Life on an Island: a Simulated Population to Support Student Projects in Statistics

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Abstract

It is important for students learning statistical reasoning to see data in context. One of the best ways of achieving this is to involve students in data production and so in the past ten years we have had first-year students undertake real experiments of their own choosing as part of our introductory statistics course. However in practice students are limited in what they can do. Many want to conduct experiments involving human subjects, requiring ethics approval, while even those not wanting to use humans may have general health and safety issues. Epidemiological studies have really not been possible at all.

We present an open-ended virtual environment, the *Island*, to help overcome these limitations while still engaging students with study design and data collection. Students work with a population of virtual humans living on the Island and are able to conduct a wide variety of experiments with them as subjects. The Islanders also live in villages, have ancestors and die from a range of diseases, allowing students to study the epidemiology of the island as well. In this paper we will give an overview of this Island and its design, highlighting some of the features and the issues, and sharing our experiences of using the Island in teaching and learning.

1. Introduction

Project work in a statistics class is a valuable tool for giving students a context to the data they are using and a motivation for learning statistical reasoning (Mackisack 1994; MacGillivray 1998; Forster and MacGillivray 2010). Projects also give the students an appreciation of the practical issues involved in carrying out experiments and collecting data, an outcome encouraged by Higgins (1999). However there are also practical issues in implementing student projects in a curriculum, particular in large classes. For example, our biomedical students are very keen to use friends and family as subjects in their statistics experiments, raising ethical concerns, while other students want to use equipment and resources that are beyond the scope of an introductory statistics course. The result has been that the students often end up doing simplistic experiments which may actually reinforce a trivial view of the role of data analysis in science.

An alternative to real experiments is to have students collect data in a virtual environment (Wild 2007). Such environments are particularly useful in helping students understand issues in experimental design by giving them more complex settings than they would have access to in a real experiment, as in the industrial process and greenhouse simulations of Darius *et al.* (2007) or the virtual vaccination trial of Duchateau *et al.* (2010).

In this paper we present an online environment, the *Island*, where students can conduct studies involving virtual human subjects. Again the first aim of the environment is to engage the students in thinking about the design of the experiment given a statistical question of interest. The second aim is to provide them with data from their design that they can then use in learning statistical methodology.

The Island involves two main simulations running at different timescales. In Section 2 we give an overview of the historical simulation that forms the basis of the Island population while in Section 3 we describe the simulation that runs in the present to allow students to conduct experimental studies. In both sections we will outline the design of the corresponding simulations and their role in supporting learning. We emphasize this in Section 4 with four examples of student engagement with the Island.

1.1. Visit the Island

The Island is located at `http://island.maths.uq.edu.au` and we invite the reader to interact with the virtual environment in conjunction with this paper. A login is required and can be obtained by contacting `mailto:island@maths.uq.edu.au`.

2. Population

An initial motivation for this system was the need for a virtual environment where students could collect data for addressing questions in epidemiology. While it is easy to generate some simulated data for a randomized clinical trial, for example, our belief is that thinking about issues in epidemiology requires access to a population that can be studied more deeply. Important requirements include the ability to consider the ancestors of particular individuals, to determine whether diseases have a genetic component, and to explore geographic relationships between individuals in order to look for infective characteristics. For these reasons our aim was to simulate a population over time in a spatial context.

2.1. Birth and Death

The initial state of the simulation consisted of 108 randomly generated individuals, the survivors of a fictional shipwreck in 1779. These individuals represented seven different cultural groups but were otherwise genetically unrelated.

The population simulation has a monthly time step and models a fairly straightforward birth-death process. In each month the following events could occur:

1. Each Islander has a chance of developing one or more diseases. Risk is based on genetic and environmental factors, depending on the disease, and includes various infectious

diseases that spread through contact. More detail on Islander genetics is given in Section 4.3 while Section 2.2 describes the geographic structure that was the basis for modelling infections.

2. Based on their disease state, the Islanders then have a monthly chance of dying. Once dead they no longer participate in the simulation but their stories, including cause of death, are available for study.

3. Once they reach a certain age the single Islanders have a chance to try finding a partner. Female Islanders in a relationship then have a chance of becoming pregnant with probability depending on genetic factors, age and the existing number of children. Once pregnant a new Islander is then born around 8 or 9 steps later in the simulation.

4. Islanders can also migrate to different villages, typically because they have reached the age to leave home and/or move in with a partner.

We ran this simulation for various seeds to find an outcome population that was reasonably large after 240 years but that also had suffered some major epidemics. The result is a current population of 15,674 Islanders in the environment that consists of 6,401 who have died and 9,273 who are still alive.

2.2. Structure

The Islanders live in 39 villages that range in population from just 26 (in Melville Cove) to 2,292 (in Macondo) and provide environmental effects in the simulation of the Islanders. Figure 1 shows samples of the Islander images that are included in the interface, created using the approach discussed in Bulmer and Engstrom (2005). The Island map and other features of the interface can be seen online using the link in Section 1.1.

Within each village the Islanders then live within houses. Many live in families while others live as couples or alone. Again there are environmental effects tied to houses, such as an increased chance of taking up smoking if other people in the house already smoke. The location of the house is also important since various diseases are linked to particular parts of the Island and transmissible diseases are spread based on distance between individuals.

Sampling an Islander at random is deliberately a difficult task. Each village does have a hall with records of births, deaths and marriages but Islanders do move around during their lives. To choose an Islander from the interface as a subject for a study the student needs to select their village and then select their house and then select the individual within the house. With variable numbers of houses and individuals in each of these layers the naive solution for choosing a 'random' sample will likely be biased.

The design of the Island simulation is that it should run in real time. We continue the historical simulation, updating the population at the start of each month. In this way the underlying environment changes slowly over time with some Islanders dying and new ones being born. In December 2010 the Islanders even settled a new village (Naoki Falls) that previously had not existed in the simulation.

Figure 1: Sample Islander images - Ian Lopez and Summer Quinn

2.3. Reality versus Fantasy

There is a fundamental tension in our design. We want the simulation to be realistic since we believe that will help students engage with the virtual environment. However there is a point at which realism becomes counterproductive towards our aims of engaging students in the role of statistical reasoning in scientific inquiry. For example, suppose we included a cause of death called *Lung Cancer* and made it so that Islanders with higher smoking levels were more likely to die from this disease. Students could collect data on smoking history and cause of death and look for this relationship but if they found an association it would probably not be surprising or interesting to them since it is the outcome they expect. They will not have discovered anything new by conducting their study.

Instead of using real names for diseases we have thus tried to use poetic names wherever possible. These include *Summer's Pain* (named for Summer Quinn, the first person on the Island to die of that condition, and also shown in Figure 1), *Diego's Cough*, *Ruin* and *Jungle Sickness*. One of these four is indeed modelled on lung cancer, including the association with smoking history, but now it is a more open question for students to explore. For example, what data do you need to collect to distinguish between these conditions and how can you convince somebody that you have identified 'lung cancer' on the Island?

3. Experimental Studies

The virtual population described so far can be viewed as a framework for adding further simulations. The histories and images of the population give a broad context for experimental investigation. Returning to the original aim of this paper, we can thus enable students to obtain the various benefits of project work by adding the kinds of tasks which would provide the appropriate data to help learn statistical thinking.

We have used this environment with an introductory statistics course for science students with around 1,200 students per year. They are asked to complete an experimental project to "demonstrate your understanding of the statistical methodology you have learned in the course". One particular advantage of the online environment is that students can conduct their experimental work quite quickly towards the end of the semester. This means that they can have a clear statistical method in mind rather than the all too common practice of just collecting data without any plan of how to analyze it. Section 4 will show some examples of student work but we begin in this section with an overview of the design and mechanics of the experimental environment.

3.1. Collaborative Design

A key feature of this innovation has been the involvement of students in its creation. From the outset we planned a two-phase curriculum design process for developing and using the Island in experimental projects. The first phase involved an assessment task where students had to prepare a research proposal with the Islanders as their subjects. For each student proposal that required an addition to the Island we began by searching for existing research on the topic. This gave plausible ranges for response variables as well as suggesting relationships that might be included in the simulation.

As before there is tension between reality and fantasy here. Making the simulated processes perfectly match reality would be technically difficult and, as with the smoking and lung cancer example, may not actually be desirable. We felt it was important to keep students on their statistical toes by omitting some associations that they might expect to find while adding some other associations that would surprise them, though we did keep this at a low level. A better alternative for the long term is to add tasks that are somehow native to the Island. For example, in the first phase we added the fictional *Dalpa Leaves* and allowed Islanders to "chew lime-soaked dalpa leaves for ten minutes". This was added as a control for chewing lime-soaked coca leaves (a treatment requested by a student) but dalpa leaves were given their own effects that students could study independently in the future.

3.2. Simulations

The simulations used to generate the data that students observe involve a wide range of approaches. Our own earlier systems to simulate data for statistical exercises were based on standard models, such as using a linear model to generate outcomes based on parameters to which random Normal variability was added. In contrast the Island relies heavily on differential equations to capture changes in physiology at a more basic level and then links these with various statistical models as needed.

While the population simulation moves in monthly steps, the experimental simulation updates at 30-second intervals. At this level each student has their own copy of the Island, tied to their login, so that changes they make to Islanders through experimental treatments are independent of changes made by other students. Similarly, such changes made by the students do not affect the underlying historical simulation. For example, a student can never kill an Islander through their actions since this would mean that they would then need a separate timeline in the historical simulation. (Islanders do become unconscious if they are given too much alcohol, for example, during which time they cannot be given any more until they have recovered.)

The following list shows some of the processes and relationships that are currently included.

- Many students were interested in the effects of **caffeine** and we included models relating to running (Wiles *et al.* 1992) and swimming (MacIntosh and Wright 1995).
- **Alcohol** was another popular topic and we included effects on blood pressure (Jackson *et al.* 1985), body temperature (Danel *et al.* 2001; Desruelle *et al.* 1996) and general health (National Health and Medical Research Council 2009).
- Students were also interested in a range of other drugs and some of the ones included were **LSD** (Greiner *et al.* 1958), **cannabis** (Ashton 2001; Cone and Huestis 1993) and **paracetemol** (Heading *et al.* 1973). Another popular substance of interest was **chocolate** (Grassi *et al.* 2005; Ding *et al.* 2006). One model looked at the effect of morphine on wound healing (Peyman *et al.* 1994).
- Other models linked regulation of **body temperature** to walking, running and swimming (Lim *et al.* 2008; Fuiishima *et al.* 2001), ageing (Kenney and Munce 2003), the environmental temperature (Grollman 1930) and sweating (Wyss *et al.* 1974). Students were also interested in factors affecting **respiration** (Burr *et al.* 1974; Helliesen *et al.* 1958) and **rehydration** after exercise (Barr *et al.* 1991; Gonzalez-Alonso *et al.* 1992; Burke and Hawley 1997), and whether **oxygen breathing** could improve cognitive and physical performance (Dripps and Comroe 1947; Daly and Bondurant 1962; Moss *et al.* 1998).
- To allow study of diabetes we added a simple model of **glucose and insulin dynamics** (Yipintsoi *et al.* 1973; Fisher and Teo 1989). We supported this by providing information on the glycemic index (Jenkins *et al.* 2002) of foods that the Islanders could consume as well as allowing injections of synthetic insulin (Marki and Albercht 1977).
- Obesity was a popular topic and we included various models relating body mass index to health outcomes such as cholesterol levels (Suka *et al.* 2006), diabetes (Narayan *et al.* 2007), and the effect of glucose on pulse rate (Welle and Campbell 1983). Related models looked at various dietary effects on **cholesterol** (Connor *et al.* 1961; Schlundt and Hill 1993; Howell *et al.* 1997), including vegetarian diets (John *et al.* 2002).
- The Islanders go through **sleep** each night because many students were interested in the effects of sleep deprivation on various mental tasks. We used a Markov chain model developed by Kemp and Kamphuisen (1986) to initiate sleep onset and move the Islanders through various sleep states.
- Some of the Islanders are smokers and we included the effects of **smoking** on blood pressure (Omvik 1996), energy expenditure (Hofstetter *et al.* 1986) and appetite regulation (Miyata *et al.* 1999).

- To get some insight into Islander **emotions** we included a sample of questions from the Profile of Mood States (Shacham 1983) in a survey tool that could be used with the Islanders (as described in the next section below).
- Models for various hormones were included, such as **oxytocin** (Carmichael *et al.* 1994; Turner *et al.* 1999; Lucas *et al.* 1980; Bell *et al.* 2006), **ghrelin** (Weltman *et al.* 2008) and **endorphins** (Schwarz and Kindermann 1992).
- One student wanted to investigate differences in **liver size** (Kratzer *et al.* 2003; Niederau and Sonnenberg 1984). While the literature suggested the differences of interest did not exist, access to ultrasound measurements of liver size was added.

We also based models on data from the real experiments carried out by students in earlier years. These included simple estimates of outcomes like the increase in pulse rate after drinking 250 mL of caffeinated cola or the time someone could hold their breath.

There are many more specific details about the simulation, such as seasonal and geographic effects, that are beyond the scope of this paper. Readers are welcome to contact the first author to discuss any of these aspects in greater depth (and to contribute suggestions!).

3.3. Tasks

Students conduct experiments by selecting an Islander and then allocating a task for them. There is a flat list of the 175 tasks currently available with few constraints on how they can be used. (The main constraint is that most tasks cannot be used while an Islander is asleep.) This gives students freedom in the experiments they design.

Some of the tasks apply treatments, such as giving the subject a tablet containing 1 mg of alprazolam or making them swim freestyle for 200 m. These do not show any output in the interface but the tasks have changed the state of the Islander in the simulation. Since the simulation happens in real time the students need to wait to observe effects. Other tasks then produce data, such as measuring blood pressure or pulse rate, or taking a blood or urine sample to detect a particular substance. The onus is on the student to develop the protocol for applying the treatments and making the measurements.

In addition to tasks that mostly behaved like measurements, the students could also design a survey for their Islanders to complete. Questions that students were interested in asking were added to the system, along with a range of standard survey questions that we typically ask the students themselves (such as age, height, weight, eye colour, which superpower they would most like to have and how attractive do they think they are to members of the opposite sex). The Islanders would take longer to complete longer surveys, discouraging students from just asking all the questions. Some Islanders were predisposed to lie on the surveys, particular for questions related to age and weight. Students can always tell they are lying because the actual age of each Islander is displayed on the profile and there is a measurement task for weighing an Islander. There is also a chance that an Islander will decline to respond to a survey. This chance varies between the different cultural groups on the Island making a pattern in nonresponse bias for students to explore.

The instructor can see all tasks assigned by an individual student to each Islander they used as well as Islanders that have been visited by the student but who have not had any tasks assigned to them (as is the case with students doing observational studies). These monitoring tools provide a useful level of accountability for individual student work and also give the instructor a broad insight into how the environment is being used by their class.

3.4. Mobile Hardware

It is worth noting that the current interface to the Island requires no typing beyond the initial login. Villages and individuals, tasks and results are all navigated through mouse clicks on a web browser. This has made the Island well suited to the many mobile devices that now have touchscreen interfaces. For example, although it was released after the Island was conceived, the iPad has been an ideal hardware interface to the Island.

Mobile devices are also useful with the Island since the experimental simulations run in real time. For example, students can allocate their treatments to subjects during group work in a computer lab and are then able to check on the subjects, such as monitoring blood pressure or some hormone level, while riding on a bus.

4. Examples

4.1. Basic Comparative Study

We have used the Island in an introductory statistics course for science students since 2009. Their project assessment task asked them to use the Island to demonstrate their learning in the course, typically by choosing one or more statistical methods and designing an experiment that will give them appropriate data to analyze with those methods. Here we give an example of the minimum expected effort, a two-sample comparison between means. The student's abstract for their paper on the study began with:

> Dextroamphetamine is used to treat narcolepsy and ADHD. However, the drug has been known to interrupt sleep patterns by decreasing nightly sleep time. This study seeks to determine whether a 40mg dose of dextroamphetamine causes a decrease in nightly sleep time. Participants in the study received dextroamphetamine or a placebo and were surveyed on sleep patterns.

Although the experiment is being conducted with fictional characters, this outline illustrates that students often do put their study in a real world context.

To conduct their study the student used 40 subjects and started by asking all of them a survey with the question "How many hours did you sleep last night?". It took around 30 minutes for the student to administer all of these surveys. Half of the subjects were then given the dose of dextroamphetamine while the other half were given a placebo tablet. This again took around

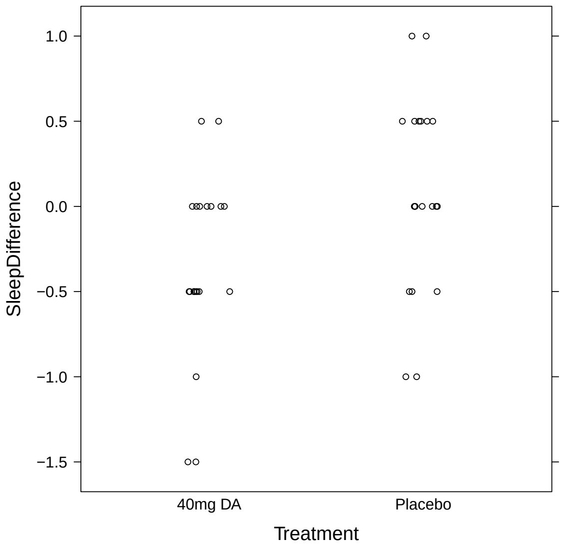

Figure 2: Observed differences in sleep durations (hours) for two treatments

35 minutes to complete. The student then returned the following day and repeated the same surveys. A summary of the data he obtained is given in Figure 2, with a one-sided p-value of 0.01 supporting the claim that the 40mg dose of dextroamphetamine causes a decrease in nightly sleep time.

4.2. Publication Bias

The following email was received from a student while conducting her experiment with the Islanders:

> I am doing my experimental project and I'm trying to find a change in anything basically after my islanders take marijuana. First I tried to give them cannabis tea and waited ten minutes and measured pulse, IQ and gave them my survey but there weren't any significant changes between before and after. So today I tried again and gave them a reefer instead, waited 10 minutes and again no changes. Is ten minutes too long or not long enough? I'm using a variety of age and sex so it's not that they are too young or old. Does it matter that the changes aren't very good? ... Will I lose marks for this?

This is a good illustration of the engagement students have with the environment and their projects but also shows the dangers in any project task of students hunting for significant effects. As with a real experiment, the Island environment itself does not attempt to prevent this behavior and it is thus important to have structured tasks to facilitate the pedagogical aims of the activity. In this case we now ask students to submit a justification of their study design, including power analysis, as part of their project work.

However the telling point in this student email is the final sentence. Even at this tender age the students have the idea that unless they find statistically significant evidence from an experiment they have somehow failed in their task. We use this quote in class as a motivation for discussion publication bias (Easterbrook and Berlin 1991) and other related issues.

4.3. Microarrays

The Islanders have a pair of chromosomes that they inherit in the usual way from their parents. The 256 'genes' on each these chromosomes are used to determine a variety of attributes, including the physical characteristics seen in Figures 1, measures of disease susceptibility, and other parameters required by the task simulations described in Section 3.2.

We give students access to this genetic information through a task that generates the analog of a microarray image for one or both of the chromosomes. Students can use this task to carry out studies that mirror microarray techniques in the real world. For example, Bulmer and Meiring (2010) describe a student project that looked for evidence of a gene linked to diabetes on the Island. In that study the student obtained microarray images for 10 Islanders with diabetes and 10 without, giving the results shown in Figure 3. The question is whether there is any systematic difference between the intensity levels expressed in each set of images.

Figure 4 shows a more quantitative summary of the results with side-by-side box plots for each of the 256 genes appearing in the microarrays. For convenience we label the positions with B000 at top left, along to B015 at top right and then continuing by rows to B255 at bottom right. The student carried out a two-sample t test to compare the levels between the subjects with diabetes and those without for each of these. The four strongest effects were for genes B116 ($p = 0.0010$), B041 ($p = 0.0014$), B186 ($p = 0.0016$) and B118 ($p = 0.0057$). Figure 5 shows the box plots for these four comparisons in more detail. For B116 the intensity distribution for non-diabetics seems uniform while it appears systematically lower for diabetics.

We now use this student study as an example in class. Of course the p-value for B116 needs to be treated by caution since it arose from a large number of multiple comparisons. In our introductory course we use the very conservative Bonferroni adjustment to the p-values, whereby B116 becomes non-significant, but the overall example illustrates to students the practical issues involved in this kind of screening as well as an area of current research in the discipline of statistics itself. A great advantage of this approach is that new students can replicate the study if they want, or search for other similar genes.

4.4. Life-changing Events

Our final example illustrates the open-endedness of the Island through a new measurement devised by a student based on the existing data. The student was interested in possible risk factors for smoking and she wanted to test the hypothesis that major life-changing events

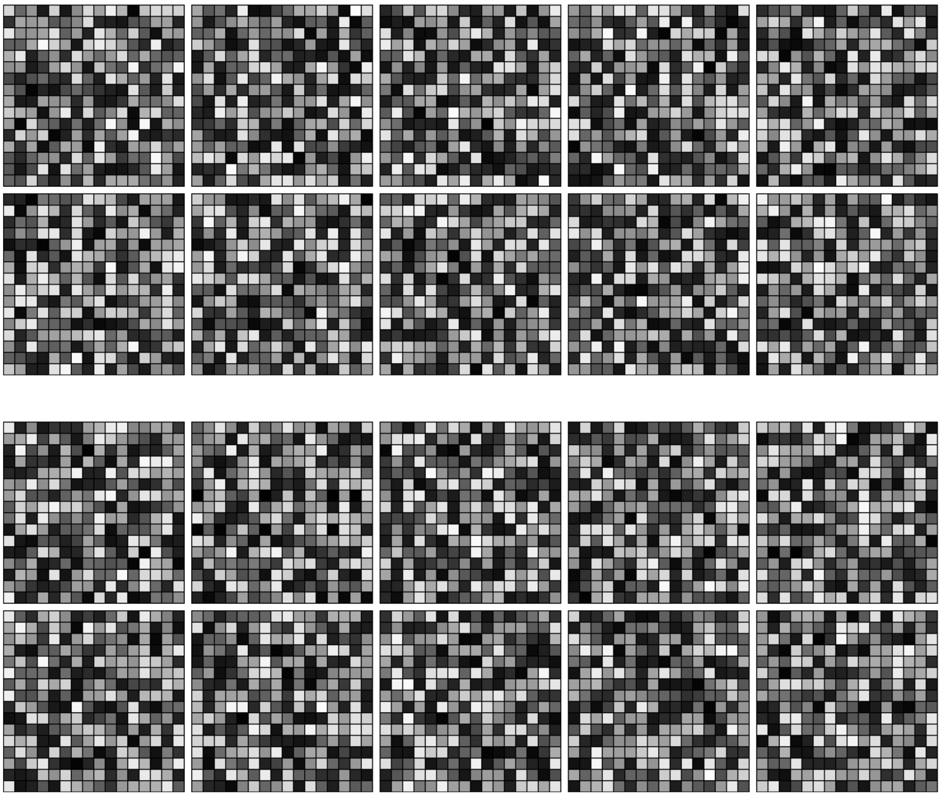

Figure 3: Islander microarray data for 10 diabetics (top) and 10 non-diabetics (bottom)

could increase the incidence of smoking due to stress. Using a sample of 40 Islanders, she counted the number of life-changing events each of them had experienced. She defined these to be any of illnesses, marriages, child births, loss of spouses and migration between villages. She recorded their current smoking status and then looked for a relationship between the two variables.

A logistic model for the relationship is shown in Figure 6. This was an interesting outcome for the student since the conclusion was the opposite of her original hypothesis: there was significant evidence that Islanders with higher numbers of life-changing events were actually *less* likely to be smokers. However it was also a very interesting outcome for the authors because this relationship was not an explicit part of any of the simulation models. This emergent phenomenon is most likely an example of *survival bias* in the results since smokers tend to die younger and so ultimately have less time to experience life-changing events. Future students can replicate this study and try to adjust for age, for example, to confirm whether this is the case.

5. Feedback and Evaluation

Student feedback to the Island has been very positive. In our context the role of it has

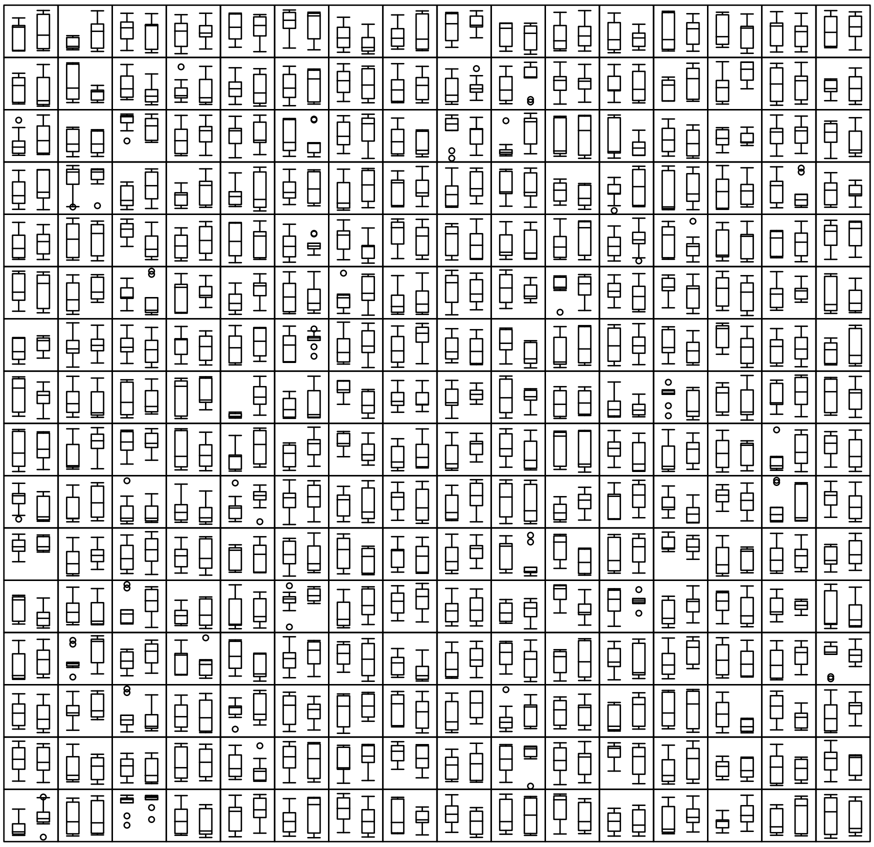

Figure 4: Box plots for comparing gene levels between Islanders with diabetes (left) and without diabetes (right)

been to replace real experiments and this is reflected in many comments such as that "they were interesting and a great way to find results of experiments. It made the experimentation process nice and easy to conduct". However students were also engaged with the Islanders beyond a basic tool for generating data: "I liked how we were able to see their whole history on their profiles; it was interesting seeing some of their troubled past".

As mentioned earlier, we do have a tension between reality and fantasy in our design and it was interesting to read comments on the reality aspect, such as that "the Islanders were a little too real, especially as they improved reaction times after repeating the action. We really had to think of them as real people - which I suppose was the whole point". In contrast there have not been open comments on the 'unreal' aspects, such as the Islanders with elven ears or the unusual disease names. We suspect that students are used to these features in computer games and are not surprised by them. This is an interesting area for future studies.

The consistent negative feedback has been on the Islanders sleeping each night. While some students were interested in studying sleep, as in the dextroamphetamine example above, for

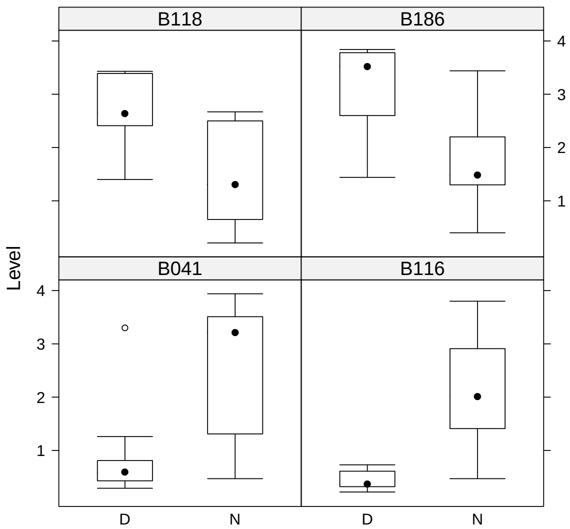

Figure 5: Box plots comparing strongest gene effects

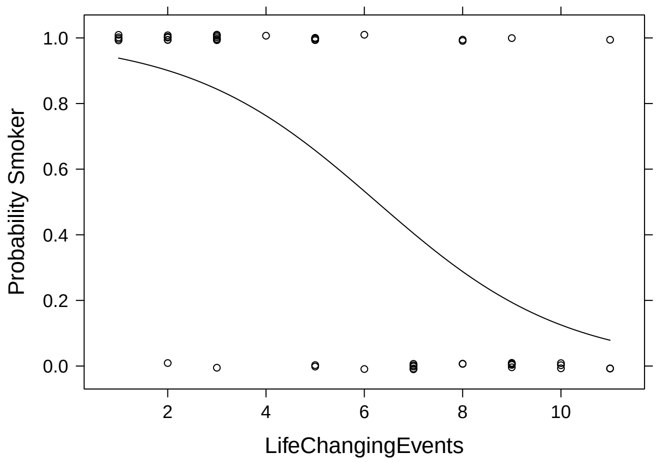

Figure 6: Logistic model for smoking status by number of life-changing events

the majority of students the fact that the Islanders go into an uninterruptible sleep each night is often a nuisance. At this stage we are continuing to include this constraint, as part of our general philosophy summarized in the following section. However we have made the Islanders go to bed a bit later each night and have introduced some tasks that can be performed on sleeping Islanders, such as the various blood tests and a simple polysomnography tool, so that students are not completely stuck if they have left their project until the night before it is due.

In general it is not surprising that the Island has been successful in engaging students with the task for which it was designed. We are interested now in evaluations from other users of the Island in contexts different from our own. For example, Linden *et al.* (2011) give outcomes of a research grant that has investigated the use of the Island as a tool in teaching clinical trial design and management. Edwards and Crowther (2011) give an evaluation of the Island in a health systems management course where the focus was not on statistical reasoning at all. Such projects give insight into the transferability of the tool while also feeding back ideas to further expand the models included in the simulated environment. Bulmer (2011) gives more details regarding this collaborative approach.

6. Discussion

The overall design philosophy of the Island can be summarized by listing some of the things the Island *does not* do for students:

1. There is no mechanism provided for automatically generating a random sample from the population. It would be trivial to add such a tool but we want students to have to deal with the real issues involved in finding a suitable sample, across or within villages, age groups, medical histories and so on.

2. There are similarly no tools for applying tasks to multiple Islanders. We want students to understand there is a cost in taking samples and making measurements. An original idea had been to incorporate funding and participant costs into the simulation but in the end we have found it is simpler to make the cost be the students' time. A large sample requires a large amount of time to administer tasks and gather data, highlighting the value of thinking about power and the sample size that they require. The real time nature of the simulation is also important here.

   Note however that it is still much easier for students to complete the virtual experiment than to attempt the corresponding study in the real world. The basic dextroamphetamine study described in Section 4.1 only took around two hours, spread across two days.

3. There is no display of combined data. Students need to visit each Islander to obtain the results from the tasks they set them. Again we believe it is important for students to develop skills in collating and structuring data for statistical analysis. For example, taking an Islander's blood pressure gives a result such as "133/82 mmHg". It has been common for students to copy the "133/82" into software for analysis, leading to obvious

problems when they try to do calculations. If the software just provided a list of systolic and diastolic pressures then students would miss this important practical step.

4. Related to the previous point, the Island does not include any statistical tools. At the end of a study on the Island a student could just as well do their analysis using an old-fashioned pencil-and-paper *t*-test. The aim of the Island is to provide a virtual replacement for the experimental work and does not go beyond that.

These deliberate omissions place a virtual environment somewhat outside the typical roles of technology in statistics education described by Chance *et al.* (2007). We suggest such environments provide an important connection for students between the context of investigation and the statistical understandings we aim to teach in an introductory couse.

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