Exploring graphical user interfaces and interaction strategies in simulations

Janet Saw and Matthew Butler
Berwick School of Information Technology
Monash University

Simulations are capable of replicating complex systems using a set of determined rules and variables. However, many people are still unable to understand the results from scientific computer simulations, as they can be quite abstract. Current use of 3D graphics in games and virtual environments can facilitate new innovations and perceived affordances for interacting with simulations, therefore user interfaces could be upgraded with these functionalities to create interfaces with a high level of usability for users with or without expertise in the simulated content, particularly in education of traditionally complex areas. A proposed artefact with a new user interface for scientific simulations was developed to explore its possible acceptance and benefits to users. The new user interface was user evaluated against a control that was built to mimic the most common features of a traditional simulation interface. Analyses of the evaluations indicate that the modern approach was successful. Users felt the modern interface was more engaging, more efficient and was aesthetically preferred compared to the traditional user interface. This was mainly due to the extensive use of the direct manipulation idiom in the modern interface which improved ease of use and allowed direct interaction with the output display. With additional research into the area of direct manipulation, further interactions and user interfaces can possibly be developed to improve the usability and user experience of scientific simulations.

Keywords: simulation, graphical user interface

Introduction

Simulations are able to replicate complex systems using a set of rules and variables (Banks 1998, p. 10). They enable the understanding of reasons why certain phenomena occur, and are able to test or visualise aspects of a proposed change without committing resources (Banks 1998, p. 11), however, many people are still unable to understand scientific relations and complex systems using these methods of modelling (Davidson and Reiman 2006). The results from scientific computer simulations can be quite abstract, although accurate (Pegden 1989) for those unfamiliar with the simulated context. Furthermore, many simulations are also perfectly suited to experts in the particular field or to those that crafted it, but do not transmit information that is easy to interpret by other users (Cohen 1991). The reduced usability of typical scientific, or "traditional", interface features may also be the cause of confusion for many non-experts. The lack of intuitiveness and real-time visual feedback in graphical user interfaces gives minimal support to the user of the simulation (Odhabi et al. 1998).

Computer simulations became immensely popular in the entertainment industry, using complex systems in goal-based strategy games. These simulation games were designed mainly for entertainment, but they evolved the hardware and software in modern personal computers and began to shape the popularity of 3D. Interfaces in 3D games are excellent examples of successful interface and interaction strategies which can be applied to increase the interactivity of scientific simulations. User interfaces could be upgraded with extra functionalities to create interfaces with a high level of usability that can assist users with or without expertise in the simulated content. This will not only enable all users to easily learn and use simulations, but it will also promote exploration and interaction, which can subsequently eliminate the notion of simulations being confined to the domain of expert users.

The main objective of this research is to explore the possibility that incorporating a modern approach to designing user interfaces for scientific simulations can be of benefit to users, particularly those without considerable expertise in simulation theory. Additionally, the research attempts to investigate which user interface features are most useful and efficient for the completion of certain tasks, as well as examining whether the modern interface also promotes more engagement, stimulation and learning than the current traditional user interface. As an increasing number of traditionally 'scientific' topics, such as ecological issues, become of greater importance to the general public, new ways must be found to provide education and understanding of such simulation content.

Computer simulations and VIS

A simulation is essentially a problem solving methodology used for the resolution of real-world problems (Banks 1998, p. 3). They are able to replicate complex systems using a set of rules and variables (Edwards 1973), and is essentially an imitation of a real-world process or system. Simulations are controlled representations of reality, and allow the study of phenomena in ways that natural conditions prohibit or discourage due to various safety reasons and limited resources (Ochoa 1969).

Since the 1980s, personal computers prevailed and programming languages became more powerful and widely learned by university students (Chi 2000). Computer simulations already had a strong base, and soon the need for more visual output of results led to the creation of a new simulation model called *Visual Interactive Simulation* (VIS). A VIS is the use of a simulation application where the user can suspend execution of the application, modify one or more parameters and then resume the simulation (Bell and O'Keefe 1987). These simulations also employ the aid of graphic displays or iconic animation. They allow the user mass freedom in interacting with a running simulation and provide deeper insight into the simulated system (Hurrion, 1993), which could identify results that would not have been possible otherwise. Bell and O'Keefe (1987) also affirm that a visual display of a simulation has wider appeal to users that enjoy being able to watch the system operating.

The combination of statistical analysis, interactivity and visual output with VIS can help with interpretations of results and solutions, making it an integral aid to simulation users. Many modern simulations already include some form of visual output and interactivity. This possibly rendered VIS as a standard component of simulation applications, subsequently reducing widespread use of the term. Nevertheless, concrete research was conducted on visual interaction in the 1980s and the early 1990s. The visual user interfaces in VIS were rudimentary and may have been more suited solely for experimental purposes. Even so, past research in VIS is a key stepping stone towards further studies and improvement of visual-based simulations and interactivity.

Visualising simulations and user interfaces

Although simulations are effective in producing scientifically accurate results, there are a number of limitations that hinder non-experts from fully understanding their purpose or the conveyed meaning of results. Firstly, these traditional or specialist simulation applications produce output that is highly abstract, although accurate if analysed by experts (Pegden 1989). The results generated are usually visualised in simple 2D form such as grids of coloured shapes, scatter plots and graphs.

The abstraction of results in simple 2D can sometimes be difficult for non-experts such as students to comprehend, especially when learning about intricate complex systems and theories through the use of simulations. Many simulation applications are perfectly suited to experts in a particular field, but do not transmit a great deal of information that is meaningful or easy to interpret by a novice user (Cohen 1991). This problem with abstracted output does not only impact simulations, it also applies to any form of visual output or data. Lehaney et al. (1998) concur that abstracted circles and squares in output displays which are often used to convey information can be off-putting to non-experts. Textual forms support the analysis phase of data but concrete representations should be used to assist the exploration of new problems and creative thought. Less abstract visual simulations can make the model look like the real world it represents, subsequently increasing ease of comprehension.

Besides abstracted output from simulations, there are also problems associated with the usability of standard interface elements. Complex systems are difficult enough for non-experts to understand, yet the low levels of interface usability present an additional hurdle and complication for the user to surmount. Hix and Hartson (1993, p. 33) declare, 'To users, the interface is the system'. Indeed, an interface is the part of a system that users come into contact physically, perceptually and cognitively (Kuljis 1996), making it a fundamental factor to the success of any system, including simulations. A faulty interface can potentially trap the user in undesired situations, therefore affecting user attitudes towards the application (Gerlach and Kuo 1991). The efficiency of a system can be encumbered very quickly if there are defects with navigation, interface design and layout. In addition, Davis and Bostrom (1993) assure that there is a need to provide users with a conceptual model of the system. Graphical representations are the only on-screen conceptual model of the simulation that is seen by users, and therefore should be characterised as compellingly as possible.

The use of 3D in simulations and simulation games

Several simulation applications are incorporating the use of 3D geometry for displaying output. One example is by Govindarajan et al. (2004), who are simulating forest dynamics using 3D geometry to represent trees and shrubs. Users were given the ability to zoom in and out, controlling viewing points and viewing direction in the 3D scene. The 3D geometry used is basic due to software and hardware constraints; however the research is a crucial first step towards the future use of 3D in simulations.

Nonetheless, advanced 3D simulations require more processing power, leading to the fact that large-scale simulations may no longer be scientifically accurate. Jinling et al. (2004) successfully simulated high-quality 3D crops, but only managed to render small plots of vegetation since the structure of the 3D models needed to be modified in real time as part of the simulation process. In essence, the accuracy of the data was maintained by running simulations of a much smaller extent. Even so, scientific accuracy is not a prominent issue for public education where diminutive details are not essential. The use of higher-quality 3D geometry is acceptable and a lower level of accuracy will still provide an adequate representation of the emulated complex system.

The definition of a simulation environment has broadened over time, now even extending to games that use simulation models to replicate or mimic a complex system (Galvão et al. 2000). As mentioned previously, simulations in games have been popularised by the entertainment objective and are created solely for pleasure. The engaging and intelligent games today have evolved in the last three decades as a direct result of developments in hardware and software (Khan 2002). These developments have further resulted in modern personal computers being empowered with advanced computational abilities compared to a decade ago. This has enabled more 3D graphics to be used in simulations, which were previously only possible on expensive workstations with dedicated hardware. As a result, simulation games are growing in popularity and user interfaces are becoming more intuitive and involving because of the significant development being done with games. The user interfaces and interactivity such as those in *The Sims*, *Cultures* and other strategy games are much more graphical, easy to use and effortlessly attract the user, subsequently demonstrating that interfaces need to be visually captivating and engaging.

Interactivity in scientific simulations

Explorative educational theories can also be applied to game-like environments, as they have become a successful paradigm in recent years (Khan 2002). The combination of simulation applications and games are excellent for communicating the inner workings of complex systems (Chi 2000; Davison and Reimann 2006). Simulations allow users to obtain a better comprehension of the underlying knowledge and information of how complex systems function. They are considered a form of explorative education because they provide users with the ability to 'manipulate reality' (Din 2006), thus allowing them to recognise the consequences of their actions. For instance, the strategy simulation game, *Sim City*, predominantly employed the use of a learning environment in the game, which also acted as a real-life informal learning aid. It was successful for urban planning education because it is explorative, allowing users to manipulate and control the environment and observe the results of their decisions (Khan 2002).

The interactive nature that simulations can achieve is also an excellent tool for research, and a great medium for teaching, learning and communicating ideas (Chi 2000; Galvão et al. 2000). Interactive simulations are able to complement learning in museums and exhibits in order to support active interaction and participation (Din 2006). They provide the opportunity to avoid abstraction by facilitating the demonstration of tasks and mechanisms rather than just explaining them (Khan 2002). This can help users avoid any undesired abstraction and possible misconceptions.

Methodology, artefact development and evaluation

Methodology

This research attempted to gain perspective over the types of graphical user interfaces and interactions that users consider to be most instinctive, useful and valuable in the understanding of traditionally complex simulation content. Primary research questions comprised investigation into whether users feel more engaged and stimulated when using the modern simulation GUI, as well as which interface features users find most compelling for their given task.

In order to obtain and analyse user responses to the aforementioned research questions, one simulation application with two user interfaces was designed. The simulation incorporated the use of 3D geometry and two varying graphical interfaces. One interface followed a more traditional simulation setting and the other with interface styles usually seen in 3D environments. The content simulated visualised how plantation forestry can affect a complex system of an ecological nature, as this provides a prime example of traditional scientific simulation content that has a much broader reaching educational context. Using the two different graphical interfaces, both were tested and evaluated by volunteer participants.

Development

The simulation with two different user interfaces was designed in the *Artefact Development* stage. The labels Ø and _ were used throughout the research to eliminate the 'prototype A and B; 1 and 2' conundrum which could indicate to participants that the second prototype is the one being tested for superiority over the first. The content of both prototypes was identical, as it eliminated any other variables or factors that may have produced ambiguities in the evaluations of the user interfaces. These labels are used here with clarification where appropriate.

These prototype simulation applications were constructed using 3D modelling software, *3Ds Max*, and a gaming engine, *Virtools*. These applications were chosen because of the nature of the simulation prototype which encompassed 3D graphics and real-time navigation. *Virtools* is a prototyping game engine that allows quick scripting and is also able to export for viewing on the web. It also allows the incorporation of custom user interfaces, which is a fundamental requirement in this artefact.

The artefact designed was a VIS of how plantation forestry can affect a natural ecological complex system. The aim of the simulation was to manage water levels in the catchment by considering the amount of plantations to maintain, the various stages between plantations, the location of plantations, and also partly sustain a small town by providing employment in the forestry industry. Literature and information on plantation forests was obtained from the *Australian Bureau of Rural Sciences* (2008).

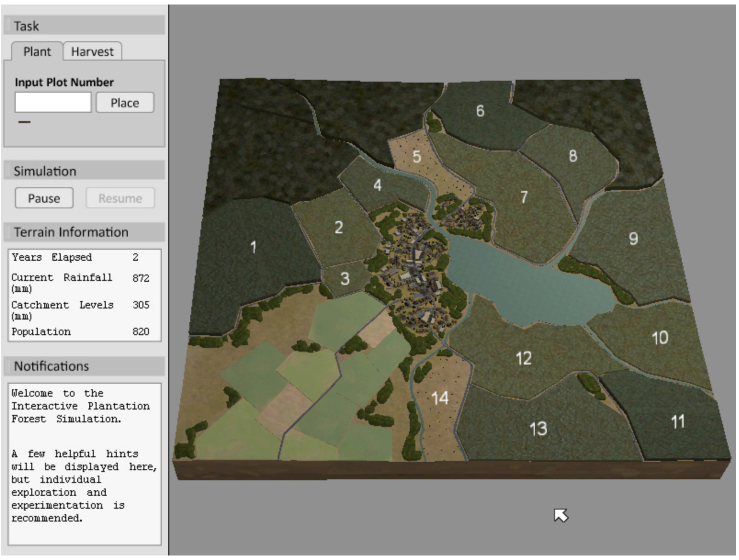

Figure 1: Screenshot of simulation Ø (the traditional user interface)

Traditional GUI
Figure 1 shows the actual prototype interface that was developed for Simulation Ø. Interface Ø (traditional GUI) was designed to mimic the functionalities of a real scientific simulation graphical user interface. There would normally be only a limited amount of interactivity with the output display, as most controls or parameters were set using the panels or user interface elements provided. Examples of simulation interfaces that were used for reference purposes used textboxes and dropdown boxes for value entry and selection, non-scrollable or panning output displays, logical grouping of functions, regular text-labelled buttons, and GUI panels placed on the left or right of output displays. Information and value displays are represented as graphs or simple text.

This interface also used textboxes for value input, multi-line text boxes for textual information, buttons for committing actions and logical grouping of functions and segments. The output display shows each plot's number for use in the harvest or plant input textboxes. The output display could not be panned, rotated or directly interacted with by any means, as this was also not possible in current scientific simulations.

Figure 2: Screenshot of simulation Δ (the modern user interface)

Modern GUI
Figure 2 illustrates the prototype interface for Simulation Δ. Contrastingly to interface Ø described earlier, interface Δ (modern GUI) was designed to match interface styles that are normally utilised in 3D environments and games. These interface styles also allow the user to directly interact with the output display, and can be termed the 'environment' once it is able to be manipulated and interacted with.

The entire panel is located at the bottom of the environment display, customarily seen in 3D game user interfaces such as *The Sims*. The tools panel contains buttons that control the simulation. The harvest and plant buttons are clicked to enable the function until it is disabled by clicking on the button once more, or the button for the opposite function. When the harvest or plant button is enabled, a loaded cursor will visually indicate to the user that the mouse supports an additional function. This is shown using a modified mouse cursor icon when the function is active. Figures 3 and 4 show the represented mouse cursors depending on the function enabled.

Figure 3: Normal and loaded mouse cursors for Simulation Δ

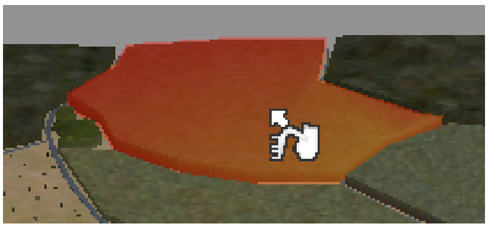

Figure 4: Highlighting plots: Real-time feedback

In this version of the simulation, additional navigation and rotation functions have been added to the mouse and visual interface. Moving the mouse cursor to the edges of the simulation display pans the view in a particular direction. Turning the middle mouse scroll wheel then allows the view to be zoomed inwards or outwards, while clicking on and holding the scroll wheel button while dragging allows the view to be rotated for a customised view. In addition to using the mouse to access these panning, zooming and rotating view functions, a graphical panel provides buttons to accomplish the same functions. The keyboard keys W, A, S, D and arrows can also be used to pan the environment view. The information and notifications panels are similar to that of interface Ø, with only minor aesthetical changes to fonts and sizes. This places the research focus on the new interaction strategies.

Evaluation

A survey was developed to obtain both quantitative and qualitative data on background, opinion, and simulation preference of the participants. The survey contained 4 main sections:

- Section A: Preliminary Information, which gathered background information on the participant, including age, gender, etc.
- Section B: Background Knowledge, which obtained information about the participants experience with computers, 3D, scientific simulation, and simulation games.
- Section C: User Interfaces, which asked a series of questions for each user interface. These included eight semantic differential scales matched with contrasting adjectives on each side, allowing participants to indicate their preference towards adjectives that describe the simulations. These were the same for each simulation. Qualitative opinions were also obtained for each simulation.
- Section D: Comparisons, which obtained opinions of participants on whether one interface was particularly better than the other, whether the interfaces helped them understand the content and why the participant believed so.

Once the simulation explorations were completed by a participant, a computer screen informed the participant to complete the provided questionnaire sheets.

Analysis

Following is an analysis of the data obtained. The sample consisted of 52 participants of varying ages and interests. Analysis for each question is not presented, rather only data relating to the specific research questions of the paper.

Aesthetical preferences and patterns of engagement

When analysing the overall engagement level of the simulations, the means of the scale ‘Engaged/Disinterested’ from each simulation was calculated and compared using a paired samples t-test. A scale from 1 to 6 was used to record participants’ responses towards each adjective in the scale, where a ‘1’ indicates a higher engagement level and ‘6’ indicates a lower engagement level or higher disinterest. As seen in Table 1, Simulation Ø scored a mean of 3.71 while the mean for Simulation Δ was 2.25. Generally, the means suggest that participants were more engaged with Simulation Δ (modern GUI).

Table 1: Engagement levels: Paired samples statistics

		Mean	N	Correlation	Sig.
Pair 1	Ø Engaged/Disinterested	3.71	52	-.314	.023
	Δ Engaged/Disinterested	2.25	52		

A paired samples t-test procedure was conducted to ensure the difference between the means was genuine. The test has revealed a difference between the engagement levels of both simulations, $t(51)=5.476$, $p<.001$. Since the significance value is less than .05, the difference between the means is real, showing that the mean rating for Simulation Δ ($M=2.25$) was significantly different from the mean for Simulation Ø ($M=3.71$). Thus, this difference supports the suggestion that Simulation Δ was indeed more engaging than Simulation Ø.

Table 2: Engagement levels: Paired samples test

	Paired Differences							
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)
				Lower	Upper			
Ø - Δ Engaged	1.462	1.925	.267	.926	1.997	5.476	51	.000

The test also revealed a significant negative correlation ($r=-.314$, $p<.03$), showing that whenever a participant gave the engagement of one simulation a high rating, generally, the other simulation would be given a lower rating.

Knowledge of simulation theory

A participant’s knowledge of simulation theory or simulation processes may affect their rating behaviour, thus warranting the need for further exploration of the data. Figures 5 and 6 depict the number of votes for each rating in both simulations, sorted in accordance to knowledge of simulation theory.

In Figure 5, the chart indicates that the participants without prior knowledge of simulation theory tended to rate their engagement with Simulation Ø as a less positive experience. 11 participants without simulation theory rated Simulation Ø with a 5, which is close to the negative end of the scale. On the contrary, participants with some knowledge of simulation theory generally thought that Simulation Ø was averagely engaging, with 9 votes for rating 3. However, with Sim Δ pictured in Figure 6, the responses appear to have a similar distribution towards the positive end.

An independent t-test with the same parameter settings was again utilised to determine if the differences in means are real. The mean for Sim Ø with 'Yes' to 'knowledge of simulation theory' scored a mean of 3.16, and 'No' with a mean of 4.03. These scales are once again categorised as '1' for the most positive rating, and '6' for most negative. With 'equal variances not assumed', the *p* value of .008 indicates that the mean difference for Simulation Ø is significant.

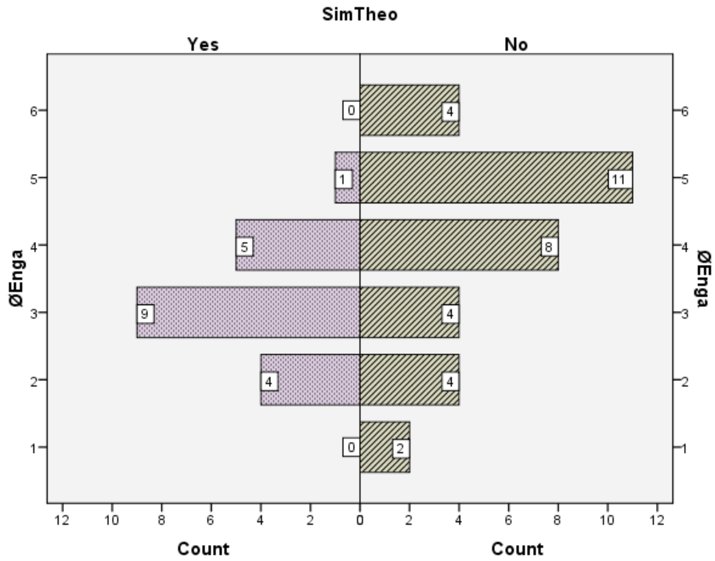

Figure 5: Chart of simulation knowledge against engagement levels for simulation Ø (Traditional GUI)

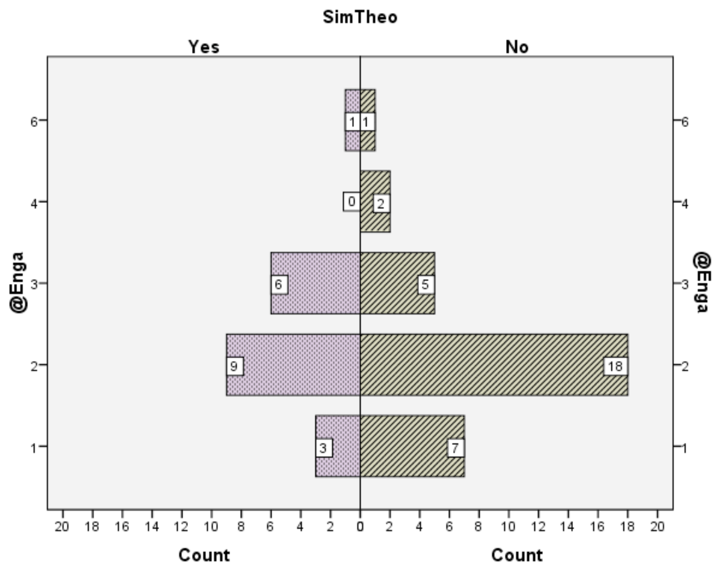

Figure 6: Chart of simulation knowledge against engagement levels for simulation Δ (Modern GUI)

However, the difference in means for Simulation Δ, with 'equal variances assumed', was not significant (p>.54). Therefore, both these results confirm that participants without knowledge of simulation theory did not feel engaged with Sim Ø (traditional GUI), while those with knowledge felt it was of average engagement. For Sim Δ (modern GUI), participants with or without prior knowledge of simulation theory provided a similar average vote. This verifies Simulation Δ as the version that is preferred by both groups.

Cross-tabulations for other case attributes collected in Section A of the questionnaire did not reveal any significant results. However, due to the uneven distribution of responses for both 'interests in graphics and 3D' and 'interests in visiting parks, gardens and reserves', there is a small possibility that the participants' attitudes towards the simulated content could have been affected. Nevertheless, no significant conclusions were derived from the analyses of those attributes.

In considering if users feel more engaged and stimulated when using the modern simulation GUI, results from the preceding analyses show that users certainly felt more stimulated and engaged with the modern GUI. The results also show that knowledge of simulation theory did not impact on the engagement rating of Simulation Δ, and so was also generally preferred by user groups within this sample.

Qualitative data

A detailed analysis of qualitative responses was also completed as an addition to the primary analysis. Two emerged categories, 'missing mouse functions' and 'missing navigation' were associated to the difference in experience between Simulation Ø and Δ. Simulation Δ (modern GUI) included several navigational and point-and-click functionalities for interacting with the simulated environment, while Simulation Ø did not incorporate those functional components.

Results revealed that participants who felt that more mouse functionality would be beneficial completed the evaluation of Simulation Ø first before Simulation Δ. Participants that felt 3D navigation was absent and should have been included, viewed Simulation Δ first, and therefore experienced the function before it was effectively 'removed' in Simulation Ø. The results also uncovered that the input method used in Simulation Ø was not liked by participants from both evaluation orders, successfully validating that the method of committing actions using text entry was deemed genuinely unpleasant.

For Simulation Δ, a similar chart showed that 19 responses were categorised into 'highlight', which refers to the ability to receive instant visual feedback from directly hovering the mouse cursor over plots in the environment. Many participants felt this mouse-over feature allowed them to easily determine which plots could be harvested or planted, which therefore increased their efficiency when using the simulation. Besides the 'highlight' category, a further 15 sources reported were placed into 'point and click'. Participants liked the additional mouse functionality and support, such as navigating through the environment and being able to directly click on an area to harvest or plant, rather than inputting numbers.

Furthermore, the most useful features against the order of simulations evaluated was charted, and subsequently revealed that the 'highlight' category scored the most comments from 19 sources while still being nearly even in distribution. This suggests that the highlighting mouse-over feature was generally the most useful with minimal effects from the order of simulations evaluated, while the 'point and click' category was the second most useful for Simulation Δ.

The numbers of sources for worst features in Simulation Δ were almost even. Categories 'edge scrolling' and 'rotate and zoom' received comments from 12 sources each. Charting these categories against the order of simulations evaluated did not reveal any notable patterns. Participants mainly commented that the panning mechanism for Simulation Δ was very sensitive and often activated when the mouse cursor was moved to the interface panels. Rotating and zooming were also frequently disliked by participants because the mechanism was awkward to control and they believed it was disorienting. Nevertheless, these appear to be simple technical issues that can be rectified with adequate time, resources, and a more powerful development platform that is able program well-learned user interface conventions.

With regard to which interface features users find most compelling for their given task, the obtained results from questionnaires suggest that for Simulation Ø (traditional GUI), users found the notifications, feedback/messages, and the visual representations provided were most useful when using the simulation. Results from Simulation Δ (modern GUI) revealed that the majority of users believed highlighting feedback and the ability to point and click in the environment were the most useful features, as they were commended for improving efficiency and ease of use.

The final aim was to determine if one simulation's user interface was preferred over the other, and whether the proposed modern interface is of benefit to the achievement of goals in simulation. Participants were asked which interface they preferred and which one aided them the most when using the simulation. Out of the forty-six participants that believed one interface was better, thirty-five chose Simulation Δ (modern GUI), while six participants chose Simulation Ø (traditional GUI). Five participants did not reveal their choice, but believed there was a difference between the two versions.

Participants that chose Simulation Δ generally felt that the functions were easier and faster to perform through direct interaction with the environment. The significant difference in choice between the two simulations suggests that Simulation Δ, with the most sources, is superior to Simulation Ø.

Conclusions and further research

The modern approach to scientific simulation user interfaces has proven to be successful when compared to a simulation that utilises a more traditional user interface. The main research question was successfully answered, with results and analyses from 52 participant questionnaires indicating that employing this modern approach to the simulation user interface was indeed successful and worth exploring further. The research sub-questions were also successfully addressed, with Simulation Δ (modern GUI) being generally and aesthetically preferred over Simulation Ø (traditional GUI). The Simulation Δ artefact was also deemed to be more engaging, and was the version generally favoured by all users with or without prior simulation knowledge.

Qualitative analyses also identified that the majority of users believed that user interface features that promoted direct manipulation with the output or environment was most useful when managing Simulation Δ. Moreover, users admitted that it was more efficient to execute functions and complete tasks when using Simulation Δ as compared to Simulation Ø, thus indicating that the modern user interface has indeed surpassed the traditional interface in terms of usability and aesthetics.

Although the results were conclusive during this study, a few refinements to the sampling and survey methods would improve the quality of data received during the evaluation stage. This would allow more conclusive analyses and user observations to be performed, in turn providing further useful information on the users' perspectives of the artefacts. In addition, further research could investigate why certain interface elements did not help participants engage and interact with the simulation, and which areas of direct manipulation can be further explored to improve the usability and user experience of scientific simulations for as many user types as possible.

The success of this approach to simulation user interfaces could potentially allow more simulations to be utilised for educational purposes and training, consequently opening doors and spreading its use to different audiences after sufficient advancements. Simulations of sophisticated but nonetheless important topics could be designed with this new approach to enable vital information to be conveyed in a way that is engaging and explorative to the wider community.

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Authors: Janet Saw, Berwick School of Information Technology, Monash University, PO Box 1071, Narre Warren, VIC, 3806. Email: janet.saw@infotech.monash.edu.au
Matthew Butler, Berwick School of Information Technology, Monash University, PO Box 1071, Narre Warren, VIC, 3806. Email: .butler@infotech.monash.edu.au

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