Challenges to Develop an Interactive 3D Virtual World for Psychological Experiments

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Abstract: This article is a case study which discusses the implementation of a 3D virtual environment that will enable psychology students to conduct experimental investigation for the testing and analysis of models and theories relating to operant conditioning. Teaching and learning in psychology focuses on how people think, feel, and behave. Students must learn to use scientific methods to collect data from participants, and then analyse the data to testify related models and theories learned in the classroom. Experiments may be performed to study at different levels: individuals, groups, organizations, and communities. In the real world there are limited opportunities and various challenges for undergraduate students to be involved in experimental investigations. 1) There are difficulties recruiting participants. This often results in the use of convenience samples consisting of undergraduate students. The problem will compounded in campuses with a low student population and a limited variety of participants resulting in small sample sizes or skewed samples which can makes statistical analysis meaningless. Alternatively a lecturers may provide a dummy data sets for analysis. In this situation students do not practice appropriate experiment design nor learn to administer surveys for data collection. 2) There are difficulties conducting longitudinal studies relating to reinforcement or induced behavioural changes due to time limitations. This is essential for some theories and models such as developmental psychology which may require longitudinal studies over many years. 3) It is risky to allow undergraduate students to conduct experimental investigation on human subjects. These issues may be addressed through the use of a virtual environment which will allow students to explore a range of psychological phenomena without the need for close supervision required when dealing with human subjects. A range of simulation software is currently available to simulate learning behaviour and experimental design, but none is suitable for scalable psychological studies. It is proposed that a single-user virtual environment or multi-user virtual world can be created for this purpose using intelligent agents and 3D avatars with physical, physiological, and emotional responses. This would allow students to interact with avatars, participate in the virtual world to conduct experimental investigation, and collect and analyse data. A prototype virtual environment currently under development for the teaching of experimental design and learning theory in psychology is discussed. When conducting investigations, students will provide rewards/punishments to induce changes to an avatars' behaviour. For example, an avatar that is rewarded for engaging in a behaviour will have a higher probability of displaying that behaviour in the future (operant conditioning). If an avatar is punished it will be more likely to decrease that behaviour. This virtual environment will enhance student's learning experience in research design and analysis, and provide the ability to perform research that would be difficult or impossible to conduct in undergraduate psychology subjects run over a single semester. Future research proposes the addition of physiological and emotional responses, incorporating more complex learning algorithms, and extending the virtual environment into a multi-user virtual world.

Keywords: intelligent agents, virtual world, learning, reinforcement, research design

1. Introduction

It is essential that psychology students have the opportunity to engage in experimental design, testing, data collection, and analysis to reinforce their understanding of the scientific method, and to validate models and theories learned in the classroom (Wild & Phannkuch, 1999). Unfortunately there are limited opportunities and a variety of problems for undergraduate students to be involved in real world experimental investigations. As a result, students often perform limited studies using small skewed undergraduate populations with analysis performed on poor quality data or substituted third party sample data sets. In this situation they are deprived of the opportunity to see the link between good experimental design and the validity of results in a large scale scenario that can be carried through from beginning to end.

A solution to this problem is to provide a virtual environment in which students can carry out research (Darius et al. 2007, Forster & MacGillivray, 2010). This paper outlines the current problems in the teaching of experimental methods, the benefits of using a virtual environment, and the factors that

were considered in the design of a prototype virtual environment where psychology students can design and perform experimental investigations.

2. Initiating problem

In the real world, experiments are performed at many levels, from individuals through to groups, organizations, and communities requiring a true random sample from the population under investigation. For undergraduate students, there are a number of factors that limit the scale of research that can be performed.

- There are difficulties for undergraduate students to recruit participants with the time and resources available during a semester. For statistical analysis, a sample population must be randomly selected from the target population under investigation. However, in first year psychology subjects, students are often forced to use convenience samples consisting of undergraduate students. This problem is compounded in campuses with a low student population where there is a limited variety of participants. Even when participants are recruited from outside the university, they are often a convenience sample consisting of family and friends, or passersby at a local shopping centre. The problem of acquiring a suitable sample population may be further affected by the cost of participation compensation. These issues will often result in small samples sizes or skewed samples which can make statistical analyses meaningless.

As an alternative, lecturers may provide students with a dummy data set for statistical analysis. This is a simple solution; however, students are denied the opportunity to observe the consequences of their experimental design and to participate in the administration of the data collection procedures.

- Time available during a semester is limited and there are difficulties conducting longitudinal studies relating to reinforcement or induced behavioural change. This is essential for some theories and models such as developmental psychology which may require longitudinal studies over many years.
- There are health and safety issues that must be considered when dealing with human subjects. It is risky to allow undergraduate students to conduct experimental investigation on human subjects without supervision. Any problems that arise due to inexperienced students acting in an unprofessional manner may cause harm to the participants and will reflect back on the reputation of the university.

3. Advantages of a virtual environment for psychological research

It is not appropriate for a first year undergraduate psychology student to perform behavioural modification of their own design on human subjects, thereby limiting their ability to conduct appropriate research investigation in this area. Performing these tasks in a virtual world will allow students to explore a range of psychological phenomena without the need for the close supervision required when dealing with human subjects. Students will not only have the freedom to carry out an extensive intervention, they will also be able to make mistakes and see the consequences of their actions.

The proposed virtual world will provide the benefit of variable population characteristics, larger sample sizes, and control of the diversity and distribution of the population parameters under investigation. A virtual environment will also allow portions of the simulations to be run in accelerated time, allowing a longitudinal study to be completed within the time constraints of a semester long subject. This approach will also eliminate the need for ethics approval which can be administratively cumbersome and takes time to complete.

3.1 Learning and retention

Learning in a 3D virtual environment offers a number of advantages over traditional learning techniques. It provides deep learning with improved engagement through interactivity and immersion in the learning tasks and the environment (Hamilton & Tee, 2009). Learning is experiential and situated within the environment, enhancing retention through the use of spatial memory and experience of events.

3.2 Data collection and assessment

A virtual environment would provide a great deal more facilities for assessment than would be available in a real world research investigation.

Observation

Students will be able to observe and report on events during a real time play through of a scenario in the virtual world. When the simulation is complete, both the students and lecturer can compare and review the student's observation skills using the replay facilities.

Time stamped event logs

Every action taken by a student in a virtual world can be time stamped and logged to a file for later review by the lecturer. This provides a detailed report on the sequence of actions performed by the students through the intervention.

Recams

Recams record positional data of avatars in the virtual world which can be used to reconstruct the student's play through, providing detailed information for both formative feedback and also for assessment. The recam facility allows additional cameras to be placed in the scene to provide a more comprehensive view of the events that have transpired. This facility will also allow students to move to a point in time where they made a mistake and restart the simulation from that point.

Technical data

A simulation can record data and present it in text or graphical formats. For example behavioural probabilities, learning rates and any other state can be recorded and displayed.

4. Existing software

Existing computer based simulations for operant conditioning and statistical reasoning range from simple web delivered simulations through to more complex virtual environments. An example of a simple simulation is a 2D black and white simulation of a bird that is to be trained to press a button to get a food reward (Hay, 2007). The player can click on the food container to release a food pellet to reinforce the pecking behaviour. A single line graph is provided to indicate pecks and reinforcement events. As simple as this is, it is very effective in conveying the nuances of training using reinforcement and highlights the need to balance the complexities of real world models of behaviour and learning with the specific requirements of the training platform and desired learning outcomes.

Sniffy the Virtual Rat (Alloway, Wilson & Graham, 2012) is a software learning tool that has been used extensively in psychology since the 1990's (Graham, Alloway & Krames, 1994) as an ethical alternative to live animal testing. The software simulates an operant chamber with a bar that Sniffy or the researchers can press to dispense food and water. Sniffy can be trained using either classical conditioning or operant conditioning to modify specific behaviours selected from his repertoire of actions. The simulation allows for complexities in the reinforcement schedule and provides graphical representation of reinforcement events and behavioural changes, Sniffy is limited in respect to the aims of this project as it provides only a single square environment (the operant chamber) and a single reward mechanism. However, the underlying mathematical modelling of operant conditioning in Sniffy is relevant to virtual humans that have an appropriate set of behaviours that can be reinforced.

The island (Bulmer & Haladyn, 2011) is a virtual environment designed to teach statistical reasoning to first year undergraduate students. The inhabitants of the island are survivors of a shipwreck which occurred in 1779. The population has since grown to consist of thirty-nine villages with a population of over eight thousand. The island has been designed for epidemiological studies focussing on the characteristics and distribution of health related events in well-defined populations to allow students to see data in context, which is an essential of teaching experimental research methods (Forster & MacGillivray, 2010). This allows students to run an investigation on virtual human subjects, addressing the limitations and management issues relating to studies involving human subjects.

To initiate a study, students design an appropriate intervention. They can select from 175 tasks that can be assigned to the virtual patients to treat the condition that has affected the population. They will then measure and collect data such as blood pressure. In addition to collecting test results, the students can administer questionnaires to the islanders. To emulate the limitations of questionnaires in the real world, the islanders may delay the completion of long questionnaires while others may lie. To add to the realism, students must contend with the islanders sleeping during the night (based on an accelerated time scale).

To set up the study, the simulation has an historical phase where the seeds of a disease are planted. The simulation then generates current state data for the scenario using a range of mathematical models. The students are given individual copies of the environment primed with the relevant historical scenario in which to design treatments, collect data, and perform the relevant statistical analyse to report their findings.

5. Proposed solution

A virtual environment for psychological research can be created as a single user application similar to The Island, or an on-line virtual world where a group of students can come together and perform more complex collaborative experiments.

Within the virtual environment, avatars would exhibit learning behaviours based on the mathematical models of operant conditioning simulated in Sniffy the Virtual Rat. This model of behaviour provides an excellent basis for experimental investigation as the outcomes are predictable and variations will occur through each student's pattern of reinforcement.

Applying operant conditioning algorithms to intelligent agents (avatars) in the virtual environment would provide adaptive character behaviours suitable for first year psychology students to design and run experimental research in a safe and effective virtual environment, This has the benefit that it would also teach the fundamentals of learning theory in a fun and interactive manner. The intelligent agents and 3D avatars could be extended to include physical, physiological, and emotional responses beyond the basic behavioural responses defined by models of operant conditioning.

In this type of environment, students would be free to experiment on the virtual humans, allowing them to gain first-hand experience of the research process. Because the agents can have a basic repertoire of behaviours (sleeping at night, getting bored etc), students will gain experience dealing with factors they will encounter in real sample populations. Students will also have the opportunity to engage with the entire research process, from conceptualization of a design, through collecting a sample, acquiring data, recording that data, and finally data analysis and reporting. This contrasts the limited studies or analysis of disembodied data sets with minimal engagement by the students, limiting their motivation for analysis of the data collected and thus the close link between research hypothesis and data analysis.

For example, an assessment exercise in learning and behaviour might require students to pick a behaviour for a virtual human and alter it using behavioural modification techniques. This exercise would require students to take the knowledge they have gained via more traditional teaching techniques and apply it in a practical application in the virtual world. Thus the exercise requires far deeper learning and application of the principles of behavioural modification than simply training a bird to press a button for food using existing software. Students will then apply research methods that involve the formulation and testing of a hypothesis relating to the effect of changes in the behaviour of the virtual humans. This exercise is almost impossible to do with real subjects on an individual student basis because of the ethical (and practical) requirement for close supervision of undergraduate research students and the large number of students involved.

6. Prototype development

The authors are currently developing a prototype virtual environment to demonstrate the effectiveness of this approach for the teaching of experimental design. The first stage of this project has targeted the development of a single user application in which individual scenarios (behavioural weightings) can be created for each student. Students will interact with the avatars in the virtual environment to reinforce selected behaviours and conduct an experimental investigation, collect behavioural data, and then analyse the data.

When conducting the investigation, students will provide rewards/punishments to induce changes to the avatars' behaviour based on learning theory (Rescorla & Wagner, 1972). For example, an avatar that is rewarded for engaging in a behaviour will have a higher probability of displaying that behaviour in the future (operant conditioning). If the avatars are punished they will be more likely to decrease that behaviour. Thus, over time, the behaviour of the avatars in the virtual environment will take on unique characteristics as a function of their interactions with students. This type of study would normally be difficult or impossible to conduct in an undergraduate psychology subject within a single study period. The proposed application will enhance students learning experience in research design and analysis that normally involves human subjects, and will allow researchers to compare teaching and learning experiences of the proposed virtual environment to traditional teaching.

6.1 Virtual environment

A prototype environment has been modelled based on a public area called The Lagoon, which is situated on the esplanade in Cairns City. This area was chosen because it attracts a diverse range of people and activities in a small area. The low resolution prototype developed for testing is shown on Figure 1.

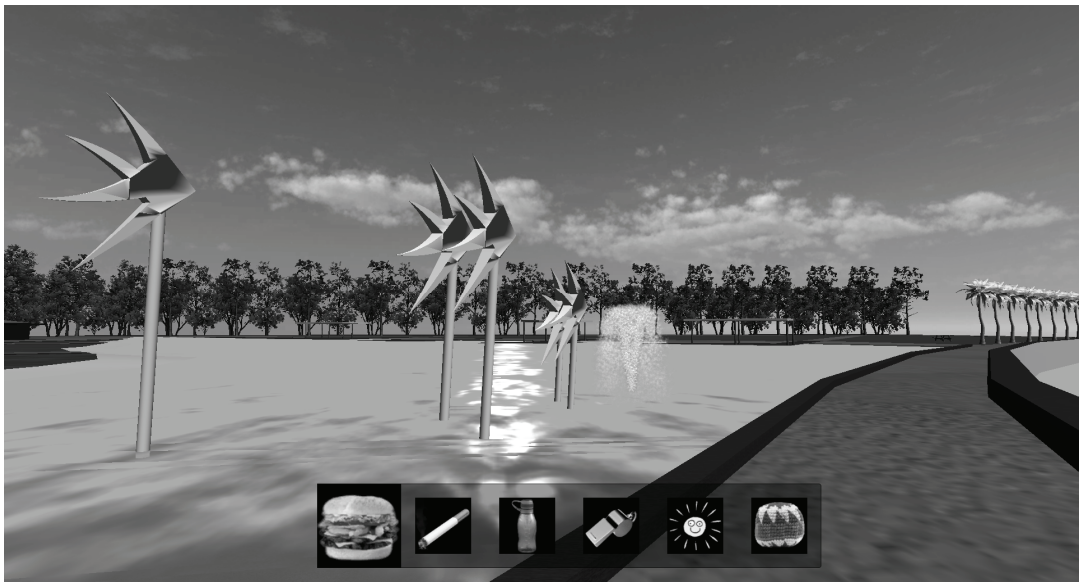

Figure 1: The Lagoon

6.2 Characters and behaviours

The first implementation decision was to determine an appropriate set of idle behaviours and reinforceable behaviours based on what were considered "normal" behaviours in the real world, with consideration of the suitability for modelling. During development it became obvious that there was no reason to distinguish between reinforceable and non-reinforceable behaviours and so the idle behaviours were included in the behavioural actions available for reinforcement (though they may not all be made available for reinforcement).

Six behaviours were chosen for the pilot which included smoking, eating, drinking, sunbathing, playing a sport/game, and punishment. The characters chosen to exhibit these reinforceable behaviours were normally dressed sunbather, sportsman, and policeman. The reinforcers were chosen as cigarettes, food, and alcohol. The punishment chosen was a whistle.

6.3 Behavioural matrix

Like Sniffy the Virtual Rat, each character will have a predisposition to exhibit all potential behaviours to some degree. This has been implemented as a behavioural matrix of probabilities for each behaviour. In the initial weighting of behaviours, a character type will have a higher weighting for their dominant behaviour as shown in figure 2. The initial matrix for each character may be randomly generated or set by the instructor before the simulation.

Figure 2: Behavioural weightings and graph of learning response

6.4 Operant conditioning learning algorithm

For the initial stage of the project it was decided to base the simulation on a predictive model that was suitable as a platform to teach research methodologies and to teach the foundations of operant conditioning. For this purpose it was decide to implement Rescorla and Wagner's model (Rescorla & Wagner, 1972).

Rescorla and Wagner (1972) proposed a model for conditioning which suggested that if a stimulus is followed by something unexpected or surprising then learning will be improved. The model proposes that conditioning is dependent on the strength of the stimulus and the amount of surprise, as defined in the following formula.

$$\Delta V_x = \alpha_x \beta(\lambda - \Sigma V)$$

Where:

V is the predictive value

α is the salience of the Conditioned Stimulus (CS)

β is the rate parameter of the Unconditioned Stimulus (US)

λ is the maximum associative strength of the US

ΣV is the sum of the associative strengths presented in the trial

and ($\lambda - \Sigma V$ = surprise)

From a real world perspective, Rescorla and Wagner's model does have some limitations (Miller, Barnet & Grahame, 1995). However, the predictive value of the model is valid in simple situations of extrinsic reward and punishment. Rescorla and Wagner's model therefore has the advantage that it gives predictable results (outside of the variability of an individual's attempts at reinforcement). This forms an excellent basis for teaching experimental design as predictions can be made and hypotheses formulated, with experimental results dependant on the ability of the users to perform the task of behavioural modification through reinforcement and punishment.

7. Future work

The prototype application will be completed in the upcoming semester and will be tested using undergraduate psychology students enrolled in the learning and behaviour subject and also the experimental design subject at James Cook University.

Implementation of the Rescorla Wagner model has formed the basis of development for the first stage of the pilot. It is planned to expand this in the second stage to implement more complex learning algorithms such as Q-Learning with motivational drivers for intrinsic rewards to guide learning (Merrick & Maher, 2009).

The project will also be extended to incorporate the virtual world infrastructure previously developed for a prototype virtual hospital using Unity3D (Lemmon, Lui, Ho, & Hamilton, 2011). This platform uses custom middleware for multiplayer networking and zoning, animation state machine, VOIP with lip sync, management mode, logging, and recams. The virtual world functionality will provide additional facilities for online access, role play, and collaborative learning in addition to the facilities provided in the first stage.

8. Conclusion

This paper provides an overview of issues relating to the teaching of experimental design to undergraduate psychology students and the complications involved when using human subjects. To address these issues, the use of a virtual environment is proposed as a safe, effective, and scalable alternative. A prototype virtual environment currently under development is discussed. This application will allow psychology students to participate in research methods in a virtual environment where they can modify the behaviour of virtual human subjects using operant conditioning. This will allow students to engage in research in a safe environment free from the supervisory and ethical considerations associated with studies that involve humans or animals. Students will have the opportunity to engage with the entire experimental process from the initial experimental design through to the administration of the proposed methodologies, data collection, analysis, and reporting.

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