1 Introduction

1.1 Background On Vector Magnitude

Vectors are used in physics to describe a line with magnitude and direction. The magnitude refers to the length of the vector. The magnitude of a vector in Cartesian coordinates can be found using the Pythagorean theorem [1]. The Pythagorean theorem is one of the oldest theorems in all of math and was named after its founder, Pythagoras. However, there is evidence that Babylonians and maybe even ancient Egyptian and Chinese civilizations had used the theorem before Pythagoras formally discovered it [2]. The equation for the Pythagorean theorem can be seen in equation 1.

$$c = \sqrt{a^2 + b^2} \tag{1}$$

1.2 Background On Physics Learning

Learning in a university Physics class usually consists of reading a textbook, attending a lecture, and practicing problems. These tasks can often feel mundane and boring to students. However, if learning is fun, students are more motivated, concentrated, and willing to learn something new [3]. The question then arises, is it worthwhile to change how Physics is taught? [4] suggests that video games are an alternative way of learning. Given that video games are highly visual, students can see a physics concept applied in real time. [5] uses two video games to teach basic physics concepts to students. They tested students' understanding of concepts before and after playing the video game, with positive results for students' knowledge. Hence, there is a need to make learning physics more enjoyable due to the benefits mentioned earlier. A video game is a good way to do this, as research suggests that video games positively impact students' learning.

1.3 Objective

There are two main goals in this study:

1. Create a video game focusing on one physics concept for simplicity
2. See how well the video game teaches a physics concept compared to traditional teaching methods

2 Video Game

2.1 Video Game Description

The video game for this project focuses on the concept of vectors. Specifically, how a student can use the Pythagorean theorem to find the magnitude of a vector. The game was created in Unity and used C # as the programming language. The name of the game is called Ratitican and features a character who is an evil rat mathematician. The game's background is a Cartesian coordinate graph from zero to ten in both the x and y directions. The game starts with the rat moving to a random point on the graph. Once the rat stops, a text box along with how far the rat moved in the x and y direction is displayed on screen. The user is then expected to use the Pythagorean theorem to find the magnitude of the vector that the rat moved. If the user is within ± 0.5 of the correct magnitude, the answer will be correct. If not, the game will end, and the user can restart. Below the game is a brief description about the game and how to calculate the magnitude of a vector.

2.2 Video Game Design

Often, when designing video games, a good practice is to use the model, view, controller (MVC) architecture. The design for this video game is similar, but it features two scripts as opposed to three:

1. GameManager.cs

2. RatController.cs

GameManager.cs is used to detect actions, such as when the rat has stopped moving and when the user has entered an input. The GameManager also displays visuals on the screen and decides when they should be hidden. RatController.cs is not used for detecting user input, as the name suggests. Instead, it is used specifically to control where the rat moves on the screen. RatController.cs starts by calling the MoveToRandomPosition() function. In this function, a random number between zero and ten is selected. Then, a function called GraphToWorld() is called. GraphToWorld() takes the random numbers chosen and scales them down to the positions they should be on the screen. For example, if the point (1,3) is chosen and this function is not used, then the rat will end up somewhere completely random on the screen. However, by scaling the coordinates to fit into the height and width of where the graph is located on screen, the rat will end up in the correct place. This is similar to a conversion between model and view coordinates, often seen in the MVC architecture. Once it has been determined how far the rat has moved, the WorldToGraph() function is used to convert the scaled coordinates back to Cartesian coordinates. Then the result of the magnitude is sent to the GameManager.cs file. The user then inputs their answer for the magnitude of the vector that the rat moved, and the GameManager determines if this answer is correct.

3 Methodology

3.1 Study Design

This study compares how well the video game teaches the concept of vector magnitude compared to traditional textbook learning. An analysis was performed in two sample groups to determine which method was superior. One group received an excerpt from a textbook [1]. The other group received the video game. After each participant reviewed the learning material, a computational and conceptual question was asked. The computational question was pulled straight from the earlier-mentioned textbook. It gives an x and y component, and asks participants to calculate the magnitude of the vector corresponding to it. The conceptual question asked students to describe what the vector of a magnitude meant. This was reasonable as both the textbook and video game described the magnitude as the length of a vector. The other acceptable answer to the conceptual question was to restate the formula provided. At the beginning of the survey, participants were also asked to time how long the entire process took. This was used as a potential tiebreaker as the quiz results between the two groups could be statistically insignificant. Participants were also asked at the end of the quiz if they could have answered the questions before taking the survey. This was used to eliminate participants already familiar with the material, as the study's goal was to see how well people learned new material.

3.2 Data Analysis

For the data analysis, three statistical tests had to be performed:

1. Difference between the percentage of correct answers between the textbook group and the video game group for the computational question

2. Difference between the percentage of correct answers between the textbook group and the video game group for the conceptual question

3. Difference between the mean time to complete the survey between the textbook group and the video game group

This can be measured by performing a two-sided hypothesis test. In statistical notation, these tests can be rewritten as

1. Test of hypothesis for percent differences on the computational question,

   $H_0 : \rho_{textbook} - \rho_{video\ game} = 0$

   $H_1 : \rho_{textbook} - \rho_{video\ game} \neq 0$

2. Test of hypothesis for percent differences on the conceptual question,

   $H_0 : \rho_{textbook} - \rho_{video\ game} = 0$

   $H_1 : \rho_{textbook} - \rho_{video\ game} \neq 0$

3. Test of hypothesis for the differences in mean survey time,

   $H_0 : \mu_{textbook} - \mu_{video\ game} = 0$

   $H_1 : \mu_{textbook} - \mu_{video\ game} \neq 0$

In other words, we are testing to see if there is a statistical difference between the two groups for each population parameter (ρ and μ) based on sample statistics ($\hat{p}$ and $\bar{x}$). Each of these tests was performed at a 99% confidence level. This was due to the severity of the results, as they could be used to influence the way an entire cohort of students is taught Physics. The table of data collected from the surveys can be seen below.

Computational Question ($\hat{p}$)	Conceptual Question ($\hat{p}$)	Time in Seconds($\bar{x}$)
4/7	3/7	190.57

Table 1: Raw Data For Textbook

Computational Question ($\hat{p}$)	Conceptual Question ($\hat{p}$)	Time in Seconds($\bar{x}$)
5/7	5/7	466

Table 2: Raw Data For Video Game

In these tables, $\hat{p}$ represents the sample percentage of participants who got the question correct, and $\bar{x}$ is equal to the sample mean time it took for a participant to complete the study in seconds. The survey data needed to be processed, as outliers could skew the results. The actions needed to process the data were as follows:

1. Remove participants already familiar with the learning material
2. Remove time outliers from remaining participants

Before showing the processed data, it is necessary to explain the criteria for removing an outlier. A participant was classified as being familiar with the material if they could have answered one or more questions before taking the survey. This was a tricky process as some of these participants answered a question wrong. This could imply that they were overconfident in their abilities and did need to spend some more time learning the material. This arose with two participants, one in each study. After talking to the participants about why they got the question wrong, both answered that they were rushing through the survey as they already knew the material. Because both were still familiar with the material, it seemed better to leave them out of the study to avoid having low-quality data. As for removing time outliers, one data point in each study seemed to be too low. After reviewing with the participants, both had a misunderstanding of when to start the timer. The responses the participants gave to each question were still valid, so those were kept. However, their time value was removed as it was misleading. After data processing, the final tables looked like this.

Computational Question ($\hat{p}$)	Conceptual Question ($\hat{p}$)	Time in Seconds ($\bar{x}$)
2/5	1/5	230.25

Table 3: Processed Data For Textbook

Computational Question ($\hat{p}$)	Conceptual Question ($\hat{p}$)	Time in Seconds ($\bar{x}$)
4/5	3/5	698

Table 4: Processed Data For Video Game

The test of hypothesis was performed in the R programming language. For the two tests of hypothesis about the questions, Fisher's method was used [6]. Fisher's method is used because the questions are categorical binary data, and they have a small sample size. For the test of the time differences, a t-test is used. To use a t-test, the sample must have more than thirty samples or follow a normal distribution. This study only contains five participants in each group, so a test to see if the timing variables are normally distributed must also be performed. To do this, a Shapiro-Wilk test can be used [7]. A Shapiro-Wilk test is used to see if the data is normally distributed. The test can be performed when the data is continuous, independent, and the sample size is greater than three. Another condition of a t-test is that the data must have a similar variance between groups. To test if this is the case, an F-test can be performed [6]. An F-test assumes independent data, random samples, and that the data follows a normal distribution. Once all these conditions are met, a t-test can be performed.

4 Results

This chapter provides screenshots of the source code along with an interpretation of the results. The first test performed was to see if there was a statistical difference between the two groups in the percentage of answers entered correctly for the computational question. The sample statistics were $\hat{p}_{textbook} = \frac{2}{5}$ and $\hat{p}_{videogame} = \frac{4}{5}$. The confidence level was set to 99%. A screenshot of the results is in Figure 1.

````
```{r}
#Testing difference between correct answers for computational question

#Documentation Reference:
https://www.rdocumentation.org/packages/stats/versions/3.6.2/topics/fisher.test

compMatrix <- matrix(c(2, 4, 3, 1), nrow = 2, byrow = TRUE)
rownames(compMatrix) <- c("Correct", "Incorrect")
colnames(compMatrix) <- c("Form 1", "Form 2")
resultComp <- fisher.test(compMatrix, alternative="two.sided", conf.level=.99)
print(resultComp)
```
````

```
        Fisher's Exact Test for Count Data

data:  compMatrix
p-value = 0.5238
alternative hypothesis: true odds ratio is not equal to 1
99 percent confidence interval:
 0.0005205269 9.6224367864
sample estimates:
odds ratio
 0.2033268
```

Figure 1: Results for Computational Question

The p-value (0.5238) for this test is greater than the value for alpha (0.01). Hence, the conclusion is to fail to reject the null hypothesis and reject the alternative hypothesis. In other words, there is not enough statistical evidence to conclude that there is a difference between the percentage of correct answers for each group. In the second test, the goal was to see if there was any difference between the two groups in the percentage of answers entered correctly for the conceptual question. The sample statistics were $\hat{p}_{textbook} = \frac{1}{5}$ and $\hat{p}_{videogame} = \frac{3}{5}$. The confidence level was set to 99%. A screenshot of the results is in Figure 2. The p-value (0.5238) for the conceptual question was the same as the p-value for the computational question. Thus, the same conclusion can be drawn: fail

```r
```{r}
#Testing difference between correct answers for conceptual question

#Documentation Reference:
https://www.rdocumentation.org/packages/stats/versions/3.6.2/topics/fisher.test

conMatrix <- matrix(c(1, 3, 4, 2), nrow = 2, byrow = TRUE)
rownames(conMatrix) <- c("Correct", "Incorrect")
colnames(conMatrix) <- c("Form 1", "Form 2")
resultCon <- fisher.test(conMatrix, alternative="two.sided", conf.level=.99)
print(resultCon)
```
```

```
        Fisher's Exact Test for Count Data

data:  conMatrix
p-value = 0.5238
alternative hypothesis: true odds ratio is not equal to 1
99 percent confidence interval:
 0.0005205269 9.6224367864
sample estimates:
odds ratio
 0.2033268
```

Figure 2: Results for Conceptual Question

to reject the null hypothesis and reject the alternative hypothesis. The final test of hypothesis is for the differences in average time between each group. This was performed using a t-test. However, before this could be performed, a test for normality and variance had to be performed. Normality was tested using the Shapiro-Wilk test. The results can be seen in Figure 3. The test appears twice, as normality needed to be checked for both tests. In the test for the textbook, the p-value (0.9111) is greater than alpha (0.01). For the video game, the p-value (0.4685) is greater than alpha (0.01). Because both p-values are greater than alpha, there is not enough evidence to reject the null hypothesis. In other words, there is not enough evidence to prove that either dataset differs from a normal distribution. Next, both groups must be tested to see if there is statistical evidence that the variance between the groups differ. This can be completed using an F-test as seen in Figure 4. The p-value (0.08008) is greater than alpha (0.01). Hence, there is not enough evidence to reject the null hypothesis. This implies an assumption that equal variance is fair. With normality and variance tests now complete, the t-test can be performed. The t-test is performed at a 99% confidence interval and can be seen pictured in Figure 5. The p-value (0.03517) is greater than

```{r}
#Testing to see if timing for each group follows a normal distribution

#Documentation Reference:
https://www.rdocumentation.org/packages/stats/versions/3.6.2/topics/shapiro.test

textbook <- c(240,360,201,120)
videogame <- c(480,1052,360,900)
shapiro.test(textbook)
shapiro.test(videogame)
```

```
        Shapiro-Wilk normality test

data:  textbook
W = 0.98155, p-value = 0.9111


        Shapiro-Wilk normality test

data:  videogame
W = 0.90736, p-value = 0.4685
```

Figure 3: Results for Shapiro-Wilk Test

alpha (0.01). Hence, there is not enough statistical evidence to reject the null hypothesis. In other words, there is not enough evidence to conclude a difference in average time to complete the survey.

```{r}
#Test to see if the variances differ significantly between the two groups

#Documentation Reference:
https://www.rdocumentation.org/packages/stats/versions/3.6.2/topics/var.test

var.test(textbook, videogame, conf.level = .99)
```

```
        F test to compare two variances

data:  textbook and videogame
F = 0.091314, num df = 3, denom df = 3, p-value = 0.08008
alternative hypothesis: true ratio of variances is not equal to 1
99 percent confidence interval:
 0.001923726 4.334420334
sample estimates:
ratio of variances
        0.09131395
```

Figure 4: Results for F-test

```{r}
#Perform the t test

#Documentation Reference:
https://www.rdocumentation.org/packages/stats/versions/3.6.2/topics/t.test

resultTime <- t.test(textbook, videogame, mu=0, alternative = "two.sided", var.equal =
TRUE, conf.level=.99)
resultTime
```

```
        Two Sample t-test

data:  textbook and videogame
t = -2.7087, df = 6, p-value = 0.03517
alternative hypothesis: true difference in means is not equal to 0
99 percent confidence interval:
 -1107.956   172.456
sample estimates:
mean of x mean of y
   230.25    698.00
```

Figure 5: Results for t-test

5 Conclusion

The results for the difference between the textbook and video game were to fail to reject the null at a confidence level of 99% for all three tests. There are a few reasons why this was the case. The first was due to the very small sample size. This is despite a trend starting to emerge in the sample. Participants in the video game group had a higher accuracy on questions, while the textbook group completed the survey much quicker. However, with the limited number of participants in each group it can not be stated that these differences were statistically significant. Another limitation was a high confidence level. For example, if the confidence level had been set at 95% then there would be enough evidence to reject the null hypothesis for differences in time to complete the survey. This would mean that there would be enough evidence to prove with 95% certainty that the textbook group was faster than the video game group. However, a high confidence level was chosen because changing the way a curriculum is given to students has a high cost for incorrect results. The best decision is to either stick with traditional learning methods or include video games as a supplemental learning method. For references to source code or data, refer to [8].

References

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