Vectors in the Time of Scalars Summary

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1 Hypothesis

Preliminary data suggested an inference effect between students' ablilities to answer vector/scalar related questions and the type of instruction that they were receiving at the time. For example, if students were presented with a vector-type problem during vector instruction, they would perform better than if they were presented with the same problem during scalar instruction. Thus, this project was designed to further investigate the interference effect of vector/scalar instruction on students' ablility to answer questions.

2 Data

The data used was taken from the RAWR (Rapid Assessment and Web Reports) project. Data from University Physics I (UPI), University Physics IA (UPIA), University Physics II (UPII), University Physics IIA (UPIIA), and University Physics III (UPIII) was used from Rochester Institute of Technology (RIT), as was the Physics 1 course from the United States Military Academy at West Point (West Point). The data used was collected over a two years, from the Fall Quarter of 2010 to the Winter Quarter of 2011-2012.

RIT is on the quarter system, so the introductory courses are split into three classes rather than the traditional two. (UPIA and UPIIA are remedial courses; these classes cover the same amount of material at the same time as the main stream courses, however they have two extra hours of class each week.) UPI and UPIA cover kinematics, forces, energy, and gravitation. UPII and UPIIA cover rotational kinematics, rotational dynamics, and optics. UPIIIA covers electric fields, circuits, and magnetic fields. We were unable to contact someone at West Point to get a course syllabus.

The data was collected by surveying introductory calculus-based physics students. Each student was given a weekly task to complete, consisting of 4-10 questions. The tasks are distributed such that each student takes each task only once during the semester; this prevents retesting effects.

For this project, 35 questions were examined from the following tasks: Electrostatics, Field Potential Energy, Gravitational Potential Energy, Magnetism, and Vectors.

The data itself comes in a single .csv file, which can be opened and manipulated in Excel. The columns of data that were used for this project were: Question, Student_SysID, Task_Name, Answer, Answer_Number, Start_Date, QuarterWeek, Course_SysID, Course_Name, CurMath, Gender, and Grade. Question refers to the question number assigned within the RAWR system. Student_SysID refers to the identification number assigned to each student (there are no repeats of identification numbers). Task_Name gives the the task that the question falls under (for example question 96 falls under the Magnetism task). Answer gives what that student chose (like a, b, c or d). Answer_Number gives whether or not the answer given is right or wrong, 1 and 0 respectfully. Start_Date gives the date on which the student completed the task. QuarterWeek gives the week that the student completed the task (whether it was the first week in the semester or the eighth week in the semester). Course_SysID gives the internal numbering system of the classes at RIT. (1 = University Physics I, 38 = University Physics IA, 2 = University Physics II, 39 = University Physics IIA, and 3 = University Physics III. and 40 = Physics 1 from West Point.) Course_Name is the corresponding name to each of the course ID numbers. CurMath gives whether the student is currently enroled in a math course. Gender, obviously, gives the gender of the student, 0 = female and 1 = male. Grade gives the final grade of the student in that course.

3 Statistical Tests

There were two statistical tests that I learned about over the summer; however, I only used the ANOVA test in the data analysis.

3.1 Factor Analysis

Factor analysis is used to discover simple patterns within a large set of data with many variables. The goal being to reduce the large number of variables to a small, managable number of factors. It can be used to find groupings of data that otherwise would have gone unobserved. This is done by a lot of complicated math, but it is very simple to do in R:

- Read in the data file
  FAdata = read.csv("location", header = TRUE)
- Create a correlation matrix
  cormat = cor(FAdata)
- Perform the Factor Analysis
  FAsolution = fa(r = cormat, nfactor = 2, rotate = "oblimin", fm = "pa")
  Note that the nfactor refers to the number of expected factors. There are two options for the rotate input: orthogonal ("varimax"), which does not allow the resulting factors to be correlated, and oblique ("oblimin"), which does allow the factors to be correlated. The fm input is the factoring method. There are many options here which can be looked up online. "pa" is the principle factor solution.

The output is given in terms of a pattern matrix, with the first n columns for each factor. The listed percentages can then be used to determine whether the factor corresponds to something meaningful. Below the matrix, there is a percentage listed which shows how much of the variance within the data was taken into account.

I referenced the following websites to learn about factor analysis.

- Factor Analysis by Richard B. Darlington. http://www.psych.cornell.edu/darlington/factor.htm
- Understanding Factor Analysis by R.J. Rummel. http://www.hawaii.edu/powerkills/UFA.HTM
- R Tutorial Series: Exploratory Factor Analysis by John M. Quick.
  http://www.r-bloggers.com/r-tutorial-series-exploratory-factor-analysis/

3.2 ANOVA Test (Analysis of Variance)

An ANOVA test is used to test whether the variance in a set of means (more than 2) is significant. In my case, this test was used to tell whether the mean number of students who gave the correct answer one week was significantly different from the means in other weeks. This is like a T-test, but for more than two variables. (T-tests are not used in this case because multiple T-tests introduce a lot of error). Similarly, the math for this can become very complicated, but with R the steps are very simple:

- Read in the data
  dataTest = read.csv("location", header = TRUE)
- Perform the ANOVA test
  aovTest = aov(DependentVariable ∼ IndependentVariable, data = dataTest)
- A graphical resprentation can be created using a box plot (I did not use this personally, but it can be useful.)
  boxTest = boxplot(dataTest$DependentVariable ∼ dataTest$IndependentVariable)
- The results can be found using:
  summary(aovTest)

The results given are the degrees of freedom, sum square, mean square, F value, and the corresponding P value. If F is large and P is small, then there is a significant difference among the means. A table will also appear reporting how significant the results are: *** is very significant, ** is fairly significant, * is significant, . is marginal.

I referenced the following websites to learn about ANOVA tests.

- ANOVA: Analysis of Variance Between Groups. http://www.physics.csbsju.edu/stats/anova.html
- ANOVA by David W. Stockburger. http://www.psychstat.missouristate.edu/introbook/sbk27.htm
- Anova in R by Edward L. Boone. http://www.youtube.com/watch?v=Dwd3ha0P8uw
- R and Analysis of Variance. http://personality-project.org/r/r.anova.html
- One Way ANOVA: Statistics Workshops. http://www.wadsworth.com/psychology_d/templates/student_resources/workshops/stat_workshp/one_anova/one_anova_01.html

4 R Programming

R is a free source program (which means it can be downloaded for free) that is very good at handling statistics. For this reason, R was used to analyze all the data. When R is first installed on your computer, you must first install packages. This requires adminstrator access to whatever computer you are using (under the start menu right click on the R program and choose Run as Administrator.) To install packages, go to the Packages tab and click on Install Packages. Select a CRAN mirror that is close to your location. Then select the needed packages. All of them are not needed. See the list below for the packages I used. Then, under the Packages tab, click on Load Package. You can then select the packages that are needed for your work. Note that you do not need to install packages every time, but you will need to load your packages every time you open R. In addition, some of the packages require other packages to load. Therefore, the order in which you load packages is very important. The packages and order that I used are shown below:

1. lattice
2. binom
3. bitops
4. caTools
5. gdata
6. gtools
7. grid
8. KernSmooth
9. gplots
10. psych
11. GPArotation
12. MASS
13. stats

R works off of scripts, which are basically functions in C++ or C. The basic form is you pass in stuff, it does stuff, and outputs stuff you want. For the majority of the scripts used below, the file location is the input. The scripts I used and created are shown below.

- anova.weektest - This function performed the ANOVA test with an independent variable of Answer_Number and a dependent variable of QuarterWeek.
  - Inputs - The location of the data file in a .csv format.
  - Outputs - The ANOVA summary table and significance rating
- anova.gender - This function performed the ANOVA test with an independent variable of Answer_Number and the dependent variables of QuarterWeek and Gender. The purpose was to see if there were any interference effects due to gender.
  - Inputs - The location of the data file in a .csv format.
  - Outputs - The ANOVA summary table and significance rating.
- anova.grade - This function performed the ANOVA test with an independent variable of Answer_Number and the dependent variables of QuarterWeek and Grade. The purpose was to see if there were any interference effects due to the student's final grade in the course.
  - Inputs - The location of the data file in a .csv format.
  - Outputs - The ANOVA summary table and significance rating.
- anova.math - This function performed the ANOVA test with an independent variable of Answer_Number and the dependent variables of QuarterWeek and CurMath. The purpose was to see if there were any interference effects due to whether a student was enrolled in a math course at the time or not.
  - Inputs - The location of the data file in a .csv format.
  - Outputs - The ANOVA summary table and significance rating.
- create.weeks - This function creates a column vector of the week numbers. This function was originally created because the week numbers were not all consecutive. Once all the data was obtained, this changed, but it was already built into my code
  - Inputs - A numerically sorted data set (from within R)
  - Outputs - A column vector of the week numbers
- create.matrix - This function created a matrix of specified dimensions for the plotting function described below. It creates a matrix based on the number of weeks in the semester, the total number of people who took the task per week, and the number of people who got the correct answer per week.
  - Inputs - A data set (from within R)
  - Outputs - A matrix with 4 columns that can be used as the input to the response.plot script
- response.plot - This function created a graph, with error bars, of the input matrix (from above). The function is designed to give the response fraction (fraction of students with the correct answer) as a function of quarter week. The errors bars are generated using binomial statistics, which is an approximation in this case (The students have more than two options in a multiple choice question, but the only possible answers are right or wrong. Thus, it the data is approximately binomial.) This function allows the user to change the shape of the points, the color, add titles, and place multiple graphs together.
  - Inputs - myMatrix -¿ This is from the create.matrix script, myConfint -¿ Confidence level (usually 0.68), myXrange -¿ range on the X axis, xlabel -¿ x axis label, ylabel -¿ y axis label, mytitle -¿ title of the graph, myPoint -¿ shape of the points on the graph (21 - 25), addme -¿ whether to add the current graph to the previous graph (T or F), mycolor -¿ color of the points.
  - Outputs - A response plot of the given data set.
- plot.total - This function combines the scripts above into a single easy to use script that creates a plot.

- Inputs - A file location, a title for the graph, a flag that indicates whether to add this graph to the last graph, and a color.
- Outputs - A response plot of the given color with the given title.

It should be noted that if the location is not provided, the script is set up to open a browser, which allows you to choose the file.

Much like the loading of packages, the scripts must be inputed into R. Typically, I would source in all of my scripts at the beginning, just so I would not forget to do it later. To source in scripts you can either open the folder that they are in and "drag and drop" them into R, or use the command: source("location").

After the packages have been loaded and the scripts have been sourced into R, the program is ready to run the scripts, perform ANOVA analyses and plot graphs.

5 Data Analysis

5.1 Complete Data Analysis

For each question, the data was first sorted by school, and saved as separate .csv files. The RIT data was then sorted by course and week. Since the courses are sequential in the year, the weeks were changed to reflect that. For example, UPI and UPIA were weeks 1-10, UPII and UPIIA were weeks 11-20, and UPIII was weeks 21-30. ANOVA tests were then conducted on the organized data files using the anova.weektest script, testing the correct answer as a function of the quarter week. (This test was actually performed twice, because half of the data was missing the first time). 27/35 of the questions were found to be statistically significant. The 27 significant questions were then graphed. The graphs were divided into sections according to the type instruction at the time (vector or scalar). Table 1 shows how the weeks were divided into sections.

Table 1: This table shows the topics covered per week in the RIT introductory physics sequence. It also labels the type of instruction.

Week	Type	Topic
1, 2	Scalar	Intro Error, 1D Kinematics
3, 4, 5, 6	Vector	Intro to Vectors, 2D Kinematics, Newton's 2nd Law, Newton's 3rd Law
7, 8	Scalar	Energy and Work
9, 10	Vector	Momentum, Gravitationa
11, 12, 13	Vector	Rotation, Dynamics of Rotation, and Equilibrium
14, 15, 16, 17, 18, 19, 20	Scalar	Periodic Motions, Waves, Optics
21, 22, 23	Vector	Electrostatics and Electric Fields
24, 25, 26	Scalar	Electric Potential and Circuits
27, 28, 29, 30	Vector	Magnetic Fields, Inductance

The graphs were then analyzed by section, paying attention to students' performance based on vector/scalar instruction. I was also looking at whether they were close to the chance line (which is .25 for a standard 4-answer multiple choice problem) and if the answers were at the ceiling/floor. The ceiling is around 0.8, which is about as good as it gets. Likewise, the floor is around zero. Both of these options, do not provide any meaningful analysis.

After performing the quarter week analysis, the questions were analyzed according to gender (anova.gender script), final grade in the course (anova.grade script), and co-registration with a math course (anova.math script). ANOVA tests were performed as two variable tests (as a function of quarter week and gender for example). 19/35 were significant by gender, 9/35 were significant by math co-registration, and 24/35 were significant by final grade. The significant questions were then graphed. There were no clear interference effects seen by gender, math, or final grade. In addition, the number of students per data point was too small to provide meaningful results (aka, there were huge error bars).

After performing this analysis, the questions were sorted into two files: scalar questions and vector questions. The combined data was graphed to check for effects. There was no overall pattern, and this is not a valid test given that the questions are statistically different from one another.

5.2 Previous Data Analysis

The data analysis was performed several times due many reasons. The first time the data analysis was performed, I had an incomplete set of data. With the incomplete set of data, an ANOVA analysis was run as a function of the scalar/vector type and whether it was pre, during, or post instruction. The results did not provide any other conclusions and was largely inaccurate. The data analysis was performed again with all of the data, however, I had initially neglected to treat the independent and dependent variables as factors. This meant that the program was treating the answer types of 0 and 1 as numerically important, rather than indicators for right and wrong answers. This significantly changed the results found. These analyses are not included in the dropbox due to their highly inaccurate nature.

6 Conclusion

Having performed the data analysis, it was concluded that there is no correlation between vector/scalar instruction and students' ability to answer related questions. The graphs produced while significant, were not significant with respect to type of instruction. In most of the graphs a "Hey, they learned something" curve was obvious, but that was the only effect seen. There was a lot of noise in the first set of data; however, this was mostly resolved with the second set of data, which had significantly more data. It can also be concluded that neither gender, final grade in the course, nor co-registration with a math course has an effect on how students answer a vector problem versus a scalar problem.

7 Designing New Tasks

Given the lack of results that were found, my project has also included designing new questions for 5 of the RAWR tasks: electrostatics task, fields and potential task, magnetism task, gravitational potential task, and the vector task. About 20 questions were written for each of these tasks, designed to be more comprehesive in material and hopefully reveal more about what the students know. They were designed to be longer than the previous tasks, now taking 5-10 minutes for the students to complete rather than 2-3 min.

I pulled some problems from a variety of books, listed below; some were taken from the Physics 1 and Physics 2 studios and homework problems from Colorado School of Mines; and some I created based on my experience as a TA and what I have noticed students struggle with.

The questions were validated using 11 REU students, graduate students, and faculty members. The questions were scored, and comments marked onto a single copy of the test. Those questions that 4 or more people missed were seriously considered, and most of them removed. Dr. Sayre and I went over every question in detail, removing ambiguities, and taking out questions that were too difficult. A few questions were added to replace good concepts but bad questions.

The resources I used in creating the questions are:

- Magnetism Tools for Learning and Assessment: TIPERs. Curtis j. Hieggelke, Tom O'Kuma, and David Maloney
- Peer Instruction for Astronomy. Paul J. Green
- Tutorials in Introductory Physics: Homework. Lillian C. McDermott, Peter S. Shaffer and the Physics Education Group. Department of Physics, University of Washington.
- Tutorials in Introductory Physics. Lillian C. McDermott, Peter S. Shaffer and the Physics Education Group. Department of Physics, University of Washington.
- Tutorials in Introductory Physics: Instructor's Guide. Lillian C. McDermott, Peter S. Shaffer and the Physics Education Group. Department of Physics, University of Washington.

8 Still to be Done

There were several sections of the test that needed further development, but I have ran out of time. First, a few questions were designed to test whether students knew where to start on a problem (i.e. what equation to begin with). This were thrown out because several different answers were possible. The idea of testing how students pick equations is good, but it needs a different approach. Second, there needs to be more work done on how to test students on Lenz's Law and induced current. The questions written were confusing to produce straight answers, but problems that involved Lenz's Law would be a good addition to the magnetism task.