Virtual Experiments and their Role in Teaching Design and Analysis of Experiments

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1. Introduction

The ability to design experiments in an appropriate and efficient way is an important skill, but students typically have little opportunity to get experience. Most textbooks introduce standard general-purpose designs, and then proceed with the analysis of data already collected. Some recent textbooks (e.g. Cobb 2002, Dean and Voss 1998) stress the importance of including projects in which the students actually have to prepare, perform and analyze a real experiment. Such projects provide an invaluable experience, but are very time and resource consuming, for the student as well as for the teacher. In this paper we explore an additional tool for gaining design experience: computer based virtual experiments.

What we call “virtual experiments” are software environments, which mimic a real situation of interest, and invite the user to collect data to answer a research question. The data are generated by an underlying realistic stochastic model, invisible to the user. Once the data are collected, they can be transferred to a standard statistical package. The user can train his/her design skills by relating the quality of the statistical results obtained to the data collection strategy used.

A number of such environments have been implemented. The collection is called VIRTEX (VIRTual EXperiments), and is a companion to the VESTAC collection, previously developed for other statistical purposes (Darius et al. 2000). The environments are all realized in the form of JAVA applets, and are freely available on the web at http://www.kuleuven.ac.be/ucs/virtex/ . They can be run on any computer with a web browser that supports JAVA (the vaccine applet needs the SUN virtual machine). Due to the safety requirements of applets, they cannot read or write data from or to the user’s hard disk. Yet data can be exchanged with other programs through cut and paste.

2. Sampling Applets

The first applet introduces simple sampling problems. The user sees a window, showing part of a large (50x100) array of candies with different colors. The purpose is to get an idea of the percentage of candies that are colored red (fig 1).

When the user moves the mouse over a candy, its coordinates appear. With a left click, a candy is selected and the counters for the number of candies selected and the number of red candies are incremented.

Since there are so many candies, simply counting the number of reds is not an option. The user will have to use some form of sampling. Hence he/she will have to decide on a sample size and a sampling scheme (e.g. random or stratified sampling), but will discover that each of those requires careful planning before it becomes operational.

In the first version, patches are clearly visible where one color occurs more frequently. In the second version, the candies are wrapped in black and the color of a candy is only revealed after it has been included in the sample.

The second applet represents an environmental sampling problem. The user sees an aerial photograph of a section of a railway track (fig 1). It is explained that for many years a diesel train uses this place to take a halt. Hence diesel pollution of the site is suspected, and should be investigated.

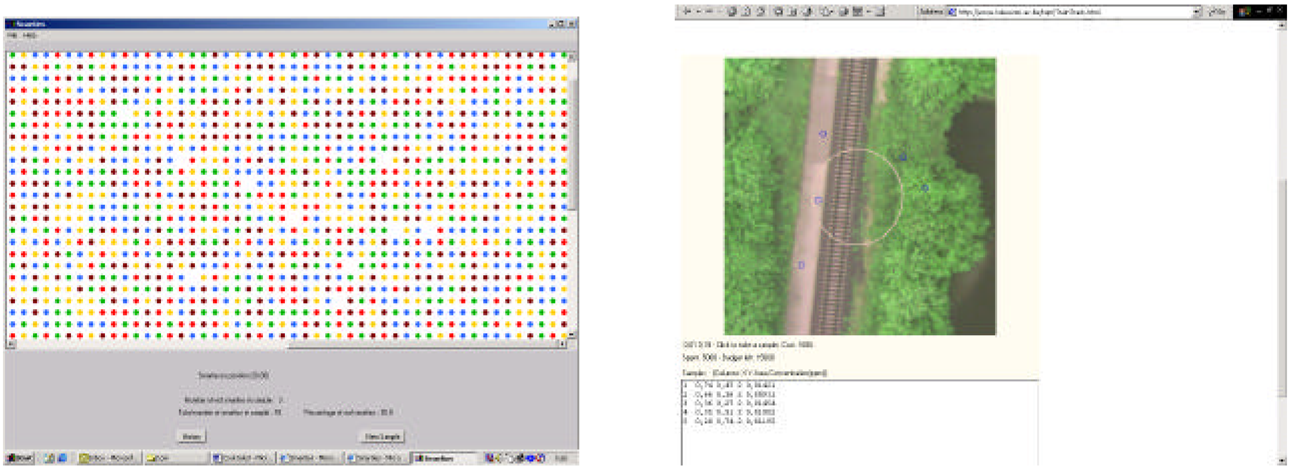

Fig 1. The candy applet (left) and the environmental sampling applet (right).

The user is invited to take a set of soil samples (by clicking the mouse on the selected spot). Since there is a limited budget and analysis is expensive, at most 20 samples can be taken. The results of the analyses are shown in a separate window, from where they can be cut and pasted into e.g. a spreadsheet or a statistical package.

Again the user is confronted with a sampling problem, but now simple random sampling will not work. The user will have to set up a sampling strategy that takes the context (the layout of the site, the fact that part of it is covered by water and hence cannot be sampled,..) into account.

3. The Factory Applet

In the factory applet, the user has to experiment with a pilot plant in order to find optimized settings for the parameters of a production process. The experiment runs in "real" time: the user has 39 "weeks" (one "week" is about 3 minutes of real time) to complete the experiment. Each experimental run takes a number of "days" before the results are visible.

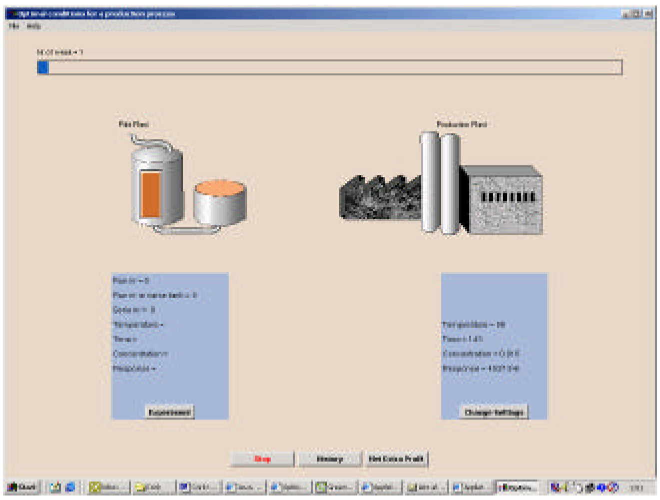

Fig 2. The factory applet.

The production plant appears at the right hand side. The current settings for the parameters temperature, time and concentration are shown, as well as the current mean yield per batch. The left hand side shows the pilot plant. This is a scaled down version of the production process with (hopefully) similar characteristics. The raw material for the pilot plant is stored in a tank, which can contain enough material for 10 trials. When the tank is empty (or upon request of the user) it will be refilled, but the new raw material may have slightly different characteristics.

The user can set up an experiment by opening a separate window and filling in the parameter settings for any number of runs (as well as instructions for handling the tank), or by using an external package to generate a design and pasting it in. After waiting an appropriate amount of "time", the results become available in the "History" window. This also shows the results of all previous experiments. Data from this window can be copied and pasted into an external program for statistical analysis.

The user now has to decide whether sufficiently promising new parameter settings have been found. If so, the production plant can be halted and the new parameter settings installed. The resulting new average yield becomes available after 6 "weeks".

The "Profit" window gives an overview of the current situation of costs (initial costs, cost per run of the pilot plant, costs for changing settings of the production plant,...) and benefits (increased production). At the end of the 39 weeks, the balance should be positive and as large as possible.

This applet allows the user to get some hands on experience with several important concepts. All types of designs discussed in Response Surface Methodology courses can be tried out. The tank-to-tank variability has to be dealt with. Moreover the user is confronted with at least two other problems: when to change the production plant settings, and how to choose between one large experiment or many small experiments.

4. The Greenhouse Applet

The greenhouse applet requires the user to set up an experiment with (tomato) plants in a greenhouse. To succeed, the user has to deal with the problem of selecting appropriate levels for a treatment variable, and with the many problems caused by diversity in raw material and experimental circumstances.

The purpose of the experiment is to find the optimal dose of a new fertilizer. At the start, a set of 144 young tomato plants is available (12 trays of 3x4 plants) (Fig. 3). The young plants are not all the same: the initial weight is shown on the screen. The user has to select plants for the experiment and place them on the greenhouse tablet in the middle. The tablet is bordered on the left and the right with central heating devices (the thick black vertical lines). The tablet is also lighted by four special light bulbs. The resulting pattern can be seen on the screen. Consequently the positions on the tablet are not identical, and the differences in light and heat can be expected to affect the growth.

The user also has to decide which plant gets which amount of fertilizer. Defining and selecting doses, and applying doses to plants is done with simple mouse operations. To account for the difference in locations and initial weights, "grouping" factors can be defined. This is done on the left side of the screen.

When the plants have been properly placed, the user should select the time period for the plants to grow with the buttons at the bottom. When the "Grow" button is hit, the growth of each plant is simulated on an hour-to-hour basis, and the final weight (along with all the other variables) is available in a window. The growth simulation uses an adapted version of TOMGRO, a well-known growth model for tomatoes (Jones et al. 1991), as well as standard climatic data.

This applet allows the user to get comparative experience with almost all classical designs: completely randomized, complete or incomplete block, Latin Square, etc. There is also ample opportunity to invent and use new setups, made to accommodate the specific features of the greenhouse situation.

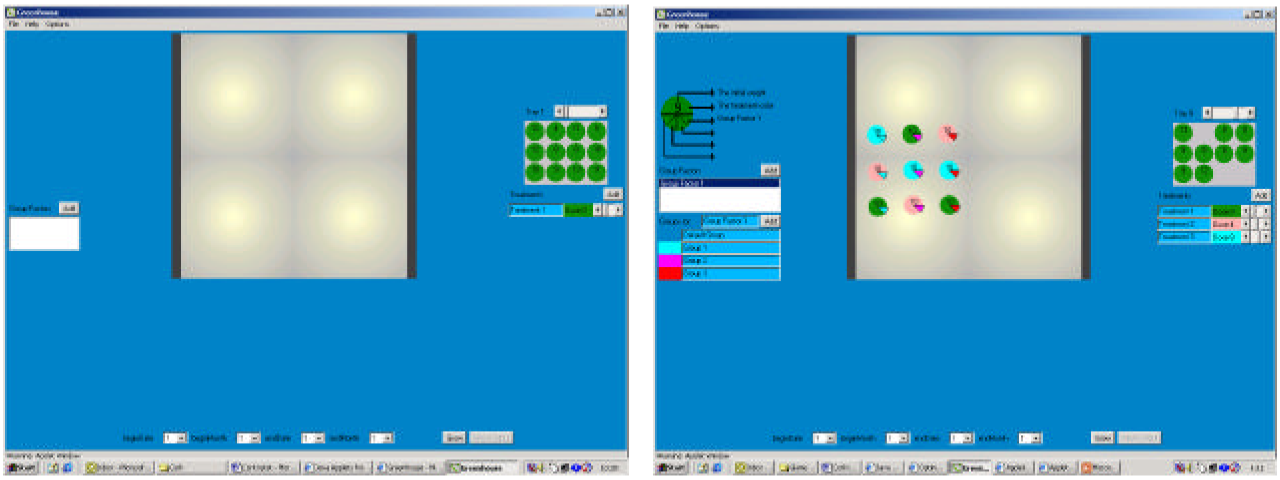

Fig 3. The greenhouse applet: initial view (left) and with a simple experimental setup (right)

5. The Vaccine Trial

The effect of a vaccine for E. coli mastitis (udder infection) needs to be assessed by comparing the reduction in milk production in vaccinated and control dairy cows 48 hours after challenge with either a low or a high E. coli inoculum dose. The user has to select, from the available set of farms, which animals will participate and which challenge dose they will be given. Both factors inherent to the animal (e.g. parity) and environmental factors (linked to the farm) have an impact on the overall reduction and the vaccine effect.

The objective of this applet is to demonstrate two important aspects of experimental design: randomisation is essential for valid conclusions, especially as random variability due to environmental factors is substantial. Second, efficient designs enable the investigator to explain part of the random variability and reduce error variability leading to more powerful testing. Randomized complete block designs, Latin Squares, split plots and blocked split plots can be generated in this experimental setup.

6. Conclusions

The applets show that current computer technology allows the creation of special purpose, accessible and rich environments that have, in the area of data collection and analysis, the potential to give learning experiences well beyond those of traditional textbook exercises.

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RÉSUMÉ

On décrit VIRTEX, une collection de logiciels de simulation disponibles au world wide web. Chaque logiciel évoque une situation réelle et d’une importance pratique. L’étudiant est invité à collectionner des données de telle façon qu’elles sont utiles à répondre à une question de recherche. Les données contiennent du bruit et sont générées par un modèle sophistiqué mais invisible à l’utilisateur. Une fois collectionnées, les données peuvent être transférées à un logiciel d’analyse statistique. L’étudiant peut entraîner ses capacités de collection de données en comparant ses résultats d’analyse à la stratégie de collection employée.