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ABSTRACT

To provide practice in making design decisions, collecting and analyzing data, and writing and documenting results, a professor of statistics has his graduate students in statistics and research methodology classes design and perform an experiment on the effects of fertilizers on the growth of radishes. This project has been required of students in a graduate-level class in statistics and design in each of the last three times the professor has taught the course. Students in the class are typically working toward advanced degrees in education or nursing, and many have weak backgrounds in science. An informal evaluation based on 7 written comments from student course evaluations and 32 student reports indicates that students learn from the project and meet at least the minimal expectations, although only a few go beyond the minimal statistical requirements. Several changes are planned to enhance the project as a teaching tool. Two tables present procedural details and the frequency of design and treatment decision. (SLD)

Return to Our Roots: Raising Radishes to Teach Experimental Design

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Running Head: RETURN TO OUR ROOTS

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Abstract

Students design and perform an experiment on the effects of fertilizers on the growth of radish seedlings for a graduate class in design and statistics.
The goal of this project is to provide students practice in making design decisions, in collecting and analyzing real data, and in writing up results. An informal evaluation, based on written comments and a content analysis of the individual reports, suggests that this approach is a promising technique for teaching experimental design.

Return to Our Roots: Raising Radishes to Teach Experimental Design

Over the past three decades alternative ways of teaching applied statistics have been described in such journals as the American Statistician (e.g., Hogg, 1972; Tanner, 1985), Chance (Joiner, 1988), Teaching of Psychology (Hettich, 1974) and the Journal of the Royal Statistical Society Series A (Jowett & Davies, 1960). In this literature a recurring theme is to have students work with data. For example, Singer and Willett (1990, p. 223) argue that "real data sets provide a more meaningful and effective vehicle for the teaching of applied statistics" [than do synthetic data, no matter their numerical tractability]. Perhaps ideally, students should pursue their own research interests, collecting data from studies they designed and executed (see Jowett & Davies, 1960; Tanner, 1985).

Some who teach psychological and educational statistics are concerned for students who can do the assigned computational exercises but do not understand the purpose of the computation. For example, one of my students correctly computed a two-way analysis of variance (ANOVA), but could not distinguish between the number of levels in a factor and the number of independent variables. This incident illustrates the limitations of textbook exercises.

Although students could replicate classic experiments or design and complete simple studies of their own, both options are time consuming. In addition, one now has to comply with institutional guidelines for human subjects. Fortunately, many of these problems can be avoided. Students can work with real data by conducting simple agricultural experiments, what I call "returning to our roots." After all, as Lovie (1979, p. 151) noted, "the first practical application of analysis of variance (ANOVA) was on the effects of manure on the rotation of potato crops (Fisher & Mackenzie, 1923)."

The last three times I have taught our second course in statistics, an ANOVA-based course using Keppel (1991), I have required each student to collect and analyze data from a gardening experiment. Students assess the effect of growth accelerators on radish seedlings that they grow at their homes.

Typically, students enrolled in our second statistics course are working toward advanced degrees or certification in education or nursing; they tend to be mature, employed, and female. Our students live off campus. Except for the nurses, our students tend to have weak science backgrounds and minimal mathematical preparations.

Equipment

The inexpensive equipment consists of plastic ice cube trays or egg cartons, potting soil, fine gravel, mechanical drawing dividers (for measuring the heights of the seedlings), a ruler, radish seeds (or any other fast germinating vegetable seeds), several jars with lids, and one or more growth accelerators (e.g., Miraclegro or RA-PID GRO).

Procedure

Instructions for the procedure and analysis are given in Table 1.

Insert Table 1 about here

Students decide whether to compare different growth accelerators (qualitatively different levels) or different amounts of the same growth accelerator (quantitatively different levels). Other issues each student considers are those of experimental mortality, unequal *n*s, unit of analysis, number of comparison groups, and choice of the dependent variable. Most students use seedling height but germination rate and length of tap root are possible also.

Students have reported that seeds germinate in 3-5 days. Most students have been able to obtain usable measurements at 5-to-7 day intervals. I allow several days for students to gather the apparatus and set up the experiment. Two weeks has been a sufficient time for analysis and write up. Hence, students can complete the project within 5-6 weeks.

As an illustration of a typical student project, one student grew three sets of 10 seedlings each with treatments of water plus zero, two, or four drops of accelerator. After four weeks the mean growths were 1.50, 2.74, and 2.96 inches, respectively. A completely randomized ANOVA on these data yielded $F(2,27) = 7.41$, $p < .01$. To obtain equal ns, not a requirement of the completely randomized design but helpful in other analyses, students often have thinned seedlings immediately after germination.

Evaluation

Anecdotal evidence of students' positive reactions to the radish project comes from seven written comments appended to project reports and course evaluations. Examples include:

"The radish experiment . . . seemed to tie up many of the principles and techniques we learned in class."

"My classmates seemed unanimously enthusiastic about the project."

"The concept of experimental learning is an excellent one and very useful in helping students to grasp abstract concepts such as ANOVA. The requirements . . . were not too costly or time-consuming."

To further evaluate this project I did a content analysis of 31 student reports. I examined the various statistical and design features that either were used or could have been used, and I judged whether the use or non use was appropriate. For example, a post hoc analysis of trend following an insignificant omnibus F was judged an inappropriate application. And a failure to follow up a significant omnibus F with a post hoc test was judged an inappropriate non application. By contrast, not following up an insignificant omnibus F was considered appropriate non application. The content analysis is summarized in Table 2.

Insert Table 2 about here

The data suggest that, overall, students made appropriate decisions. However, post hoc analyses, whether of means or trends were troublesome. Graphing also appears to have been a problem. Perhaps this may be attributed to weak science and mathmatics backgrounds. Only seven students went beyond the minimal statistical requirements. Given Keppel's (1991) emphasis on planned comparisons, it is disturbing that only two students even attempted an a priori test. None considered low power due to small sample size as an explanation for not obtaining statistical significance. Four students reported problems with experimental control (e.g., "the cat walked on the trays"). Still, most met the minimal expectations.

Conclusion

Overall, I have been satisfied with the results of the radish project. However, several changes are planned: provide a more detailed handout of instructions (including suggested schedules); encourage and reward use of more complex designs, associated ancillary tests, and tests of model assumptions; and append a project evaluation to the anonymous course/ instructor evaluation.

Nonetheless, all of my students have been able to carry out this project within an 11-week academic quarter. Informally, nearly all agreed that the project made vivid the otherwise disembodied concepts of experimental design and ANOVA. Some, in class discussion, reported that the project was "fun" and even a topic of family conversation. In my experience having students analyze real data from experiments they designed and conducted is a successful teaching technique.

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Table 1

Instructions for Project: Procedure and Analysis

Procedure

1. Prepare three trays or egg cartons. To facilitate drainage, punch small holes in the bottom of each ice cube mold or receptacle; then add gravel. Fill with potting soil.

2. In each mold or receptacle plant 3 to 4 seeds about 1/4 in. deep. Soaking seeds in water for 15 minutes prior to planting promotes germination.

3. Use the jars to mix and store the various concentrations or brands of growth accelerators.

4. Administer the treatment, either different types of growth accelerators or different concentrations of the same growth accelerator (e.g., zero drops, one drop, and two drops).

5. Except for the application of the experimental treatment, treat all containers alike.

6. After germination (3-5 days), make three sets of measurements at equally spaced intervals (5-7 days).

Table 1 continued

Analysis

1. Write up your report in a fashion similar to writing up the method, results, and discussion sections of a journal article.

2. Under Results, present the outcomes in words, graphs or tables, and statistics (both descriptive and inferential). For each data gathering period construct a graph showing the mean height of the seedlings plotted against levels of the independent variable.

3. For the final data gathering period compute a completely randomized ANOVA, Omega Squared, and (if you find statistical significance) Scheffé and other post hoc comparisons. If your experiment involved quantitatively different levels and if you obtained statistical significance, analyze the data for trend.

4. Optional analyses (beyond minimal expectations) could include computing a repeated measures design, making a priori comparisons, and estimating post hoc power.

Table 2

Frequency of Design and Statistical Treatment Decisions

	Appropriate		Inappropriate	
Topic	Application	Nonapplication	Application	Nonapplication
Design Selection	29		2	
Post Hoc Comparisons	15	8	6	2
Effect Size/ Omega Squared	23			8
Trend Analysis	12	11	3	5
Interpretation of Significance	29		2	
Graphs	22		2	7

[a] Thirty-one student reports were analysed. Each report is listed only once in each row but may appear more than once in each column.