Statistical Games to support problem-based learning

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Abstract

With a problem-based approach it is important to have examples that illustrate or simulate the normal research process. The statistical games assist by allowing students to design, conduct and analyse simulated experiments or surveys, within the time constraints of usual practical periods. The simulations are each also engineered to emphasise particular aspects of design and analysis.

In their current form, the four games (two surveys and two experiments) described have stood the test of time. Recent work has updated both the games themselves and the associated training materials so these ideas may easily be used in both University teaching and in specialised training courses, particularly for staff involved in agricultural research.

Ways the games can be further extended, given the advances in computing, are also described.

History

The department of Applied Statistics at Reading University introduced a series of statistical "games" in the early 1970's and a series of publications described their use, e.g. Mead and Stern (1973), Pike (1974). Although called "games" they were effectively simulations of scenarios for designed experiments or sample surveys.

They were designed to complement, not replace, exercises where students conduct a real experiment or survey. Their advantage was that they could typically be "played" within the time constraints of a 2-hour practical session. They typically were a simulation of the full process of designing a study, collecting the data, data entry, analysis and then writing a report. Sometimes only the design and data collection were within a practical session, with later work needed for the analysis and reporting.

Most of the early games were "hand exercises". Students were shown the whole "population" and then collected a sample of data from cards, or slips of paper in envelopes that they chose. They then input their data and used the computer for the analysis. Some of the games were computerised in the 1990s, so the students collected the data from the computer, in a form that was then ready for analysis using a spreadsheet or statistical package. These versions were described by Barahona (1997) and Kurji and Stern (2004).

However, the hand versions continued to be use, often in preference to the computerised versions for data collections. More recently the computerised versions, prepared for early versions of Microsoft Windows, are now difficult to run.

Work in 2009 has been to make it easy to generate hand versions of the four games described here and to provide a spreadsheet version of one of the games.

The games

To the Woods

The aim is to conduct a small survey to estimate the total number of trees in a forest and the proportion of large trees. A tree is considered large if its diameter at breast height is greater than 30cm.

The area of forest from which the sample is to be taken is divided into two regions (East and West) by a river. Within each region it is possible to count the number of trees in any 50m × 50m plot. There are 168 plots in total - 96 to the West of the river and 72 to the East.

There are two alternative sampling solutions. Students take a sample of 14 plots and can either use simple random sampling or stratified sampling to choose them. They record the number of small trees, the number of large trees and the total number of trees for each of the 14 observations.

The printed version of the game consists 168 small pieces of card, which represent the plots, slipped into slits in a large piece of card, which represents the forest. A river can be drawn on the large piece of card to divide the forest into two regions. One side is labelled West and the other labelled East. The protruding sections of the plots are labelled with their region side (West or East) and plot number (1 to 96 and 1 to 72, respectively). The student pulls out the chosen plots and records the numbers of large and small trees, which is printed on the lower section of the plot.

Students can work in pairs or small groups to compare the two methods of sampling. The results can then be collected together and discussed with the class as a whole.

Students use their data to calculate the estimates and the standard error of the estimate of the total number of trees in the forest. Consequently, they can see the value of the stratified sample in reducing the standard errors. Students can also think about sample size by calculating the number of plots required, using a simple random sample, in order to obtain the same precision as the 14 observations from the stratified sample.

A further challenge is to discuss how knowledge about the split of data into the east and west side of the river can be applied (post-stratification), to improve the estimates derived from data using a simple random sample.

Paddy

This game is a rice survey based on an actual survey carried out in Sri Lanka. In a small district there are 10 villages with a total of 160 farmers who each have one field in which to grow rice. A census of the area has been undertaken and the acreage cultivated by each farmer is known. There is now to be a crop cutting survey whose main aim is to estimate the mean yield of rice per acre and hence the total production of rice in the district. The survey will also be used to investigate the use of fertilisers and the different varieties of rice used in the district.

The resources available are assumed to allow for up to about 30 plots to be sampled. Students use a multistage sampling scheme. For example:

1. Select x villages
2. From each village choose y fields
3. Select z plots from each field

The Printed version of the game consists of 10 boxes each containing a number of envelopes, which themselves contain a number of slips of paper. The boxes represent a village, so students select the boxes corresponding to their chosen villages. They open the boxes and select the envelopes labelled with their chosen field number. Information on the size of the field, the variety of rice used and the amount of fertilizer applied is also displayed on the envelope label. Finally, they select one or more slips of paper and record the yield from each.

Students must decide how many villages to include and how to sample the villages. Sampling villages is usually either:

- equally likely: choose random numbers between 1 and 10
- with probability proportional to size, with size either the number of farmers, or the area of each village:.

The number of fields selected, within each village, can either be the same in each village or proportional to the size of the village. The fields selected are either a simple random sample or will be selected with probability proportional to their acreage. The number of plots sampled is likely to be 1 or 2 per field.

The first part of the analysis is to estimate the total production of rice in the district, together with its standard error. The second part of the analysis is a study of the relationships between the yields of the farmers and their inputs. Students could prepare a few tables, and/or fit a linear model to the data.

Mice

Mice is a simple experiment designed to test the effects of two drugs, A and B, and a placebo, C, on the lymphocyte counts in mice. There are six litters of mice.

The students can choose one of two designs:

Design 1: The litters from which the mice come are ignored and 15 mice are chosen at random. The litter number is recorded for each mouse. Five mice receive each treatment.

Design 2: It is assumed that mice from the same litter are more homogeneous in their responses than mice from different litters and this is taken into account when designing the experiment. Four litters are selected and then 3 mice from each litter chosen, which results in a total of 12 mice being used. From each litter one mouse, selected at random, receives each treatment.

The printed version of the game consists of two boxes, each containing a set of cards. One box is for design 1 and the other for design 2. The first box is divided into 3 sections, one for each treatment. Students randomly pick five cards from each section and record the treatment, litter and lymphocyte count. The cards in the second box are broken down into litters and treatments, so there are 6 x 3 = 18 sections. Students randomly choose 4 litters and then randomly pick one card from each treatment and record the treatment, litter and lymphocyte count.

Students create a table of means and fit a linear model to the data. The model for design 1 does not take litter effect into account. The model for design 2 does take litter effect for account. A further challenge is to consider the effect of post-hoc blocking for design 1. This game demonstrates that a lack of blocking can hide a treatment effect and decrease the precision of the treatment means. It also shows how adjusted treatment means are required when the design is unbalanced.

Tomato

Tomato simulates an experiment to test the effect of a number of factors on the yield of tomatoes grown in a greenhouse. Students simulate the conduct of an experiment starting from the discussion of the appropriate design up to the conclusions.

There are three factors (variety, heat, light), each at two levels (Coward/Doger, Standard/Supplementary, Standard/Supplementary). Students have to allocate the 8 treatments to the 12 plots in the greenhouse. They are asked to take account of the different sides (North/South) of the greenhouse when allocating the treatments, which introduces a blocking factor. A second blocking factor, year, has also been built into the model; the experiment can be designed over 2 years, resulting in two seasons of the crop. The player can decide which treatments to apply in the first year and use the results to determine which treatments to apply in the second year. Alternatively, they may choose to design the scheme for both years, at the same time. This means that the game incorporates blocking and the possibility of using unbalanced designs. It also introduces the factorial structure of the treatments.

The first objective is for the students to recommend the combinations of the three factors of light, heat and variety that maximises the yield. The second objective is for the students to recommend the strategy of growing tomatoes taking into account of cost of the different treatments. In this case, the aim is to maximise profit.

The printed version of the game consists of 24 boxes, each containing 8 envelopes, which themselves contain 20 slips of paper. Of the 24 boxes, 12 represent the plots in year 1 and the other 12 represent the plots in year 2. Each box contains 1 envelope for each treatment, resulting in 8 envelopes. Each envelope contains 20 simulated yields. Players open each box and pick out the envelope corresponding to their chosen treatment. They randomly select 1 slip of paper from each envelope and record the yield displayed.

Use of the games

Recent use of the games includes sessions within short courses at Maseno University (Kenya) and the John Innes Centre (UK). In Kenya the audience was MSc statistics students, for whom the computing resources were very limited. In the UK the students were staff or PhD students with excellent computing resources, in for whom statistics is a service course.

In both cases we chose to use the hand versions of the two experimental games, Mice, and Tomato, described above – with the students using their computers for data entry and analysis. The use of these resources was very well received, both when playing the games and in subsequent feedback.

Thus these games are potentially useful for a wide audience. When used for service teaching, scientists can relate the experimental process or survey methods to their own work and hence see how the statistics can help them. For applied statistic students the exposure to standard scientific procedure helps them to understand their role. The difference in how they are used for different groups often comes from how they are integrated into the teaching and what is expected from students in the design and analysis.

The Maseno students really benefitted from doing their own experiments and then reflecting on what role they should be able to play as statisticians. They really got a lot from the tomato game which was used in multiple practical session, to illustrate various concepts. Their reports and presentations, each pair with their own tomato data, was part of their continuous assessment and an exam question also used data generated from the same game.

The John Innes course was not formally assessed. What was particularly appreciated by the students was that the Tomato game was sufficiently "rich" that successive lectures and discussions, were able to return to different aspects of the design and analysis problem.

Part of the motivation for updating the games is the research support needed for the 25 RUFORUM Universities (see www.ruforum.org). One of the courses they are supporting is a new-style MSc in agricultural research support. This will start at JKUAT (Kenya) in late 2009, and these games are expected to be included in the teaching as part of the problem-based learning approach used in this course.

Conclusions

These relatively simple games have stood the test of time. Most teaching of statistics has been transformed by the computer. In contrast the hand versions of the games, have come into their own with the ease of use of the computer for data entry and for interactive and iterative analysis.

Future plans include updating the computer versions of the games, particularly for Paddy (rice sampling) where the data collection is relatively large, and hence the data entry is relatively time consuming.

We also plan to use the games within Maseno's undergraduate teaching and for service courses for agriculture PhD students and staff in the other RUFORUM Universities.

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