games teenagers were playing based on gender, economic status, and race. For example, female teenagers reported that they enjoyed puzzle games the most, while their male counterparts enjoyed action-based games. Male teenagers tended to play a wider variety of game types than females, however; racing, rhythm, and virtual world games were equally played among the genders. A larger proportion of teenagers coming from low-income families (i.e. under \$50,000) played racing games more than teens from high-income families. In terms of race, a larger proportion of White or Hispanic teens liked to play sports games more than Blacks who preferred survival-based games more.

STEAM's GK-12 Fellows are faced with a multitude of challenges while developing educational content for the participating middle schools in the Appalachian area. The game design process starts with Professional Development sessions, where middle-school teachers, Ohio University faculty, and the Graduate Fellows meet to identify difficult-to-teach concepts. Teachers are considered the scientific *content experts*, while the Fellows are the *technology experts*. To devise a successful game for the classroom, these experts must integrate Ohio's Content Standards for science directly into the game while keeping the game interesting to middle-schoolers. An ideal game would seamlessly integrate game play with educational content. However, it is extremely difficult to combine educational content that teachers appreciate with the playability that students like. Members of STEAM, middle-school teachers, and the middle-school students have differing views on what will make a successful game. Even if an ideal game can be planned, there are limiting factors that might not make the game feasible to design. For example, computer hardware (and software) changes rapidly, expecting that all middle schools will have the latest hardware specifications is naive. Games need to be developed in digital environments that do not require advanced hardware, which can be expensive for the schools to maintain. For this particular challenge, STEAM has developed several educational games in Macromedia Flash (Franklin, Mayles, Chang, & Chelberg, 2007), which require modest computer requirements. It should be noted that these games (and others) can be downloaded at Ohio University's Virtual Immersive Technologies and Arts for Learning (VITAL) web page (<http://steam.cs.ohiou.edu>).

One of the most successful Flash games that STEAM has developed is *Furry Family*, which teaches concepts related to sexual reproduction as shown in Fig. 1. Students are asked to determine the genetic makeup of a given set of parent's offspring by completing a Punnett squares when they are given specific information about genotypes and phenotypes (Smearcheck, Franklin, Evans, & Peng, 2008). Another game that STEAM has created

that students enjoy is *Water Cycle Travels*, which is shown in Fig. 2. This game utilizes the advantages of Flash to teach Ohio's Content Standards of water cycles interactively while controlling move along a maze.

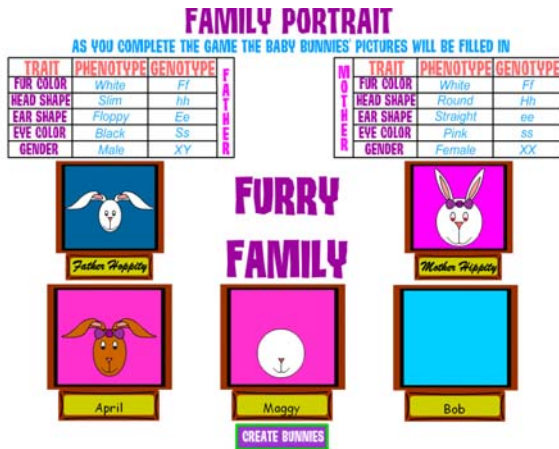


Figure 1: Furry Family



Figure 2: Water Cycle Travels

Many gaming-research scholars suggest that educational games developed in 3D environments turn passive learners into active ones by integrating competition and cooperation (Shaffer, Squire, Halverson, & Gee, 2005). Some might perceive that flash games are limited because in general, they are developed in a 2D environment. As stated earlier, certain design constraints make the Flash games a good teaching option because they are robust to problems where “higher-end” computers are required.

One 3D environment that STEAM has utilized is Linden Lab's Second Life. Players control an avatar, which is a virtual person that uniquely represents them inside the virtual environment as shown in Fig. 3. Avatars can be customized with almost infinite options, which enhance the immersive nature of the virtual environment for the students. STEAM uses a private educational “island,” which eliminates potential problems with content that the students might be subjected to in a public setting. In general, students control their own avatars in the 3D world, where they can interact with world objects and avatars controlled by other classmates. Linden Labs utilizes a scripting language called Linden Scripting Language, which is similar in syntax to C programming. The community of Second Life continually creates a wide variety of publicly available scripts that can be freely used. These scripts as well as other built-in developing tools for Second Life reduce the complexity of implementing educational games.



Figure 3: Weather Challenge

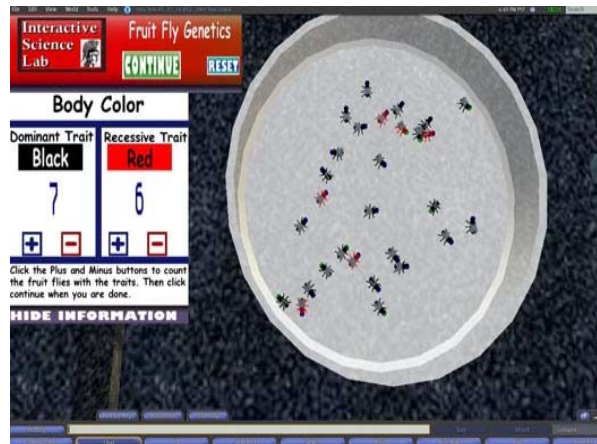


Figure 4: Fruit Fly Genetics

One Earth science game developed by STEAM is called *Weather Challenge*, which is shown in Fig. 3. In this game, students fly around the virtual world to different cloud and learn how fronts, temperature, precipitation, and pressure affect the weather. Fig. 4 shows another environment developed by STEAM in Second Life called the

Interactive Science Lab. This digital lab teaches life science through digital experiments. For example, *Fruit Fly Genetics* is a game that uses that teaches topics related to heredity, Punnett squares, and reading data from graphs.

Designing games such as like the *Interactive Science Lab* has many potential benefits. Students performing scientific experiments in real life can be costly in terms of time and money. In a digital environment, experiments can be performed one after the other irrespective of costly lab equipment or supplies. Experiments can be performed in a digital world that otherwise might not be realistic in a real-life setting.

Second Life enables an educational game to be developed that allows interactions with other students in a digital environment relatively easily. There are benefits in using Second Life as a development environment instead of Macromedia Flash. However, some of the benefits of Second Life also make it limited. For example, schools might not have the necessary networking infrastructure to experience Second Life adequately. Even if a school has computers that have adequate hardware for video and computational processing, it might not be a viable option. For schools that lack the needed hardware for Second Life, STEAM often resorts to using Flash games or games developed in by their own educational gaming engine called STEAMiE (Nykl, Mourning, Leitch, Chelberg, Franklin, & Lui, 2008). This discussion is beyond the scope of the presented research.

There are numerous challenges in designing educational video games for the classrooms that have not been mentioned in this paper. McFarlane et al. (2002) outlines the major problems faced when integrating video game technology into the classroom. He states that it is difficult:

- for teachers to identify the relevance of using games in their teaching curriculums
- to convince stakeholders that using video games in the classroom has potential
- for teachers to familiarize themselves with the technical aspects of the games
- to identify and remove irrelevant content in the games that hinder learning
- for teachers and students to orientate themselves in the games

The challenges imposed on using educational games in the classroom seem insurmountable. However, the STEAM project has performed a significant amount of work in evaluating the effectiveness that the games have on teaching Ohio's Content Standards for science (Franklin, Chelberg, & Liu, 2009). For example, each game developed by GK-12 Graduate Fellows follows a research protocol in the middle schools. The protocol uses a convenient sample because obtaining data can be difficult. The quasi-experimental model used in the protocol splits students during a class period into two groups' weeks before any instructional content is taught in the classroom. The teachers are asked to ensure that there are equal distributions of males to females in each group, but the individuals are selected at random. At this time, the first group (treatment) is pre-tested, is asked to play the game at least twice, and then is post-tested. The second group (control) at this time is post-tested without playing the game. Once two weeks has passed, the treatment and control groups are pre-tested and then post-tested after the scientific content has been taught.

From the initial research performed by STEAM, there is strong evidence that suggests that 3D games are more effective in teaching scientific concepts than 2D games. It is believed that one of the primary differences for this occurring is the massive cognitive load required to play 2D games, which is supported by authors in related fields of research (Ark, Dryer, Selker, & Zhai, 1998). Therefore, the rest of the paper is dedicated to describing the roles that self-efficacy and cognitive load has on educational video games. A proposed methodology is presented that will be used to support the hypothesis that 3D games are better suited for learning. For this study, a self-efficacy survey was given to players of 2D and 3D games respectively. Thus, results of a self-efficacy survey are presented.

Self-efficacy is the belief an individual has in their capabilities to perform a certain task successfully (Bandura, 1986). Kinzie et al. (1994) states that self-efficacy is directly related to an individual's performance level of completing a task. However, self-efficacy is separate from, but related to, an individual's actual ability. In general, people behave ineffectually when they lack self-efficacy even if their knowledge and ability is proficient (Liu, Hsieh, Cho, & Schallert, 2006). People with high self-efficacy tend to devote themselves more to becoming skillful in tasks people with lower self-efficacy (Schunk, 1991). Self-efficacy has an influence on people's choice of engaging and expending efforts in accomplishing tasks that require perseverance (Bouffard-Bouchard, 1990). Bandura (1997) hypothesized four factors that affect self-efficacy in students, which consists of:

1. a students' own performance,
2. a students' vicarious experiences,
3. a students' emotional arousals, and
4. others' verbal persuasion.

For example, when students perform well in tasks, they will be more likely to build self-efficacy because they have little hesitation on repeating the task again. When peers of a student perform well on a task, the student also benefits with higher self-efficacy levels. Naturally, self-efficacy is lowered when anxiety or other physiological factors are presented in performing a certain task. Positive persuasion also is a very effective way of increasing a student's self-efficacy, which is most likely to come from a student's parents, teachers, or other significant individuals. Either positively or negatively, all of these experiences can affect students' self-efficacy development. Consequently, self-efficacy is related to a student's attitude and engagement in classroom activities, as well as the strategies the student will take to complete the activity (Pajares, 1996).

In regards to computer skills, Miura (1987) suggests that self-efficacy is an extremely important factor in a student's ability to develop computing skills. Self-efficacy in science-based games is a specific type of perception, which is the belief of one's ability to "mobilize the motivation, cognitive resources, and courses of action needed to meet given situational demands (Wood, 1989)." Thus, self-efficacy in science-based computer games is a belief in one's capability of playing a game with scientific content and their persistence of expending their effort.

Sam et al., (2005) suggest that self-efficacy of science-based games has relationship to academic achievements and attitudes. Self-efficacy and its relationship to scientific-achievement may vary in different forms of media such as 2D and 3D-web-based computer games. These media outlets deliver information to students in different ways, which can vary in visual and mental stimulus. Students may have to orient themselves to search for and evaluate information that is being presented, which affects their processing capabilities due to the cognitive load. With the cognitive load presented, students have to process and integrate multiple representations of the information to build coherent knowledge structure, which may alter self-efficacy confidence when using educational computer games. Kirschner (2002) indicates that when the total cognitive load of an educational game is within the working limits of capability, students can engage in and positively benefit from the learning environment. If cognitive processing exceeds a student's available cognitive capacity, the learning environment will be negatively influenced (Kiile, 2005). In this negative setting, a student's self-efficacy will also suffer. Game designers should carefully consider balancing the cognitive load when designing educational video games because it can affect learning in an unintended way.

The Study

To investigate the self-efficacy using 2D/3D games, a 2-Way ANOVA will be used on data collected from the surveyed middle school students. The two independent variables that will be used will be whether the science-based computer game was 2D or 3D and the participant's gender (male or female). The dependent variable will be student's self-efficacy after he or she has completed game. The survey can be broken down into three sections: (1) student's demographics, (2) twenty items related to the student's self-efficacy, and (3) a short-answer question.

In the student's demographics section, students have to indicate their gender, grade levels, and years of playing computer-based games. The Likert five-scale survey will be used where the responses range from "Very Strong Beliefs in My Abilities" (VS) to "Very Weak Beliefs in My Abilities" (VW). The short-answer questions (e.g., Do you feel confident in playing 2D computer-based science games? Why or Why not?) were designed to help better understand students' self-confidence levels when playing games when presented in the different formats. Portions of this study will incorporate the original works of Baker and White (2003), Shuman, Heer, and Fiez (2008), and Sam, Othman, and Nordin (2005). It should be noted that the survey was reviewed for content validity in a pilot study. This study will examine the survey's reliability and ensure the participants can complete the survey accurately in an estimated time of ten minutes to complete.

The self-efficacy survey will be administered to both seventh and eighth graders at two schools in Appalachia Ohio. The human subjects have previously signed consent forms related to the research conducted by STEAM. It is approximated that 200 students in each grade level will participate in this study. A high participation rate is anticipated because the science content tested in the games is a part of the students' science curriculum in the classroom, which has previously been arranged with the students and teachers. Ideally, to test self-efficacy differences, the games that would be used for testing would teach identical science content but only differ in the programming environment in which they were designed. However, currently the STEAM project has not developed a single content driven game in both technology platforms (though it is presently being developed). Thus, the games were selected for this study differs in their specific content, but were chosen because the related topic and difficulty were similar.

Seventh graders participating in this study will be randomly divided into two groups and they will play games related to Earth science. One group will play *Water Cycle Travel* (2D) and other group will play *Weather*

Challenge (3D). The participating eighth graders will also be divided randomly into two groups and play games based on life sciences. One group of eight graders will play *Furry Family* (2D) and the other group will play *Fruit Fly Genetics* (3D).

Findings

Five categories of self-efficacy were designed into the survey that was used for this investigation. These categories included the middle-school student's ability to operate and play the game, find and use the game's help feature, and their perception of learning from the game and their overall success. An item-analysis was performed on the survey to determine its reliability. To obtain a power of 0.95 for the statistical test, a sample size greater than 200 was needed with an effect size of 0.5. Each of the five self-efficacy categories was found to have a Cronbach's alpha value of 0.78 and higher with a sample size of 276 students. To determine if the self-efficacy categories should be individually investigated, a correlation test was performed. This test indicated that the categories were highly correlated with one another, which indicates that the self-efficacy should be examined as a whole and not the individual sub categories. Since the survey obtain a high reliability, the remainder of this section will determine if gender and game format are significant effects to the self-efficacy levels between the 7th and 8th grade test subjects.

Table 1 presents the results of the 2-Way ANOVA for the 7th grade test subjects who were inquired about their self-efficacy after playing Water Cycle (2D format) and Weather Challenge (3D format). From this two-tailed test, only one factor (*gender*) was found to be significant to an alpha level below 0.05. The results for the 2-Way ANOVA test are shown in Table 2, where no independent variables were found to be significant.

Table 1: 2-Way ANOVA Results for 7th Grade

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	7.835	3	2.612	3.710	.013	.062
Intercept	2156.893	1	2156.893	3064.383	.000	.948
Gender	6.138	1	6.138	8.721	.004	.049
Game	.586	1	.586	.833	.363	.005
gender * game	.028	1	.028	.040	.842	.000
Error	118.248	168	.704			
Total	2441.248	172				
Corrected Total	126.083	171				

Table 2: 2-Way ANOVA Results for 8th Grade

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	4.234 ^a	3	1.411	1.832	.147	.055
Intercept	1112.672	1	1112.672	1444.389	.000	.939
Gender	1.251	1	1.251	1.623	.206	.017
Game	.220	1	.220	.286	.594	.003
gender * game	1.652	1	1.652	2.144	.146	.022
Error	72.412	94	.770			
Total	1313.793	98				
Corrected Total	76.647	97				

Conclusions

The goal of this research was to determine if gender or educational game type (2D or 3D) significantly affected self-efficacy amongst 7th and 8th grade students who participated in the study. The survey that was used for this research was tested for reliability from an initial pilot study. This initial test showed that the survey was statistically reliable and indicated that each of the five self-efficacy categories were highly correlated. Thus, a 2-Way ANOVA test was applied to the samples collected from the surveys for each grade level. From the ANOVA test, *gender* was found to be statistically significant for the 7th grade participants. The estimated marginal means for this effect is shown in Figure 5, where the self-efficacy amongst males was higher than females regardless of educational game format. This figure also shows a marginal gain in self-efficacy due to the 3D game format.

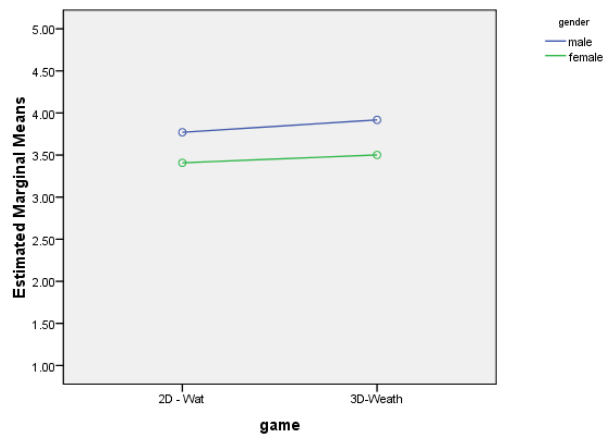


Figure 5: Estimated Gender Effects for 7th Grade

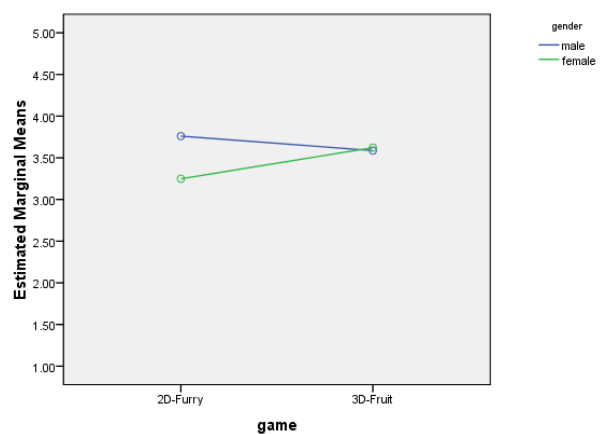


Figure 6: Estimated Gender Effects for 8th Grade

The effects plot for gender for the 8th grade participant is shown in Figure 6. Females in the 8th grade appeared to have lower self-efficacy than males for the 2D game format. They also appeared to have an increased self-efficacy when they played the 3D game format. The figure also showed an inconsistent trend with the male test subjects since their self-efficacy appeared lower after playing the 3D format. Test results found in Table 2 according to the 2-Way ANOVA did not find any of the independent variables (or their interaction) to be statistically significant. This investigation indicates evidence that game format does promote higher self-efficacy levels in middle-school students participating in the STEAM project. These levels were statistically significant in the 7th grade levels, but were not in the 8th grade.

Further testing is needed to examine if self-efficacy is affected by gender or game format in the 8th grade class. Furthermore, it is interesting to hypothesize why females of the 8th grade class seem to obtain higher self-efficacy from the 3D games and males did not. Could this reason stem from females enjoying the social interaction that is presented in the 8th grade 3D game that was tested (Fruit Fly Genetics) as this social interaction is not found in the 2D game play? Alternatively, did the males decrease in their self-efficacy levels because of the varying degrees of difficulty between the 2D and 3D format? For further investigation about self-efficacy for gender and game formation, STEAM is currently developing education games in both 2D and 3D formats that support the same science content in hopes of continuing to examine self-efficacy and possibly issues of cognitive load, which may play a role in this discussion.

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