How effective is “Fuzzies” as a tool for developing a holistic understanding of basic genetic principles?

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ABSTRACT
When learning genetics, high-school students often develop misconceptions about the concepts being taught. Of the concepts, one that is commonly misconceived is inheritance. Students often develop a very shallow understanding of what inheritance is and its underlying factors. As a solution, we chose to create an enjoyable, easy way for students to develop a holistic understanding of basic genetics concepts, such as inheritance. This paper discusses the development of a serious game that could be used as an effective tool to teach inheritance to high-school students. Within this study we asked the question,“Would player interaction in a game be conducive to learning?” The discussion also covers our design of player interaction and how this effected how much the player learned. Extensive studies will reveal whether a holistic understanding was developed.

1. INTRODUCTION
There is a problem in genetics education. The Iowa Department of Education has decided that high school students should “understand and apply knowledge of the molecular basis of heredit” (IDoE, 2010), yet studies show that many students do not understand how biological systems like meiosis relate to inheritance (Stewart, 1988; Visscher et al., 2008; Lewis and Kattman, 2004; Shaw, 2008). It is clear that traditional teaching practices alone have not been sufficient in educating students about how the biological systems relate to operational knowledge about inheritance. As genetic testing becomes more directly available to the public, it is important for people to understand how inheritance works to make informed decisions about health and reproduction (Harmon, 2010). Nurses also play a vital role in helping many patients to come to similar decisions such as those concerning reproduction. Nurses are often the key initial reference to appropriate doctors or genetic counselors and other clinical genetic resources. However, if the nurse does not have adequate knowledge of genetics, it is less likely that he or she will know or be able to refer the patient. Studies since the 1970s have shown the lack of adequate genetics knowledge in many nurses (Cohen, 1979; Gwen, 1996). Calls for reform in genetics education for nurses have been in place since 1962 and still continue (Jenkins, 2001). To help educators, serious games, games that have a primary purpose other than pure entertainment, can be developed to provide a powerful tool for helping students understand complex systems. Since serious games can simulate complex systems (be those systems chemical, physical, biological, or any other systems), they provide a context in which students can learn more than simply facts (Shaffer, 2006 [How computer games help children learn: p. 185]).

2. BACKGROUND INFORMATION
High school students throughout the past thirty years have been shown to lack a holistic understanding about genetics (Stewart, 1988; Visscher et al., 2008; Lewis and Kattman, 2004; Shaw, 2008). For instance, many high school students did not understand the difference between expressed traits and genes, nor did they understand that genes can have recessive alleles (Lewis and Kattman, 2004). A possible explanation as to why students had these misconceptions is that they lacked a holistic understanding of genetics (Bereiter & Scardamalia, 2005). Students did not understand the systems involved in the development of organisms. For example, they failed to recognize that environment can be just as important as genotype in the development of an organism (Shaw, 2008; Visscher et al., 2008). Also, although students were able to successfully solve Punnett square problems if given the correct variables to work with, they could not explain what the variables meant or why they were arranged the way they were in the given problem (Stewart, 1988). Studies from 1988 to 2008 have shown that students did not understand how Punnett squares relate to the process of meiosis (Stewart, 1988; Visscher et al., 2008; Lewis and Kattman, 2004; Shaw, 2008).

Educational serious games could be used as tools to address this lack of holistic understanding. Kurt Squire suggests that educational games have the “power for eliciting students’ alternative misconceptions and then provid[e] a context for thinking through problem” (Squire, 2004). In this instance, the context serious games could provide is the simulation of biological systems. When students confront real-world systems through a serious game, they can develop a more accurate and holistic understanding than in a traditional setting alone (Hake, 1998; Squire, 2004).

Though serious games have been shown to be effective tools, they are no silver bullet. Not all serious games that are developed reach their educational goals. For example, a previous educational game designed to teach genetics did not result in an improvement in students' understanding of genetics (Annetta et al., 2009). This does not mean that it is futile to attempt to teach genetics through a serious game. The previous game focused on teaching the whole semester long curriculum of genetics, while our scope is much more focused. There are also many variables involved in creating an engaging educational game, so approaching the game design differently can yield very different results in both engagement and learning.

3. GAME DESIGN

In the design process for the game we took an iterative approach in which two game prototypes were developed. Both games shared the same educational objectives and game mechanics and differed only in their level of interaction.

3.1 Gameplay

The player's objective is to breed organisms called "fuzzie" so that the offspring has a phenotype that matches the goal "fuzzy" for the level. Once the player selects and breeds the desired "fuzzies", the process of meiosis is displayed on the screen. In the final stage, telophase II, four gametes appear and one is randomly selected by the game from each parent. Depending on the level of interaction, a seed will be formed for the player to plant, or there will be a choice to generate a new set of gametes. These levels of interaction determine how the player must strategize win the game.

3.1.1 First Level of Interaction

The first game iteration is designed with a level of interaction in which a seed is automatically generated once two gametes are randomly selected by the game. The offspring "fuzzy" would have a genetic makeup based on gametes selected. Players must then must strategically choose the parent "fuzzies" with the correct genetic makeup to produce the goal "fuzzy".

3.1.2 Second Level of Interaction

The second game iteration is designed with a deeper level of interaction in which players may choose to generate a new set of gametes. In addition to selecting the correct parent "fuzzies", players must choose the correct combination of gametes to breed the goal outcome. Once satisfied with the selected gametes, as with the previous level of interaction, the gametes will come together and produce a seed to be placed in the ground. By allowing control over the selected gametes, the player must strategically decide both which parents and which gamete combination will produce the desired offspring "fuzzy".

3.1.3 Educational Objectives

Both games are made up of fifteen levels, in addition to the tutorial level, and are separated by educational objectives. Difficulty is increased by decreasing the probability of getting the goal "fuzzy" on the first try. The last three levels, thirteen through fifteen, are a combination of all educational objectives listed below.

Dominance (Levels 1-6)
Recessive alleles can be completely masked by a dominant allele.
The first three levels focus on color alleles, while the next three focus on pattern alleles. In the game, the "fuzzie" have a gene that determines the presence or absence of color and another that determines the presence or absence of pattern. The allele for color presence is dominant to the allele for color absence and the allele for pattern presence is dominant to that for pattern absence.

Effects of environment (Levels 7-9)
Genotype and environment both affect how traits are expressed in an organism.
"Fuzzies" that are planted in an environment near grass develop a different pattern than those that are planted away from grass. In addition, genotype still affects pattern in the same way it did in earlier levels. For example, if the pattern allele is absent the "fuzzy" will have no pattern regardless of its environment.

Incomplete Dominance (Levels 10-12)
Some genes show a mixed expression of both alleles.
The "fuzzies" have a gene that controls for color pigment. Homozygous "fuzzies" are either yellow or blue, while heterozygous "fuzzie" – those that have one blue allele and on yellow allele – are green.

Molecular Basis (all levels)
Genetics is more than packets of genetic information; it has a basis in biological systems.
The genotype of each "fuzzy" is shown as a collection of chromosomes with the gene locations and specific alleles labeled. Also, to breed "fuzzies", the player sees an animation of meiosis in order to produce gametes for use in sexual reproduction. In the deeper level of interaction, the player has more direct control over this process and is able to produce new sets of gametes by clicking a button to retry.

4. METHODS

In this study a between-subjects design was used, in which there was a distinct group of randomly selected participants for each prototype of the game. Nine undergraduate college students were divided into male and female subgroups, and were randomly assigned to either play the game with interaction level one or two. Participants were identified by a unique predetermined identification number. Prior to gameplay, participants were administered a pre-test, which measured base knowledge of genetics. The pre-test consisted of ten questions which focused on core genetics concepts that students commonly misunderstood (Stewart, 1988; Visscher et al., 2008; Lewis and Kattman, 2004; Shaw, 2008). Sample questions can be found in the appendix. Participants were instructed to complete the pre-test to the best of his or her ability, given as much time as needed to complete the test, and not told the final score. Participants were then instructed to play the game at his or her own pace. Each was given twenty minutes to play, but was not informed of this time limit. After twenty minutes or until all levels were completed, the post-test was administered. The post-test contained the same questions as the pre-test, and participants were again told to complete the test to the best of his or her ability. Both pre-test and post-test were administered through the Qualtrics survey website. After the post-test was complete, participants were administered the final evaluation survey on paper, which contained demographic questions about the participant's previous genetics experience and gender, Likert scale questions concerning the game's perceived educational value, usability, and engagingness, and an open ended question asking for any additional comments about the game. Survey questions can be found in the appendix.

During gameplay, the participant's face, computer screen, and mouse movements and clicks were recorded with Morae, a usability testing software. Facial expressions were coded independently by each investigator using âĂIJEmocardsâĂİ for inter-rater reliability (Figure 1). "Emocard" were developed by Desmet as a tool to measure user emotions during usability testing of mobile telephones (Desmet, 2000). Emotions have been strongly tied to learning and memory retention through both experiments and neural scans (Ingleton, 1999; Dirkx, 2001; Sylwester, 1994; Pekrun et. al., 2002). Both positive and negative emotions, such as enjoyment and anxiety, can be beneficial to the learner's interest, motivation, and ultimately learning (Pekrun et. al,. 2002). We used "Emocards" to code specifically for level of user engagement during gameplay, which were correlated with interest and motivation. Faces 4, 5, and 6 were rated as "calm" faces, while faces 1, 2, 3, 7, and 8 were rated as "engaged" faces. Each investigator coded the participants' emotions individually, and results were tallied into either the "calm" or "engaged" category.

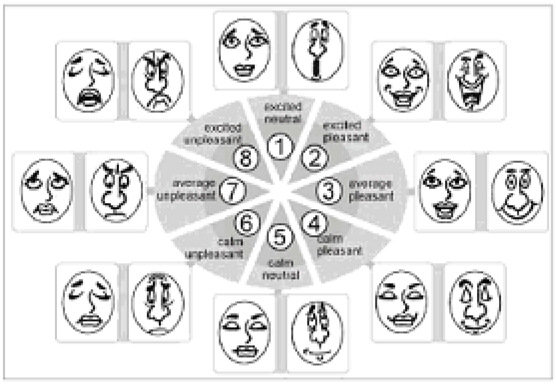


Figure 1: "Emocards" were used as a tool to measure nonverbal emotional responses to the game.

5. RESULTS

In order to justify calling this software project a serious game, one must show that it it both improves students' knowledge of genetics and that it is engaging and enjoyable to play. Nine undergraduate college students were used in this study. They were stratified by sex into male and female subgroups, with five females and four males. From these subgroups, participants were randomly assigned to play interaction level one or two. The participants were not told which interaction level they were assigned.

5.1 Learning

In analyzing test score results, displayed in Table 1, there was a wide variety of prior genetics knowledge. One participant indicated that he or she was a genetics major. This participant's test scores were excluded from the analysis. Contrary to our hypothesis, the average test score improvement was greater in the sample that played with interaction level 1, which did not have a retry button, than the increase in scores from interaction level 2, the deeper level.

A two sample t test was also calculated using the null hypothesis that the mean score change of level two minus the mean change of level one is zero. The value of t is -0.302. Thus, there is no significant difference between the two groups.

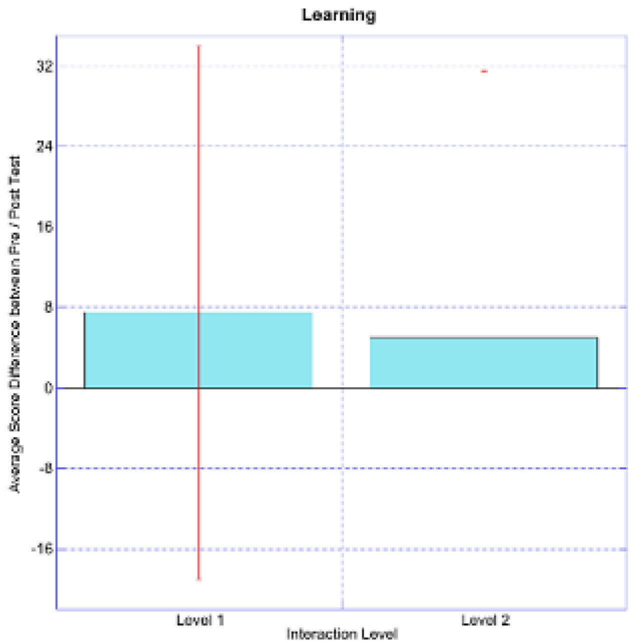


Figure 2: No significant differences in learning were found between the two samples (n=4) who played different interaction levels.

5.2 Enjoyment

To determine how fun the serious game was, the five-point Likert item "I enjoyed playing the game" was used. A score of one indicates "strongly disagree", and a score of five indicates "strongly agree". The sample that played level of interaction two indicated that more enjoyment than the sample that played level of interaction one.

A two sample t test was also calculated using the null hypothesis that mean score for level two minus the mean score for level one is zero. The value of t is 1.426. Thus, there is no significant difference between the two groups.

A single sample t test was also done for the combined group with a mu of 3, since a value of three on the Likert scale indicates neither agreeing nor disagreeing. The t-value of this is a 6. A one-tailed test whether it was agreed that the game was enjoyable indicates that the game as a whole (either interaction level) is enjoyable with $p < 0.05$.

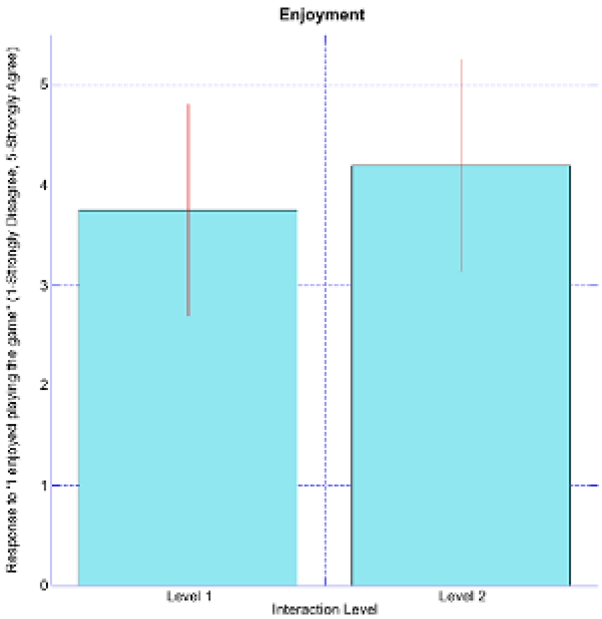
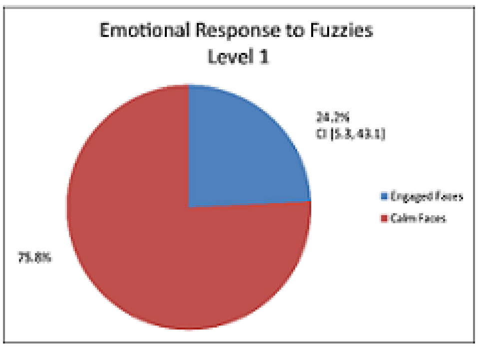


Figure 3: No significant differences in enjoyment were found between the two samples (n=4 and n=5 for level 1 and level 2, respectively) who played different interaction levels.

5.3 Engagement

To calculate player engagement, we used Emo-cards with three observers collecting data for each participant as described in the methods section. We then counted the proportion of all facial expressions considered engaged (1, 2, 3, 7, 8 on the emocard figure). The sample that played the second level of interaction showed more engaged facial expressions than the sample played the first level of interaction.

A two sample t test was also calculated using the null hypothesis that the proportion of engaged faces for level two minus the proportion of engaged faces for level one is zero. The value of t is 0.959. Thus, there is no significant difference between the two groups.



6. DISCUSSION/CONCLUSIONS

Due to the small sample size, it is not surprising that no significant differences between those who played interaction level one and those who played interaction level two. Further study is needed before one can make any conclusions about whether a slightly higher level of interaction does or does not affect learning, engagement, or enjoyment.

Though this study did not find any statistically significant differences, conducting a small-scale study had some value. In terms of game development, player testing helped uncover bugs in implementation and level design that developers did not notice. Especially in level design, players who did not know specific implementation details found aspects of the game that were confusing for someone who did not have complete knowledge of how the game works. In our case, the level that introduced environmental effects was found to be a problem. Some players had misconceptions about how the grass affected pattern (believing that all "fuzzies" planted in grass would get a pattern) or could not complete the level at all.

Even without statistically significant results to prove its effectiveness, this game could conceivably be used in classrooms. Teachers may find that while the game has not been proven to be effective at teaching genetics topics fully on its own, it can still be a useful tool for teachers to use. A teacher could use this as a class activity in conjunction with a lecture and reflection time to give students a more engaging experience than a lecture could alone. It is our hope that teachers will incorporate this game in their classrooms. In making this game runnable on multiple operating systems by developing it for the Flash platform, teachers should have little trouble in running it on any school computer.

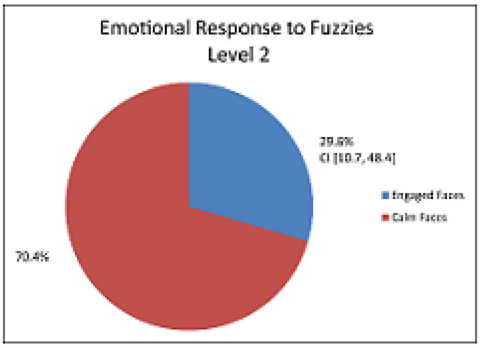


Figure 4: No significant differences found between the two samples in engagement.

7. ACKNOWLEDGMENTS

Eve Wurtele, David Kabala, Mark Stenerson, Andrea Peer, Nikolaus Karpinsky, Pam Shill, Stephen Gilbert. National Science Foundation, Program for Women in Science and Engineering, Iowa State University, Department of Human Computer Interaction, Virtual Reality Application Center. University of Wisconsin-Madison, University of Georgia, Wellesley College.

8. REFERENCES

[1] S. Salas and E. Hille. *Calculus: One and Several Variable.* John Wiley and Sons, New York, 1978.